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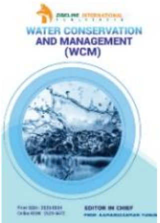

RESEARCH ARTICLE

STUDY OF THE PROCESS OF CLEANING WATER-CONTAINING IRON SOLUTIONS USING OZONE TECHNOLOGY

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ABSTRACT

In this scientific research work, the problem of studying the process of removing water - containing iron solutions with an Etro-04 device based on high-frequency corona discharge is considered. In the research work, a special Etro - 04 ozonator device was developed for the oxidation of heavy metals, i.e. chemical pollutants contained in water. Work on testing the device was carried out in order to clean the underground water “Aktogay wide place”. During the research work, various painful heavy metals were found in the composition of the source water that do not meet the maximum permissible (MPC). For example, iron (Fe^{2+}, Fe^{3+}) solutions met 2.00 – 2.2 mg/l. This means that the MPC is 7 times more than the specified value. In order to solve this problem, research work was carried out. During the technological process, various amounts of ozone (O_3) were released into the water, the amount and effective economic indicators of which were determined. In the same way, the effective time of the oxidation and cleaning process was determined. During the research process, an algorithm of theoretical calculations was developed and a mathematical model was given to bring 1m^3 of groundwater to a fixed indicator. In order to determine the effectiveness of cleaning the iron contained in the water by the concentration of ozone and the filter load, water filtration works were carried out at different speeds of 5.5 - 9.5 m/h. For example, with an ozone content of C =100 mg/l and a filtration rate of 9.5 m/h, you can see that the iron content in water is purified by 30% percent, 8.5 m/h – 55% percent, 7.5 m/h - 77% percent, and 5.5 m/h - 90% percent. Experimentally and theoretically, it was found that Iron solutions with water content were purified by 98 - 98.7% percent, respectively, with an ozone concentration of C = 500 - 600 mg/l and a filtration rate of 5.5 m/h.

KEYWORDS

electric discharge, ozone concentration, underground water, ozonator, ozonated water, ozone content iron solutions

1. INTRODUCTION

Today, based on practical, industrial conditions, water from a well or well always contains a lot of organic and inorganic pollutants, including solutions of heavy iron ions (Fe^{2+}, Fe^{3+}) and other types of chemical compounds (Draginsky et al., 2007). The use of such waters without complex pretreatment can lead to various negative health consequences: from simple food poisoning to long - term painful consequences in the future (Zhurnal, 2007; Mazaev et al., 1999). For example, leads to damage to the kidneys, liver and other organs. In most cases, groundwater is contaminated with heavy metals, including iron (Fe) ions and water. Iron ions dissolved in water are most often found in areas where fossil fuels are processed (Draginsky et al., 2007; Alekseev et al., 2001).

Increased iron content in Water leads to the destruction of household appliances, for example, washing machines, heating equipment, forming in groups in the pipes of plumbing devices in a tar state. For use in domestic conditions, the iron content in water should not exceed 0.3 mg/l - this is the maximum maximum permissible concentration (MPC) approved by sanitary standards (Mazaev et al., 1999).

In domestic conditions, various methods are used to purify underground water from Iron (Alekseev et al., 2001). Their effectiveness is different, and not all of them are suitable for use in domestic conditions (Draginsky et al., 2007; Alekseev et al., 2001). Currently, the most advanced and reliable methods of cleaning iron solutions found in underground water in domestic conditions are as follows (Figure 1). They can currently be divided into 2 groups:

Methods of pre-oxidation of iron:

- is the oxidation of the reagent;
- aeration;
- electrochemical oxidation;
- catalytic oxidation;
- biological oxidation, and etc.

Methods that do not require pre-oxidation of iron:

- ion exchange water treatment;
- sorption cleaning;

water treatment using membranes (depending on the pore size e);

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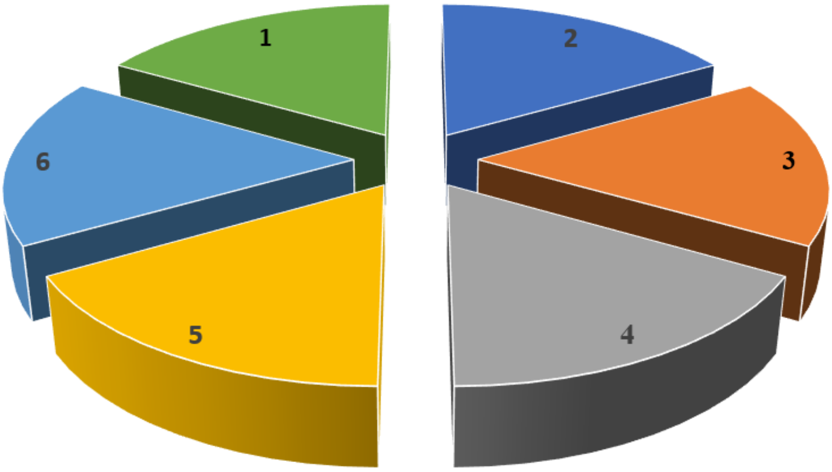

Figure 1: The best ways to eliminate iron contained in water from a well in domestic conditions

Where: 1 - household filters with cartridges loaded with active coal; 2 - column water purification systems; 3 - pressure - free aeration in the tank; 4 – pressure aeration in the tank; 5-membrane cleaning methods; 6-oxidizers (air oxygen or chlorine, potassium permanganate, hydrogen peroxide, ozone).

However, in the process of decontamination and purification of surface and groundwater in general production, a real alternative to the use of chlorine is ozonation. The use of these methods, as well as their combinations, is well developed in Europe and America (Draginsky et al., 2007). Today, the most effective way to remove iron from water is cleaning using ozone technology. It is a powerful and environmentally friendly technology that cleans water from all contaminants, including iron, while not requiring operating costs. Let's consider in more detail the specifics of technology in the following sections.

2. MATERIALS AND METHODS

One of the most common pollutants found in underground natural water sources is iron and manganese ions. Li-Nan Shao and his colleagues conducted an experiment on the kinetic parameter, taking mine water with a high content of iron and manganese as a source of research. The result of the study showed that the highest desorption rates of iron and manganese are 29.29 - 33.85% percent, respectively. Based on the results of the experiment, the adsorption capacity of iron and manganese is approximately 119.915 - 68.6 mcg/g, respectively (Shao et al., 2011). Since Iron belongs to toxic heavy metals, according to accepted sanitary standards, its maximum permissible concentration (MPC) in drinking water should not exceed the level of 0.3 mg/l (SanPiN, 2002). Groundwater containing fossil resources is characterized by an iron content in the range of 1 - 15 mg/l (Medvedeva et al., 2015). In many territories of Russia and Central Asia with fossil resources, a high concentration of iron in drinking water is recorded (up to 0.32 - 2.38 mg/l) (Grigorie and Lyapina, 2013).

The allotropic form of oxygen generated by an electric discharge through ozone is currently widely used in production, including in agriculture, vegetables and fruits, dairy products, and agricultural devices as well as in water management and medicine. Due to the excessive use of pesticides and nitrogen fertilizers in agriculture, soil water, surface water, and groundwater are subject to chemical pollution. In order to neutralize such pollutants, an ozonator based on atmospheric oxygen was installed on the barrier discharge and disinfection works were carried out. In this work, fundamental research was carried out on the change in the acidity and amount of nitrogenous nutrients, bacteria, and soil DNA remaining in the soil after ozone treatment with a system using a quartz chamber (Mazaev et al., 1999; Alekseev et al., 2001). In general, any device, be it soil or liquid, will require a certain amount of ozone to neutralize them, and ozone is produced in production with the help of ozonators of various designs.

During the process of ozone production, its inefficiency increases if the energy consumption exceeds the required value. The problem of improving the methods of processing air-mixed gas at the ozonator outlet requires increasing the physical characteristics of the flow discharge and electrode tip, i.e., electron temperature and electron density. Some foreign research works used an emICCD chamber to study the characteristics of a flow discharge by observing the process of spreading the discharge in the head of a conical electrode with a positive voltage. Then, a flow discharge with a positive voltage and Thomson scattering at the electrode tip were performed. Thomson found that scattering is considered the most reliable method for simultaneously measuring the temperature and density of an electron in plasma (Alekseev et al., 2001). At the same time, disinfection of drinking water based on electric field discharge and hydrodynamic cavitation gives positive results (Shao et al., 2011).

Today, as part of the normalization of the prevention and control of the epidemic in general, it is advisable to use traditional disinfection methods correctly. Disinfection devices can be used, for example, in plasma medicine. Plasma contains various highly active components that can effectively destroy pathogenic microorganisms. The advantage of the research work will be the waste-free, safe, and environmentally friendly technology. The dielectric barrier can be pre-decontaminated by a discharge-based device. At the same time, in this work, water activated by plasma can directly interact with microorganisms contained in it. That is, it was used in this work as the main technology for the study of its efficiency, environmental friendliness, and potential as equipment for convenient disinfection. In the same way, research on epidemic prevention and control was given a scientific justification and definition. Although the determination of effective reactive oxygen species (rot) generated by plasma has been extensively studied, the mechanisms of microbial disinfection and plasma disinfection processes have never been clearly explained. However, the research reveals in terms of comprehensive factors, including cell morphology, membrane permeability, lipid peroxidation, membrane potential, and intracellular redox homeostasis (intracellular rot and H_2O_2 and antioxidant system), the subclass mechanism of inactivation of yeast cells during plasma–liquid interaction (SanPiN, 2002).

In general, in the process of surface water disinfection, it is necessary to use environmentally friendly materials that achieve the inhibition of bacterial growth, aimed at improving water quality. In some scientific research work, silver nanoparticles (AgNPs) were developed to neutralize water in a warehouse by filtration. First, AgNPs were synthesized by the green synthesis method using an extract of Aloe Barbadensis Miller (Aloe Barbadensis Miller) as a reducing agent and $AgNO_3$ as a metal precursor. Silver nanoparticles are a platform for the production of multifunctional polymer membranes for wastewater disinfection (Medvedeva et al., 2015).

Graphene oxide, a carbon-based nanomaterial, has an antibacterial effect in the composition of water due to its large surface area, surface charge density, and various physical and chemical properties. In one study, using the composition of graphene oxide/bismuth (GO/BiVO 4), disinfection of water containing Escherichia coli (E. coli) was performed. Nanoparticles of bismuth vanadate (BiVO 4) synthesized using the sol-gel method with a particle size of 21.3 nm were used to decorate graphene oxide (GO) sheets. Composites were developed consisting of five different combinations of 0.5%, 1%, 1.5%, 2%, and 2.5% GO/BiVO 4 (GO mass). The antibacterial ability of all five synthesized composites was tested in a homemade photoreactor controlled by visible light. The results showed the efficiency of the 1.5% GO/BiVO 4 nanocomposite in 0.1 g/L with a decontamination rate of 90% in 30 min under visible light radiation (Grigoriev and Lyapina, 2013).

In the research work of V.V. Boldyrev and his colleagues, a significant excess of iron MPC in drinking water was found in the city of Tula (2 – 20 MPC), Novomoskovsk district (5.5 - 24.0 MPC), Kireevsky district (2.9 –

34.0 MPC), Donskoy city (2.8 MPC). In general, in the Tula region, the share of water samples from drinking water supply sources that do not meet hygienic standards for sanitary and chemical indicators in 2015 was 45.1% percent (in 2014 - 51.2% percent, in 2013 - 51.4% percent) (Boldyreva, 2009; State Report, 2016).

At water transport stations, the quality of drinking water is determined by the natural properties of water, as well as by the material of the water pipeline and the technology of water preparation (demineralization, chemical water treatment stations, etc.). Underground (Artesian) waters extracted from great depths can contain a large amount of iron (oxide – Fe^{2+}, $FeOH^{+}$, $FE(OH)_2$, $FeCO_3$, $Fe(HCO_3)_2$ in the form of dissolved bicarbonate). Due to the presence of excess oxygen in the water, an oxidized trivalent state of iron is found in surface water - Fe^{3+}, Fe(OH)3, as well as in the form of complex compounds of mineral (silicates, phosphates, etc.) and organic (humic acids, sulvo acids, etc.). Iron can also be found in ironbacteria (bacterial iron). In the same way, it is formed during the vital activity of iron bacteria and serobacteria, oxidizing iron to a trivalent state. Such compounds are found in the form of Colloids (Alekseev et al., 2016).

The main sources of iron formation in natural surface and groundwater are as follows: 1) soil erosion and rock melting under the influence of weathering; 2) a significant amount of iron is supplied by groundwater, wastewater from industrial and agricultural land; 3) due to acid rain, surface and groundwater are acidified (a whole series of iron compounds characterized by different solubility are formed in acidic water environments based on the Fe^{2+}, Fe^{3+} and SO_2 system (Komov, 2016).

Pollution of underground water bodies is strongly influenced by the coal industry. Water accumulated in mine sites increases the concentration of iron in groundwater by the amount of MPC. It affects the pollution of the waters of underground drinking water intakes and underground aquifers for the economic and drinking water supply of cities and settlements close to this region (Komov, 2016). One of the ways to increase the concentration of iron in water is due to long-term failure to repair water pipes. For example, in some research papers, this issue is more specifically stated (Vulpasu et al., 2021).

In the scientific research work of A.V. Mamchenko and his colleagues, mine water, which flows to the surface of the earth, as well as comes out in the form of a spring, enters surface water bodies, violating their hydrological and hydrochemical regime. In the same way, it pollutes small and medium-sized rivers with harmful substances found in mine waters. Iron in high concentrations contained in water negatively affects human health, accumulates in the liver, contributes to the destruction of its cells, and also causes allergic reactions that can lead to diseases of the blood and gastrointestinal tract (Mamchenko et al., 2009).

The most common method of removing dissolved bivalent iron from water composition is chemical and physical methods. It is necessary to oxidize the amount of iron from the water composition through various oxidizers, and then filter it using sorbents. Currently, in water preparation technology, oxygen, chlorine, ozone, potassium permanganate in the air are used to oxidize iron. Oxidized iron particles are filtered by a granular sand load.

Zheng Wang and his colleagues conducted pilot experiments on the preliminary treatment of micro-contaminated raw water. The results of the research showed that the pre-oxidation process can increase the elimination of organic pollutants more than the usual process, for example, indicators of the potential for the formation of COD Mn, UV 254, THM and HAA. Ozone has shown better performance than potassium permanganate and sodium hypochlorite. According to pilot experiments, it is reported that ozone preprocessing has a high efficiency in the destruction of COD Mn and UV 254 (Wang et al., 2011). The results of catalytic ozonation of MTBE in water containing iron hydroxide (FeOOH) and cerium dioxide (CeO_2) can be seen to give an optimized solution (Wang et al., 2010). It is known that underground water sources in most cases become polluted as a result of industrial wastewater. This contaminated water treatment work can be seen in the HV plasma Crown reactor purification system analysis research work by Nayab Pervez and his colleagues (Pervez et al., 2016). The main advantage of an electric discharge in a water treatment system is its high chemical efficiency. In plasma, electrons receive up to 10 eV of energy (Mizuno and Hori, 1988; Naidu and Kamaraju, 1996). Through electrons and photons, various chemical processes occur. It leads to the formation of gas bubbles in which the discharge phase in the liquid occurs (Kuffel, 2000; Wadhwa, 2007).

Surya Prakash L.,John Kurian P. in scientific research, it was noticed that under the influence of various natural factors, the content of Fe – Mn - oxides in water is excessive (Surya and John, 2022). Ozone has a very high ability to break down organic substances, etc.impurities, in addition to the iron contained in water. Ozonation of water is the most versatile and highly effective method of water purification from a bacteriological, physico - chemical and organoleptic point of view (Pervez, 2014; Malik, 2001). One of the hygienic advantages of ozone is its inability to substitution reactions, unlike chlorine. No foreign impurities are introduced into the water and no chlorine and organic compounds harmful to humans are formed. A feature of ozone is its rapid decomposition in water to form oxygen, which means that ozone provides complete environmental safety (Abdykadrov et al., 2021). Ozonation provides effective removal of iron through simultaneous disinfection of water (Dhote, 2012). Currently, many developing countries use 5 – 10 m of groundwater as a source of drinking water. It consists in the fact that due to the absence or malfunction of decentralized water supply stations, water is supplied to the consumer directly from wells in an untreated form. Thus, there is a need to purify a small amount of iron in groundwater. To this end, we are raising the question of studying the process of cleaning iron solutions found in underground water sources using ozonation technology.

The effectiveness of iron removal in water ozonation depends on the amount of ozone. The higher the ozone content, the lower the residual concentration of iron in distilled water. In many cases, even in small amounts, the complete removal of the iron is achieved. The depth of water purification from iron is also affected by the time of contact of water with ozone (Potapenko et al., 2002).

3. RESULT

Ozone reacts rapidly to various mechanisms in the composition of water, including the processes of oxidation of heavy metal ions and harmful microbacteria, as well as organic and inorganic compounds, in addition to iron. Ozonation technology when removing iron in water has the following features than other technologies:

- Ozone enriches the water with oxygen, which improves its taste.
- During the oxidation of organic compounds with ozone, secondary products dangerous to health are not formed.
- Ozone does not change the pH of water and the Ca, Mg, K, Na ions necessary for the body.
- During the process of disinfection and cleaning of water from harmful microorganisms, the amount of ozone is about 2.5 times less than that of chlorine.

Ozone has a disinfecting effect on microorganisms around it, without oxidizing only the iron contained in the water. Its mechanism is presented in Figure 2 below.

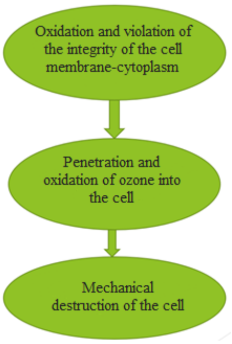

Figure 2: Mechanism of disinfecting action of ozone

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Table 1: Criterion for Disinfection of Water With Ozone Based on The Required Degree of Inactivation (Dolina, 2003; Draginsky Et Al., 2007)

Type of microorganism	Degree of inactivation	Ozone concentration of C, mg/l	Contact time T, min	CT - criterion, mg/l · min
Bacteria				
E-coli, Staphylococcus sp., Pseudomonas fluorescens	99,99%	0,009	1	0,009
Staphylococcus faecalis	99,99%	0,009	2	0,018
Mycobacterium tuberculosis	99,99%	0,009	6	0,054
Viruses				
Rotavirus, Poliovirus, Coxsackie	99,9%	0,3	4	1,2
Cysts of single-celled parasites				
Giardia Lamblia	99%	0,53	1	0,53
Cryptosporidium parvum	99%	0,5 – 1,0	5 - 18	2,5 - 18

The degree of inactivation is expressed in decimal logarithms and indicates the order in which the number of microorganisms decreases as a result of disinfection treatment. For example: 99% - 990 of 1000 microorganisms will be destroyed, and 99.9%-999 of 1000 microorganisms will be destroyed.

To ensure a given degree of inactivation, the disinfection criterion (CT) can be calculated as follows.

$$CT = C \cdot T, \text{ mg/l} \cdot \text{min} \qquad (1)$$

Where; C is the concentration of ozone in water, mg/l; T is the time of contact of water with ozone, min.

There is an influence of various factors on the effectiveness of ozone disinfection of water. For example, pH – indirectly affects. as the pH increases, the rate of self-decomposition of ozone increases. Similarly, although the efficiency of t^0C - ozone is higher in warm water, but the solubility of ozone decreases with increasing water temperature. And measured substances-indirectly accelerate the process of ozone decay on the surface of particles.

Similarly, ozone differs from other oxidizers in the following:

- Ozone is produced directly at the application site and does not require transportation, storage and preparation of working solutions;
- The volume of reagent installations is significantly reduced, in some cases, chemicals can be removed from the process;
- Environmentally friendly technology that does not leave toxic substances in the water and does not harm the environment.

3.1 Ozone Oxidizes and Breaks Down Iron During the Technological Process

Iron purification of water with ozone is a special method in which comprehensive iron purification of water is carried out without any side effects. Ozone water treatment has great and undeniable advantages over other technologies on the market. Due to its high activity as a natural oxidizer, ozone, when mixed with distilled water, quickly oxidizes impurities, transferring them from a dissolved state to a suspension, which is easily held in a carbon filter. The rest of the ozone is converted into oxygen, and water is supplied to the consumer through a carbon filter - precipitator. The process of ozone purification of water from iron occurs very quickly, no materials, consumable reagents are required, the pH level and mineral composition are maintained, so such treatment is absolutely safe from an environmental point of view.

Most of the common pollutants are metals, including iron, other pollutants – all are actually exposed to ozone oxidation. Thanks to the ozone treatment of water, the consumer always receives high-quality water saturated with oxygen, purified and disinfected. The dissolution of ozone in water is currently being given more specifically in Scientific Research (Draginsky et al., 2007). In research papers, its dissolution is described by the Henry coefficient or solubility coefficient (Rt). The Henry coefficient is directly related to the temperature around:

$$R_t = C_l / C_g \qquad (2)$$

Where is the concentration of ozone in the liquid and gas phases C_l and C_g.

Characteristics include temperature, pH indicator, electrical conductivity and the presence of impurities. The interaction of the HO_2^- ion with ozone leads to the formation of radical ions.

The trend of ozone distribution in water is given in the following expressions (Draginsky et al., 2007):

$$O_3 + OH^- \rightarrow HO_2^- + O_2$$

$$O_3 + HO_2^- \rightarrow O_2^- + OH$$

$$O_3 + O_2^- \rightarrow O_3^- + O_2$$

$$O_3^- + H_2O \rightarrow OH + OH^- + O_2 \qquad (3)$$

The solubility coefficients of ozone in water (R_t), pH up to 0.1 - 11, were determined. The decrease in the solubility coefficient (R_t) is associated with the decay of ozone. Therefore, its general mechanism is direct in nature. The greatest stability of ozone solutions is shown in a strongly acidic environment, where the catalytic effect of hydroxyl ions is significantly reduced, protonation occurs (highly active radical ions are inactive).

According to stoichiometry, the dose of ozone for the oxidation of iron in water can be determined using the following expression:

$$D_{oz} = 0{,}14 \cdot [Fe^{2+}], \text{ mg/l} \qquad (4)$$

where $[Fe^{2+}]$ is the concentration of iron in the source water, mg/l

Iron interacts with ozone in water through the following bonds:

$$2Fe^{2+} + O_3 + H_2O = 2Fe^{3+} + O_2 + OH^-$$

$$Fe^{3+} + 3OH^- = Fe(OH)_3 \downarrow$$

$$Fe(OH)_2 \downarrow + O_3 + H_2O = Fe(OH)_3 \downarrow + O_2 + OH^- \qquad (5)$$

The amount of ozone depends on the purpose of ozonation of water. The amount of ozone for disinfection of filtered water is 1 - 3 mg/l, for purification of groundwater 0.75 - 1 mg/l. the introduction of ozone for iron oxidation, discoloration of water with simultaneous disinfection, the dose can reach 4 mg/l.

3.2 Practical Testing of The Device

Taking into account the physical and chemical properties of ozone considered in the previous sections, a special installation of the ETRO – 04 ozonator based on an electric discharge was developed at the Department of Electronics, Telecommunications and space technologies of the Kazakh National Research Technical University named after K. I. Satpayev. The general image of the installation was presented in Figure 3 below. In the ozonator, under the influence of an electric current, A Corona-type discharge is formed, as a result of which ozone is formed from oxygen in the air.

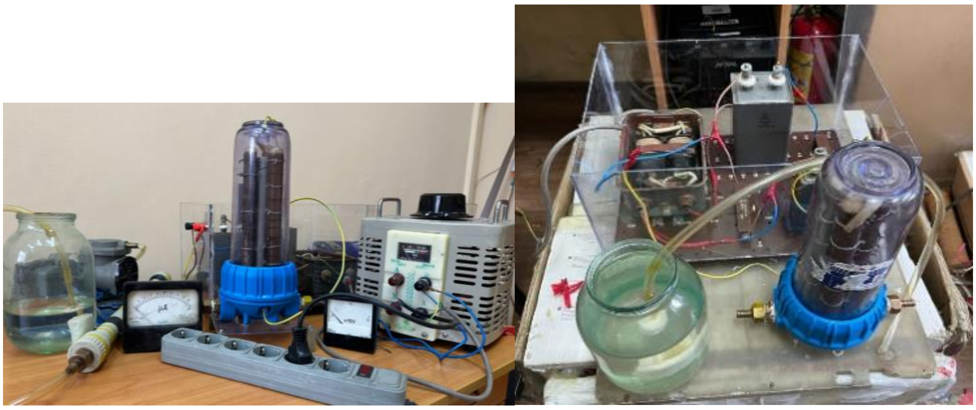


Figure 3: Laboratory electric Crown discharge-based ozonator unit

When the air temperature in the ozonator box changes, you can see that the reaction rate changes at a constant in Figure 4 below. The main reactions that lead to the formation of ozone in the ozonator are presented in Table 2.

Table 2: Reaction Constants During The Photochemical Process Inside The Ozonator Tube.

Reaction	Constanta	Reaction	Constanta
$O+O_2+M\rightarrow O_3+M$	$6,0\cdot10^{-34}(T/300)^{-2,6}$	$HO+C_2H_6\rightarrow H_2O+C_2H_5$	$6,9\cdot10^{-12}\exp(-1000/T)$
$H+O_2+M\rightarrow HO_2+M$	$5,4\cdot10^{-32}(T/300)^{-1,8}$	$HO+C_3H_6+M\rightarrow C_3H_6OH+M$	$8,0\cdot10^{-27}(T/300)^{-3,5}$
$O+HO_2\rightarrow HO+O_2$	$2,7\cdot10^{-11}\exp(224/T)$	$HO+C_3H_8\rightarrow H_2O+C_3H_7$	$7,6\cdot10^{-12}\exp(-585/T)$
$O+H_2O_2\rightarrow HO+HO_2$	$1,4\cdot10^{-12}\exp(-2000/T)$	$HO+\alpha$-pinene$\rightarrow$products	$1,2\cdot10^{-11}\exp(440/T)$
$HO+HO+M\rightarrow H_2O_2+M$	$6,9\cdot10^{-31}(T/300)^{-0,8}$	$HO+CO\rightarrow H+CO_2$	$9,1\cdot10^{-19}\cdot T^{1.77}\exp(580/T)$
$O+NO+M\rightarrow NO_2+M$	$1,0\cdot10^{-31}(T/300)^{-1,6}$	$NO_3+C_2H_4\rightarrow$products	$3,3\cdot10^{-12}\exp(-2880/T)$
$O+NO_2\rightarrow O_2+NO$	$5,5\cdot10^{-12}\exp(188/T)$	$NO_3+C_3H_6\rightarrow$products	$4,6\cdot10^{-13}\exp(-1155/T)$
$HO+CH_4\rightarrow H_2O+CH_3$	$1,85\cdot10^{-12}\exp(-1690/T)$	$NO_3+n\text{-}C_4H_{10}\rightarrow$products	$2,8\cdot10^{-12}\exp(-3280/T)$
$HO+C_2H_4+M\rightarrow C_2H_4OH+M$	$8,6\cdot10^{-29}(T/300)^{-3,4}$	$HO_3+\alpha$-pinene$\rightarrow$products	$1,2\cdot10^{-12}\exp(490/T)$

According to research studies, the increase and decrease in the reaction rate due to the increase in temperature occurs accordingly. Therefore, all selected reactions were divided into two groups: reactions whose speed decreases with increasing temperature, and reactions whose speed increases. From Figure 3, it can be seen that the slowdown in reactions with increasing temperature is linear, and the reaction rate can vary up to 3 times in the range (-5) - (-30^{0}c).

The ozone-air mixture from the ozonator is introduced into the water through ejectors or through a network of porous pipes laid in the mixing chambers. The residual ozone concentration after the mixing chambers should be 0.1 - 0.3 mg/l. The duration of contact of ozone with water depends on the composition of the water, the concentration of ozone in the ozone - air mixture, the design of the mixer, the temperature and on average 5 - 20 minutes, often 5 - 12 minutes. The technological scheme of the device is given in Figure 5.

Low - frequency and high-frequency (0.4-13 kHz) ozonators operating with industrial frequency current are produced. Ozone is very toxic and can affect the respiratory system. The maximum allowable ozone concentration (MPC) in the air of the working area is 0.1 mg/m^3. In comparison, 10 times less than chlorine. Although the ozonation method has prospects, the equipment is still quite expensive, and during the process, the device is characterized by relatively high power consumption. At the same time, it should be noted that providing the population with high-quality drinking water is the main issue of the research. In the course of the research work, let's discuss practical tests in the case of iron ions or specific bacterial contamination in water. To achieve the required CT criterion, the ozone dose and contact time are as follows: C = 600 mg/l, t = 30 min, CT = 18·103 mg/l * min.

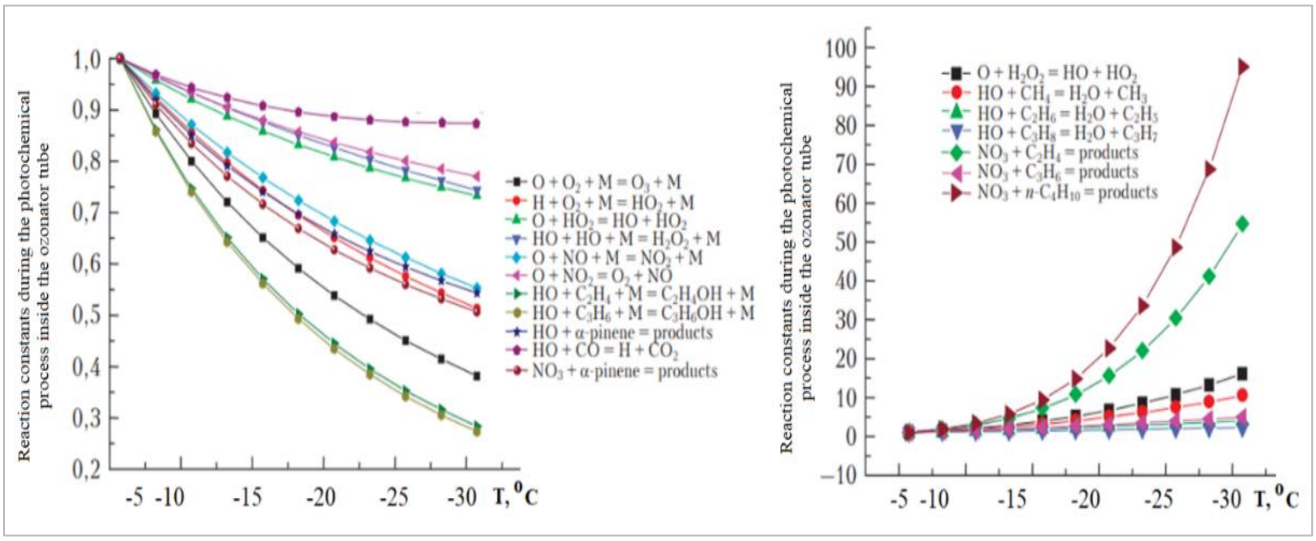


Figure 4: Reaction rate of the ozone cycle at different temperatures

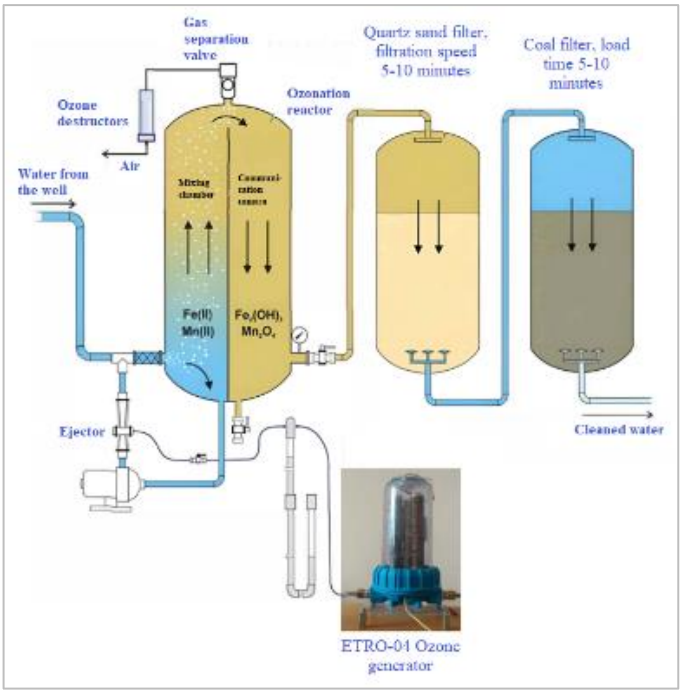
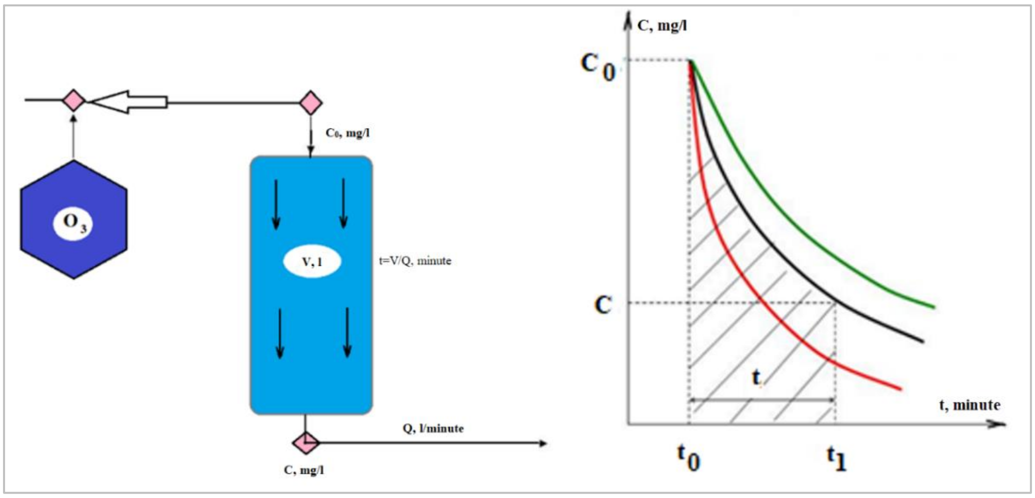


Figure 5: Technological scheme of the process of destruction of heavy metal solutions in water, including iron

a) artesian wells with a depth of 270 m. “Aktogay wide place”



b) pH, water temperature, water chemical requirement for ozone and nature of additives

Figure 6: Factors affecting the rate of ozone decomposition in a solution

To determine the effectiveness of ozone technology, laboratory tests were carried out on the chemical composition of underground water located in the “Aktogay wide area“ man in terms of iron content, as well as a complete chemical analysis of water was carried out. To analyze the composition of primary water, water was taken from artesian wells (figure 6A). The determined amount of iron in the initial water content is given in Table 3.

Table 3: Concentration of Iron In Primary Water (Underground Water "Aktogay Wide Area")

Concentration of iron in water	5.12.2022y	10.12.2022y	13.12.2022y	16.12.2022y	18.12.2022y	25.12.2022y
Concentration of iron in primary water, $[Fe]_0$, mg/l	2,012	2,024	2,028	2,0227	2,256	2,00
Concentration of iron in ozonated water [Fe]t, mg / l	1,800	0,91	0,62	0,455	0,365	0,312
Ozonation time t, minutes	10	15	20	25	30	35
Air impurity ozone content, $[O_3]$, mg/l	100	200	300	400	500	600

As can be seen from the table, the concentration of iron in water does not satisfy the normative condition established in the MPC (SanPiN, 2002). In terms of drinking water quality, iron should not exceed 0.3 mg/l (Boldyreva, 2009). The results of the scientific research work can be traced in Figures 7 and 8 below. It can be seen that the oxidation of the concentration of iron in water is inversely proportional to the amount of ozone and the oxidation time.

In Figures 7 and 8, it can be seen that the concentration of iron in water decreases to 0.365 – 0.312 if the ozone content is C_{ozone} = 500 - 600 mg/l, the ozonation time is t = 30 - 35 minutes. It has already been mentioned above that according to the quality indicator of water it is necessary to have $[F]_{general} < 0.3$ mg/l. Therefore, iron solutions that remain in the water can be cleaned using a sand filter.

Ozone content and generator performance:

$$D = k \cdot C_0,\ mg/l\ (g/m^3), \tag{6}$$

where D is the dose of water treatment with ozone; k is a dimensionless coefficient that takes into account the efficiency of the passage of ozone from the gas phase to the solution; C_0 is the required initial ozone concentration at the input of the contact apparatus, mg/l (figure 6a is given).

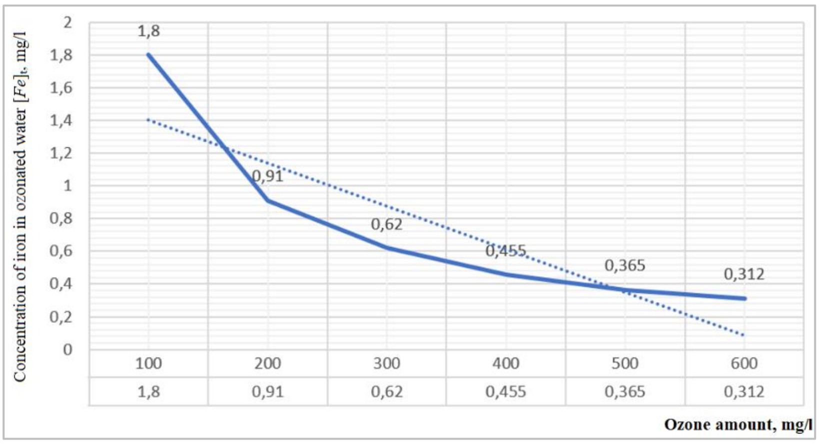
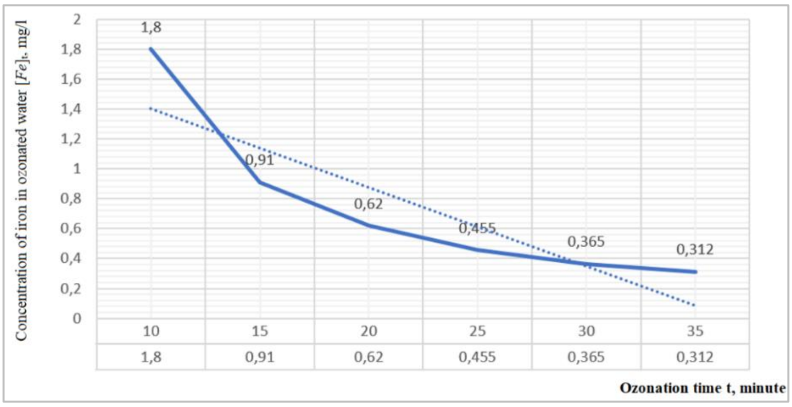


Figure 7: The relationship between the amount of ozone [O3], and the concentration of iron in water [Fe]



Concentration of iron in ozonated water $[Fe]_t$, mg/l

Figure 8: Relationship between ozonation time (t) and iron concentration in water [Fe]t

Table 4: Ozone Consumption During Research Work During The Process of Oxidation of Harmful Impurities In Water

Type of additive	Ozone consumption during the oxidation process, 1 mg of ozone per 1 mg mixture (O_3)
Iron	0,4 – 0,6
Manganese	0,88 – 4,0
Hydrogen sulfide	1,5 – 3,0
Petroleum products, surfactants	2,0 – 3,0
Phenols	1,0 – 2,0

Ozone generator performance:

$$C_{O_3} = D \cdot Q,\ g/h, \tag{7}$$

where Q is water consumption, m^3/h

The performance of the ETRO - 04 generator for water disinfection Ct = 21 · 10^3 mg/l * min. Let's figure it out according to the criterion, if water is supplied at a loss of $3m^3$/hour, and during experimental tests it was found that the concentration of ozone in the considered water decreases by 1.5 times in 15 minutes (Table 5).

The table shows that the total iron content $[Fe]_{total}$ in water after Activated Carbon has reached the established standard. And it can be seen that the amount of ozone is sufficient for the process of oxidation of iron in 500 – 600 mg/l of water.

Table 5: Results Obtained From the Experiment on the Technollegic Scheme

Ozone content, mg/l,	Iron concentration in underground water						
	Iron content in ozonated water before filter	Iron content after quartz sand filter	Iron content after activated carbon	Filtration speed			
				9,5 m/h	8,5 m/h	7,5 m/h	5,5 m/h
	$[Fe]_{\text{general}}$						
100	1,800	0,78	0,3	30-33%	55%	77%	90%
200	0,91	0,74	0,2	32-35%	58,6%	78%	90,5%
300	0,62	0,39	0,18	33-37%	60%	78,5%	96%
400	0,455	0,31	0,165	34-38%	60,7%	80%	97,2%
500	0,365	0,278	0,152	34,5-39%	60,9%	82%	98%
600	0,312	0,158	0,150	40-40,5%	70%	85%	98,7%

3.3 Mathematical Model of The Technological Process

To create a mathematical model of the process of oxidation of iron solutions $[Fe]_{total}$ in water using ozone technology, calculations were carried out using a special SMath Solver program. The algorithm of the research work is presented in Figure 8. In the figure, according to the technological process, an algorithm for reducing and eliminating the content of iron solutions $[Fe]_{total}$ in water was compiled and calculations were carried out. Theoretical calculations considered.

During the process, the concentration of ozone was changed, making the rate of water filtration constant in the load of quartz and activated coal (υ = 5.5 m/h), and vice versa. Where the time constant is t = 0.5 hours. S = $5 \cdot 10^2$ water volume (500 liters). At this point, the iron concentration $[F]_{total}$ can be calculated as

$$[F]_{total} = \frac{S}{\upsilon \cdot C \cdot t}, \ ([F]_{total} = 0.3 mg/l) \tag{8}$$

Where U is the water filtration rate; C is the amount of ozone (mg/l); t is the oxidation time (minutes).

(8) by changing the amount of ozone (C_{ozone}, mg/l) through the expression, the total concentration of dissolved iron in water $[F]_{total}$ can be calculated as:

$$[F]_{total_1} = \frac{5 \cdot 10^2}{\upsilon \cdot C_1 \cdot t} = 1{,}818\, mg/l \tag{9}$$

$$[F]_{total_2} = \frac{5 \cdot 10^2}{\upsilon \cdot C_2 \cdot t} = 0{,}909\, mg/l \tag{10}$$

$$[F]_{total_3} = \frac{5 \cdot 10^2}{\upsilon \cdot C_2 \cdot t} = 0{,}606\, mg/l \tag{11}$$

$$[F]_{total_4} = \frac{5 \cdot 10^2}{\upsilon \cdot C_1 \cdot t} = 0{,}454\, mg/l \tag{12}$$

$$[F]_{total_5} = \frac{5 \cdot 10^2}{\upsilon \cdot C_2 \cdot t} = 0{,}363\, mg/l \tag{13}$$

$$[F]_{total_6} = \frac{5 \cdot 10^2}{\upsilon \cdot C_2 \cdot t} = 0{,}303\, mg/l \tag{14}$$

Figure 9 of the above expression (8) shows that according to the algorithm of the process of oxidation of the iron concentration $[F]_{total}$ in water, the effective amount of ozone is C_{ozone} = 600 mg/l. During the technological process, the concentration of iron $[F]_{total}$ in water can be oxidized by changing the time constant at some point. If we keep the amount of ozone in the water constant (C_{ozone} = const) and change the time of the oxidation process, then we can determine the effective time constant.

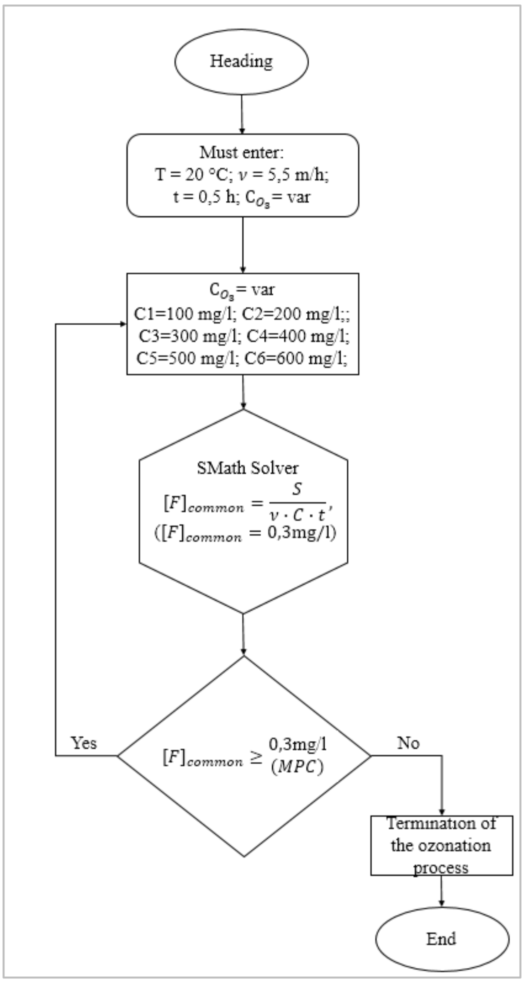


Figure 9: Algorithm for the process of oxidation of iron concentration $[F]_{total}$ in water (t = 30-35 minutes)

4. DISCUSSIONS

According to scientific research, it was found that one of the most effective methods of iron oxidation is ozonation (O_3). Ozone (O_3) is one of the strongest oxidizers that kills bacteria, spores and viruses, in addition to iron in general. Compared to chlorine, the use of ozone is more effective for oxidizing detergents, herbicides, pesticides, phenols and other difficult-to-oxidize chemical compounds. Simultaneously with disinfection, there are trends in the oxidation of iron and manganese, discoloration of water, as well as its deodorization and improvement of organoleptic properties.

The main advantages and relative potential of ozone technology over hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), hypochloritic acid (HOCl) are given (Figure 10):

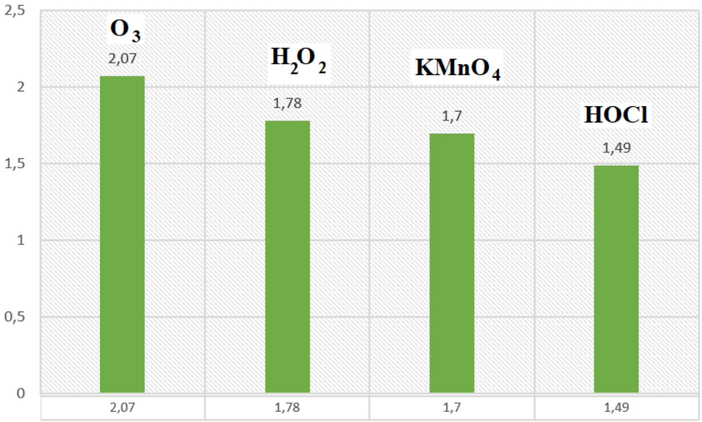


Figure 10. Relative potential of ozone with other oxidizing agents

- Treatment of iron, manganese, hydrogen sulfide, including water. their purifies from bacterial and organic compounds;
- Removes toxic impurities from petroleum products, detergents, pesticides, phenols;
- Removes toxic impurities from petroleum products, detergents, pesticides, phenols;
- High disinfecting properties when treating water from sources with a high risk of microbiological contamination (usually surface water sources);
- In lines for the production of bottled water, an ozonator device can be used.

Similarly, the effective solution of total $[Fe]_{total}$ iron before the filter and after the quartz sand filter and activated carbon, depending on the amount of ozone, was determined in the course of the research work (Figure 11).

As can be seen from the figure, as the amount of ozone increases, one can observe a decrease in the concentration of iron $[Fe]_{total}$. For example, it can be observed that the concentration of ozone is 500 - 600 mg/L, the amount of iron $[Fe]_{total}$ = 0.28 – 0.175 mg/l. And after the load of the Quartz filter, it can be seen that it decreases by 0.27 - 0.158 mg/l, after activated carbon – by 0.152-0.15 mg/l.

Depending on the filter load and the amount of ozone at different speeds, the following types of iron destruction.

In order to determine the effectiveness of cleaning iron in water by ozone concentration and filter load, water filtration works were carried out at different speeds of 5.5 - 9.5 m/h. For example, with an ozone content of C =100 mg/l and a filtration rate of 9.5 m/h, you can see that the iron content in water is purified by 30% percent, 8.5 m/h – 55% percent, 7.5 m/h - 77% percent, and 5.5 m/h - 90% percent. Accordingly, with an ozone concentration of C = 500 - 600 mg/l and a filtration rate of 5.5 m/h, it can be seen that Iron solutions with water content are purified by 98 - 98.7% percent.

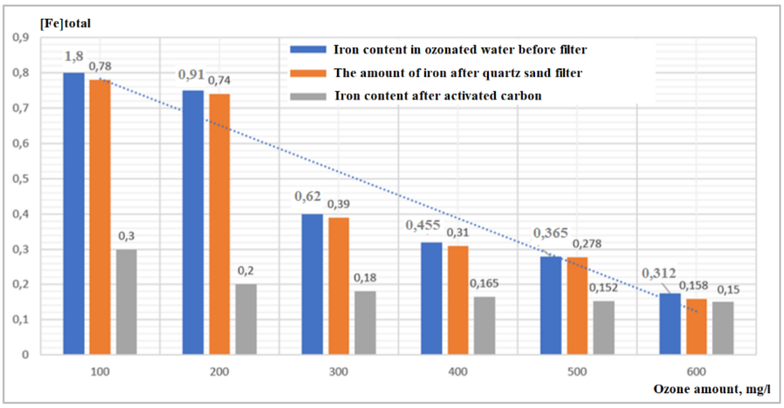
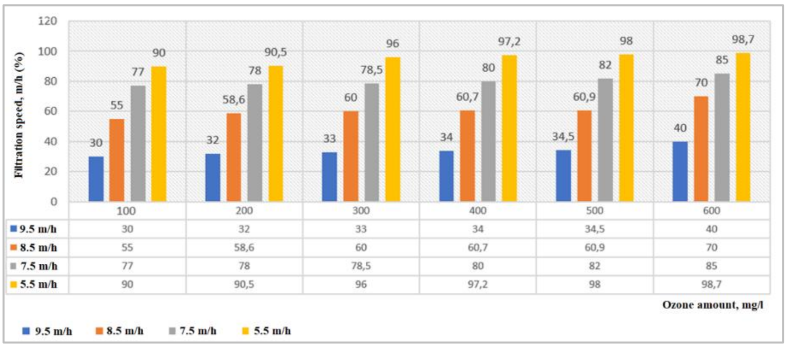


Figure 11: Changes in the concentration of ozone and total $[Fe]_{total}$ iron after filters



	100	200	300	400	500	600
■ 9.5 m/h	30	32	33	34	34,5	40
■ 8.5 m/h	55	58,6	60	60,7	60,9	70
■ 7.5 m/h	77	78	78,5	80	82	85
■ 5.5 m/h	90	90,5	96	97,2	98	98,7

Figure 12: Efficiency of cleaning iron in water by ozone concentration and filter load

5. CONCLUSIONS

Summing up the results of the scientific research work, in the future, the results obtained from this scientific work can be applied in the following directions:

- A scheme for the elimination of iron solutions found in underground water by means of ozone, quartz sand filter and activated carbon filters was proposed.
- The technological scheme can be used in the treatment of circulating water of small pools.
- In wastewater disinfection.
- it is used in the disinfection of bottled water to eliminate all unpleasant tastes and odors.

The scientific research work discussed above was carried out using the ETRO - 04 ozonator installation, based on the corona discharge, created on a new sample. Research work was carried out in the period from 2020 to 2023, the main technological indicators and results of the installation were determined.

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