

# Development and implementation of ozone purification systems for water pipes and wells

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**Abstract.** This paper is dedicated to the study of the importance and efficiency of developing and implementing ozone purification systems for disinfecting drinking water sources, water pipes, and wells. Ozone is a powerful oxidizer capable of effectively eliminating microorganisms, including bacteria, viruses, and protozoa in water pipes and wells. Such systems serve as alternatives to traditional chlorination methods and leave no polluting purification by-products in the environment. The research explores the technical parameters of applying ozone to various water sources and purification systems, as well as operational parameters like ozone concentration, treatment time, and water flow regime. It also covers issues related to the design, installation, and operation of ozone purification systems. The topic contributes to the development and improvement of efficient and ecologically sustainable water disinfection solutions by providing an overview of the working principles, technical specifications, and mobility capabilities of ozone purification systems. The introduction of ozone purification systems extends the possibilities for improving water quality and adhering to safety standards. This study also identifies key factors such as ozone solubility, reaction time, and its efficiency in dispersing through water, which can enhance the effectiveness of this method.

## 1. Introduction

Today, ensuring the population has access to quality drinking water is one of the most pressing issues. Therefore, the search for efficient and safe water purification methods is of paramount importance worldwide [1, 2]. One of the most promising and innovative approaches in this area is ozone technology, used for disinfecting and purifying water contaminated by natural and anthropogenic sources [3], as well as eliminating harmful microorganisms in water from pipes and wells. The development and implementation of ozone purification systems are aimed at measures complexly designed to improve the quality of drinking water, ensure its safety for human health, and enhance the overall environmental condition [4].

Ozone (O<sub>3</sub>) is a powerful oxidant capable of effectively destroying bacteria, viruses, and other microorganisms without leaving harmful chemical residues, including the remnants of pesticides. The main advantage of ozonation is not only its ability to disinfect water but also to improve its taste and color qualities and eliminate unpleasant odors. However, incorporating ozone water purification systems requires careful planning, specialized equipment development, and adaptation of technologies to specific operational conditions [5, 6].

The introduction of ozone purification systems into existing water supply issues begins with a thorough analysis of these issues, identifying optimal treatment parameters, and designing a system that can provide the required level of purification [7]. An important part of the process is staff training, monitoring the quality of water before and after purification, and overseeing the efficiency and safety of ozone generators based on electrical discharge [8].

Developing and implementing ozone purification systems for water pipes and wells opens new horizons in ensuring access to quality drinking water, but it requires a comprehensive approach that includes scientific research, engineering design, economic analysis, and government support. This process is a critical step towards achieving the goal of providing clean and safe drinking water for all segments of the population.

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## 2. Materials and Methods

Viruses and bacteria infiltrate into groundwater through slow percolation through the soil, a process common for shallow and near-surface water bodies and wells. This contamination mechanism is also relevant for newly constructed or repaired water pipe networks, linking these infiltrations to outbreaks of infections spread through urban water systems. The need for disinfection of wells and water pipes is determined by state sanitary-epidemiological control centers and is carried out as follows [9]:

- Based on epidemiological indicators (when an outbreak of intestinal infections occurs in populated areas or when runoff water, feces, animal carcasses, etc., enter the water wells);
- For preventive measures (after cleaning and repairing existing or new wells).

Currently, the disinfection of wells and water lines is conducted using liquid chlorine, chlorinated lime, or calcium hypochlorite [10, 11]. Active chlorine solution is obtained by dissolving disinfectants containing an allowed concentration of chlorine in water.

Wells should be treated with an active chlorine solution after mechanical cleaning. The direct disinfection of wells with an active chlorine solution is carried out in two stages by filling the well cavity to the discharge level with an active chlorine solution at a concentration of 60 – 120 mg/l, initially below the static level by 2 – 4 meters using a pneumatic packer. When the concentration of the active chlorine solution is between 60 and 90 mg/l, it should be held for at least 8 hours, and when it is between 70 and 80 mg/l, it should be held for at least 36 hours. The well's cavity is chlorinated from the static level all the way to the bottom once the upper portion has been treated. Using a hose, an active chlorine solution is introduced into the water column as part of the treatment, making sure that the concentration of active chlorine stays at least 30 mg/l after mixing. Following chlorination, the water's active chlorine content is lowered to 0.2 mg/l prior to disposal, and a bacteriological examination is carried out. In the event that the results are unfavorable, the well is disinfected once more using 1.5–2 times the initial doses of active chlorine.

When treating the interior surfaces of water pipes, continuous dosing, tablet chlorination, and the use of high-concentration chlorine solutions are distinguished. The continuous dosing approach involves flushing the water pipe with a huge volume of high-concentration chlorine solution initially, and then filling it with a chlorine solution containing 25 mg/l of concentration. The water pipe is filled with this solution and left there for 36 hours, or until the chlorine content is at least 10 mg/l. Calcium hypochlorite tablets are attached at multiple axial positions along the internal surface of the water pipe in the tablet chlorination method. After that, water is poured into the water pipe until the tablets dissolve, preserving for 36 hours at least 25 mg/l of residual chlorine. To ensure that the entire interior surface is exposed to the high-concentration chlorine solution for at least five hours, the final approach involves gently passing a high-volume flow of chlorine solution above 100 mg/l concentration through the water pipe.

*Disadvantages of chlorination methods include:*

- Insufficient effectiveness of disinfection;
- Formation of harmful chloro-organic compounds;
- Use of large doses of active chlorine;
- High corrosive activity of the solution, causing pipelines and fixtures to wear out quickly;
- High toxicity of chlorine and many compounds containing chlorine;
- Long exposure time required for effective disinfection (at least 36 hours for internal surfaces of water pipes), causing delays;
- Incomplete dissolution of tablets in the tablet chlorination method, potentially leading to ineffective disinfection in some pipe areas;
- The need for dechlorination of solutions used in each chlorination method before they can be discharged into domestic or stormwater sewer systems;
- Chlorination methods are not aligned with the scientific and rational principles of disinfection.

**Table 1.** Comparative analysis of disinfection methods

| № | Water disinfection technologies | Environmental friendliness | By-products | Effectiveness | Capital expenditures | Current costs |
|---|---------------------------------|----------------------------|-------------|---------------|----------------------|---------------|
| 1 | Ozonation [4]                   | +                          | +           | ++            | +/-                  | +             |
| 2 | UV treatment [14]               | ++                         | ++          | +             | +/-                  | ++            |
| 3 | Chlorine dioxide                | +/-                        | +/-         | ++            | ++                   | +             |
| 4 | Chlorine                        | --                         | --          | -             | +                    | ++            |
| 5 | Hypochlorite                    | --                         | --          | -             | +                    | ++            |

It should be noted that in the Republic of Kazakhstan, solutions used for well water disinfection are not typically disposed of properly; they are often discarded into the surrounding area, and in rare cases, used solutions are directed

to secondary lift stations. When it comes to treating drinking water pipes, this is only done after repairs, and preventive treatments are often only recorded in the maintenance log. Chlorine concentrations employed in solutions are frequently multiples of the average. Ozone as a disinfectant may be used as a substitute for existing techniques of eliminating heavy metals and dangerous microorganisms from drinking water and wastewater [12, 13].

Currently, the efficacy of a particular disinfectant is evaluated using the CxT criteria, which is the product of the concentration of the reagent and the contact time. According to numerous experiments cited in scientific literature, ozone exceeds the effectiveness of disinfectants like chlorine, UV light, chloramines, and chlorine dioxide. Its antibacterial impact is 400–600 times stronger than chlorine and 3–6 times stronger than UV radiation [14]. Based on a review of several literature sources, Table 2 below evaluates the efficacy of applying different disinfectants.

**Table 2.** Comparative analysis of various disinfectants

| № | Water disinfection technologies | The simplest | Bacteria | Viruses |
|---|---------------------------------|--------------|----------|---------|
| 1 | Chlorination                    | -            | +        | +/-     |
| 2 | Ozonation                       | +            | +        | +       |
| 3 | UV treatment                    | +/-          | +        | +       |

*Where: does not destroy (-), destroys it completely (+), it does not completely destroy (+/-)*

Today, though, ozonation is frequently used over chlorination. This is due to a number of factors that date back more than a century. First, compared to ozonation, working with chlorine and chemicals based on chlorine is simpler. The second reason is that ozonation equipment is difficult to operate, has little automation, and requires highly skilled maintenance workers. Modern ozonators, however, have solved the majority of these and other issues. When ozonators are controlled remotely, digital spectral-correlation techniques should be employed to measure radio signal latency and determine direction [15, 16].

At the moment, ozone-based water filtration systems are widely used in France, Canada, Switzerland, Italy, Germany, Saudi Arabia, and other nations [6]. But the only purpose of these devices is to disinfect water. A 2005 US patent was filed for an ozone-based water pipe disinfection technique [17]. The internal surfaces of the pipes are disinfected by the action of an ozone solution, which is made by dissolving ozone in drinking water. Since ozone in water quickly turns into oxygen—usually less than an hour—using it for disinfection eliminates the need to remove the solution after use, such as dechlorination. The temperature, pH, ozone content, and chemical composition of the water all affect how quickly carbon is converted to oxygen. The phenomenon of ozone converting to oxygen allows for the possibility of creating a disinfection process that ensures the residual concentration of ozone in the pipe converts to oxygen before the disinfection solution is discharged. This facilitates the disposal of the solution, enabling environmental protection. Moreover, depending on the residual concentration of the post-ozonation solution, it can be directly discharged into streets, sewers, or water streams. The low residual concentration of ozone in the considered solution (less than 1 mg/L) is quickly consumed when in contact with the surfaces of road edges, pollutants, or under the effect of the sun's ultraviolet rays.

Using an ozone-added disinfection solution also eliminates the need to store, transport, and prepare hazardous chemical substances on-site, typically used in chlorination processes (hypochlorites and hydrosulfites). Ozone for disinfection can be generated on-site using electrical discharges to convert oxygen (obtained either from oxygen supply systems or cylinders) or air as raw material. The equipment required for this process is compact and does not need large storage spaces or transport vehicles, allowing for its use in constrained environments.

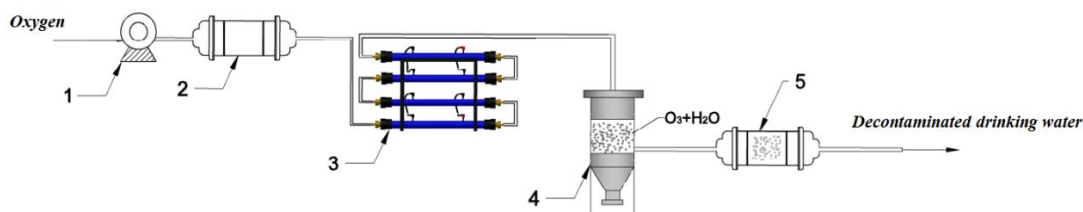
Ozone is one of the best drinking water disinfectants, and it may be used to disinfect pipes in a matter of minutes rather than an hour or more as is the case with chlorination. At a CxT value twice as low as needed for chlorination, ozone can eradicate bacteria, viruses, and protozoa, enabling a continuous process. Depending on the water's temperature and the bacteria's ozone sensitivity, 0.5 to 5 mg/(L·min) of ozone are expended.

In light of this, plans have been put out to use ozone to disinfect well casings and water system pipes. There are three alternatives available for well disinfection and one option for pipe disinfection. To ascertain the rate at which the residual ozone concentration in water degrades, plans ought to incorporate apparatus equipped with an ozone analyzer. In order to ensure that disinfection requirements are met, the control mechanism should adjust the rate of ozone introduction into the water based on information from the analyzer indicating the rate of ozone decomposition.

A logical controller is provided for system control, programmed to determine the necessary balance between the initial residual concentration of ozone and its decay stability, ensuring that the ozone concentration exiting the treated pipe section does not exceed 0.3 mg/L. For relatively short pipes, selecting a single point for ozone introduction is sufficient. For longer pipes or large-diameter pipes where the rate of ozone decay might be higher, creating several ozone introduction points along the pipe's length may be necessary to achieve the desired disinfection effect.

### 3. Results and Discussion

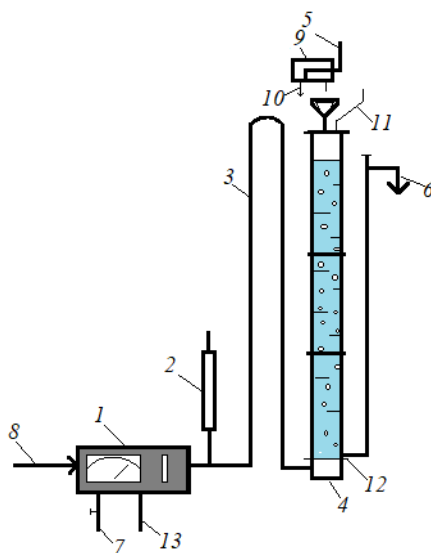
The study was conducted at the Kazakh National Technical Research University named after K.I. Satpayev, with the participation of specialists from the National Research University "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers". To conduct the studies, a technological schematic of the laboratory equipment was assembled (Figure 1), which allows for determining the effects of treatment time, ozone concentration in water, and water flow regime on the CxT value.



Herein: 1 - compressor; 2 - air dryer; 3 - ETRO-02 ozonator unit; 4 - water disinfection reservoir; 5 - membrane filter

**Fig. 1.** Technological schematic of the process for eliminating harmful microorganisms in water content

According to the selected methodology, the determination of residual ozone concentration in gas mixtures and water is based on oxidizing iodide to iodine with ozone, followed by titration with a sodium thiosulfate solution. To determine the flow rate of the gas mixture, an SKV-15 flow meter was used ( $\Delta P = 0.25$  MPa,  $t_{\max} = 89.8^\circ\text{C}$ ,  $Q_{\text{nom}} = 2.2$  m<sup>3</sup>/hour). The energy consumption of the system was measured with the help of a single-phase electricity meter. Pilot-industrial trials of the suggested technologies for the disinfection of drinking water supply pipes will be conducted based on the completed studies. A water pipe with a specific diameter was chosen for this use. Eleven parts of equal length were separated within it. The initial and residual ozone concentrations in the water, as well as the levels of microbiological contamination, were measured for each portion after the chosen section was treated with ozone-saturated water. Optimizing the water flow regime in the pipe is also essential. Since the last portion of the pipe experiences the least amount of influence, the levels of the indicators in this section are monitored to ascertain whether the disinfection aim has been met. In order to ascertain how soluble ozone is in water based on the height of the water column, experimental apparatus was developed. It is composed of a two-meter-tall plastic tube. The tube includes five sampling holes spaced 0.5 meters apart. At the bottom of the tube (Figure 2) is an ozone supply fitting [18, 19].



1 - ozonator; 2 - point for determining ozone concentration; 3 - inlet for water and oxygen mixture; 4 - contact column; 5 - inlet for hot water; 6 - outlet for ozonated mixture; 7 - inlet for cooling water for the ozonator; 8 - oxygen supply; 9 - ozone amplification unit; 10 - inlet; 11 - outlet for discharging used ozone into the atmosphere; 12 - metal-ceramic plate; 13 - outlet for draining cooling water from the ozonator.

**Fig. 2.** Ozonation unit for conducting laboratory experiments

Different gas-air mixture flow rates (with an ozone output of 14 g/hour) were utilized to find the solubility of ozone in water: 3.3, 6.6, and 13.2 L/min; treatment times: 10, 30, and 60 minutes. It was discovered through experimentation

that ozone's solubility dramatically drops as the liquid column rises (Figures 3 and 4). This is explained by known rules being confirmed by the bursting of gas mixture bubbles and the decrease in ozone concentration in the gas phase.

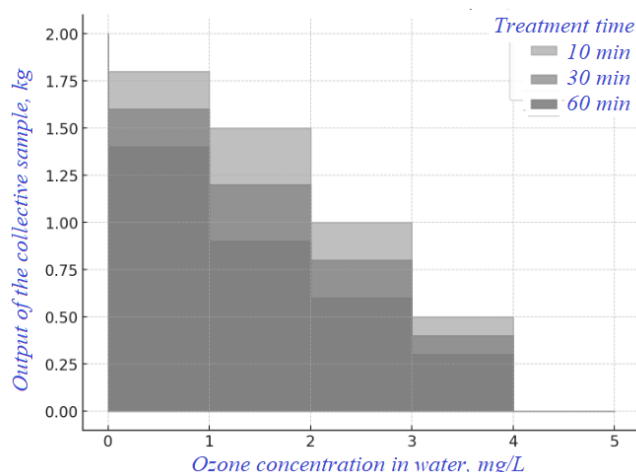


**Fig. 3.** The relationship of the treated water's ozone concentration, measured in mg/L, on treatment time, with an air mixture flow of 3.3 L/min and an ozone consumption of 14.0 g/h.

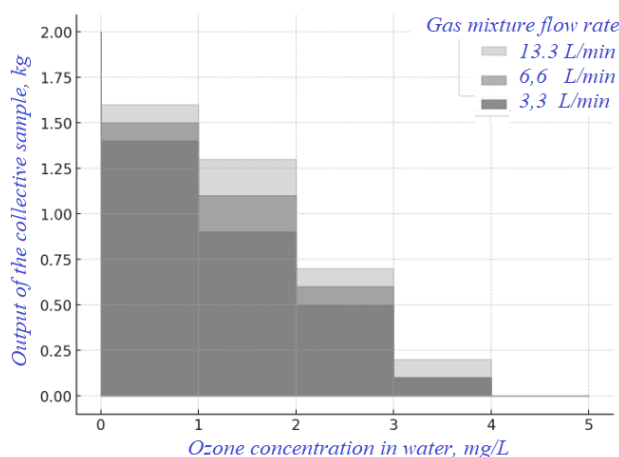


**Fig. 4.** The relationship between the amount of ozone in the treated water, measured in milligrams per liter, and the air mixture flow rate during a 60-minute treatment period (14.0 g/h ozone consumption).

As determined, the saturation of water with ozone is influenced by its concentration in the gas mixture and the size of the mass exchange surface (the size of gas bubbles created with an "air disperser"). Maximum saturation of water is achieved with a high concentration of ozone in the gas mixture and its low flow rate, as well as by extending the treatment time, which confirms known laws. The obtained data indicate the necessity of placing dispersers at intervals of 5 - 10 meters along the height when disinfecting wells with a gaseous ozone-air mixture. When saturating water pipe water (at 17°C) with ozone to a concentration of up to 4 mg/L, a 50% decay was observed after 40 minutes. In this instance, research on the impact of treatment duration, water ozone content, and water flow regime on the  $\text{CT}$  value is also required [20–21]. As was already indicated, reaching a 99.99% inactivation effect should serve as the basis for disinfecting water systems [22–25].

### 3.1 Discussion of Research Work

Various aeration devices can be used for dissolving and introducing ozone into water, differing in the dimensions of the gas and liquid phase contact area, the pressure within the system, and the duration of the reaction:

**Aeration via injectors and static mixers:** The main pipeline and the ozone suction line are equipped with injectors and two static mixers to provide water aeration. There needs to be a response period after mixing, either in another vessel or within the pipeline.

**Fine bubble aeration:** Ozone is introduced into water in the form of fine bubbles through porous metal-ceramic tubes or discs at the bottom of the reservoir.

Aeration column: Gas is introduced into the water flow in the opposite direction through an aeration column.

Aeration with mixers is used during constant water flow and when regulating a narrow range of ozone delivery. This method utilizes circulating mixers that mix the water with ozonated water. During continuous ozone introduction and mixing, approximately 5 – 25% of the ozone does not dissolve in the treated water. The residual undissolved ozone must be eliminated before being released into the atmosphere. The maximum allowable concentration (MAC) of ozone is 160 µg/m<sup>3</sup>. Additionally, when working with an ozone-air mixture, the Lower Explosive Limit (LEL), which constitutes 10 percent (%), must be considered.

Residual ozone can be removed by the following methods:

Thermal (at temperatures above 310°C and with a treatment time of at least 2 seconds);

Catalytic (using palladium and CuO/MnO-based metal oxide catalysts for ozone removal. The working temperature of the catalyst plate should be up to 60 - 80°C);

Chemical (using suitable chemical substances such as ascorbic acid, sodium bisulfite, and calcium thiosulfate for neutralizing ozone).

At least 0.2 to 0.3 mg/L of ozone should be present in the treated well or pipeline portion that needs to be cleaned. This residual concentration is low enough to safely release ozonated water from the disinfected pipeline portion into the environment without endangering wildlife while still meeting disinfection standards.

## 4. Conclusions

In conclusion, the development and implementation of ozone purification systems for water pipes and wells represent significant progress in the field of water treatment. These systems offer a highly efficient and environmentally friendly alternative to traditional chemical disinfection methods. By utilizing ozone, a powerful oxidant, these systems can effectively eliminate bacteria, viruses, and other pathogens without leaving harmful residues or by-products. The ability of ozone to decompose into oxygen after use not only minimizes environmental impact but also eliminates the need for additional chemicals to neutralize the disinfectant. This aspect, combined with the efficiency of ozone at low concentrations and its rapid action, makes it an excellent choice for ensuring the safety of drinking water. Furthermore, the adaptability of ozone purification systems, from stationary to mobile units, allows for their application in various contexts, from large-scale water treatment facilities to localized well disinfection. The development of ozone generators like "ETRO – 02 and ETRO – 03" by the Kazakh National Technical Research University highlights current innovations in the field, reducing operational costs and increasing the sustainability of water treatment processes. However, the introduction of such systems requires careful consideration of design and operational parameters, including ozone concentration, contact time, and technical maintenance, to ensure efficiency and safety. Additionally, installing these systems in well-ventilated areas is crucial to prevent ozone exposure risks. This research work presents a promising solution for disinfecting water with ozone, balancing efficiency, ecological sustainability, and safety issues. Their further development and integration into water treatment strategies play a crucial role in providing various communities around the world with clean and safe water.

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