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Investigation of the Efficiency of the Ozonator in the Process of Water Purification Based on the Corona Discharge

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ABSTRACT
In this research paper, the problem of studying the effectiveness of ozone in the process of water treatment was considered. In the course of the scientific work, a review of domestic and foreign literature was conducted; its advantages and disadvantages were considered. The research paper presented the theoretical and practical methods of water purification with ozone. The main factors influencing the efficiency of the technology in the process of water purification were also considered. It was established that as a technological method of water purification, the efficiency of the ozonation process includes not only the cost of electricity, but also the efficiency of its mixing, ozone dissolution in treated water. In addition, special attention is paid to the final stage of mixing the ozone-air mixture with treated water. From the results obtained, it can be seen that after primary ozonation, the concentrations of chromium, oxidation of permanganate, iron, petroleum products, metal ions and other pollutants significantly decreased. During further water purification, organic and inorganic pollutants are removed in the future (completely or up to the requirements of the standard). However, calcium, magnesium, sulfates, chlorides, pH value, alkalinity and hardness practically do not change. The water quality after primary ozonation according to bacteriological indicators met the requirements of the standard.

Keywords: corona discharge, ozonator, sewage, electric current, high voltage, ozonometer, ozone concentration.

INTRODUCTION

The main effectiveness of ozone in the process of water purification is that it is the most effective means of destroying harmful bacteria in the water, which react very quickly with harmful substances contained in the water. Ozone can be obtained with the help of special ozonators or with the help of ultraviolet (UV) rays. Ozone is a strong oxidizing agent used to purify water from excess organic and inorganic impurities. Similarly, any water can be neutralized with ozone [1].

Distinctive features of ozone:

- one of the strongest and most effective oxidizing agents;
- it has a strong antiviral effect (especially useful in the fight against Giardia, Cryptosporidium and other pathogenic flora);
- helps to quickly eliminate water turbidity;
- neutralizes the unpleasant smell and taste of water.

Limitations in the use of ozone:

- Ozone acts very quickly, its duration of action is only 30–40 minutes, when water is heated to t > 10 °C, ozone completely decomposes in 6–10 minutes;
- being a strong oxidizing reagent, ozone transforms complex organic elements into simple ones;
- in the process of oxidation of organic compounds with ozone, toxic substances are obtained: aldehydes, peroxides, ketones and much more. If ozone is used as a disinfectant in large quantities, it is necessary to monitor the presence of the above-mentioned compounds in the water [2, 3].

Ozone is used for underground and surface waters, as it not only neutralizes, but also removes excess chemical elements from the water: iron and manganese. After completion of ozonation, a long-acting antibacterial reagent, for example, sodium hypochlorite, is additionally immediately injected into the water. The only way to increase the efficiency of ozone in the process of water purification is the use of additional reagents and filters [2].

METHODS AND METHODOLOGY

In foreign research works (in Western European countries), from the experience of using water purification plants with active carbon filters, there is a method to increase the efficiency of sorption purification by pre-ozonation of water. The process of water purification called "biologically active coal" is known. Preliminary ozonation of water leads to the transformation of natural organic substances into biodegradable forms and reduces the load on activated carbon by mineralizing part of them with the help of microorganisms. At the same time, there is an increase in the duration of the filter cycle in activated carbon until the adsorbed impurities are removed. According to foreign data, the biological process can significantly extend the service life of coal without regeneration [3, 4].

The use of ozone in the water treatment process is currently developing in two main directions: 1) to improve the efficiency of high-frequency and high-performance ozonators; 2) to increase the speed of the ozonation process and disinfection of water with UV radiation. The choice of method and equipment for mixing water-containing slowly soluble gas (ozone) is an urgent problem in water treatment technology. Many new theoretical provisions and constructive elements, taking into account modern achievements in the theory and practice of mass transfer, new methods and equipment for disinfection of wastewater and natural waters have not yet been introduced into the practice of water purification. This negatively affects both the criteria and the efficiency of wastewater treatment technology [4, 5].

The advantages of ozone in water ozonation are as follows [6]:

- Complete disinfection of water, containers and working containers;
- The decomposition of ozone into an atom and an oxygen molecule. This, firstly, leads to the complete removal of the substance from the water and secondly, it eliminates the need for dosing;
- The ozonator receives air from the environment to produce ozone (O_3). There is no need to constantly buy reagents;
- Ozonation does not change the acidity of the water;
- Improves the organoleptic properties of water (smell, taste, color, turbidity, etc.).

The rate of water disinfection is measured in seconds. This indicator is very important for production lines.

Ozone (O3) is safe, dissolves in water for too short a time, and unlike its chlorine, residual ozone does not remain in water. In Europe, 98% of drinking water is already purified only by ozonation, and in the USA the use of chlorine has been abandoned altogether [7].

Like other methods of water purification, ozone technology has its drawbacks. The oxidized substances in the sediment must be removed by another stage of mechanical water purification. Ozone is ineffective for dry substances and phenolic compounds. Therefore, in the process of water purification, in addition to the ozonation plant, water softening mechanisms and fine filtration plants are installed. Ozone is poisonous and explosive. Most importantly, ozonators are much more expensive [8, 9].

RESULTS AND DISCUSSIONS

To conduct research at the Kazakh National Research Technical University named after K. I. Satpayev, a laboratory model has been developed to study the effectiveness of the water purification process with an ozonator based on a corona discharge (Fig. 1, 2, 3).

In the ozonator, a voltage breakdown occurs at a certain value of the electric field. This voltage is called the threshold voltage and is denoted by E_{limit}.

In the case of a flat capacitor, where the field is uniformly destroyed when the E_{limit} value is reached and a $U_к$ – voltage occurs

$$U_к = a \cdot E_{limit} \tag{1}$$

where: a – is the distance between the plates.

Ozonator devices based on any barrier discharge operate in the capacitor mode (Fig. 2b). The main feature of the ozonator design is the "cylinder inside the cylinder" design, in which the maximum value of the field strength in the structure is taken within $X = r$ (Fig. 1 and 2a), i.e. on the surface of the inner cylinder [10]:

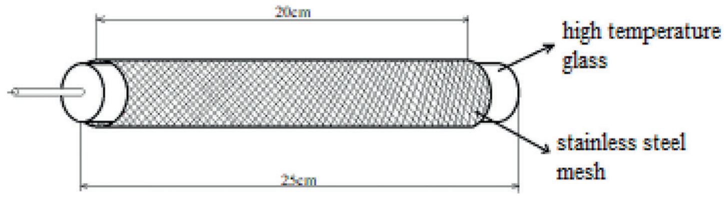


Figure 1. Surface view of the corona arrester

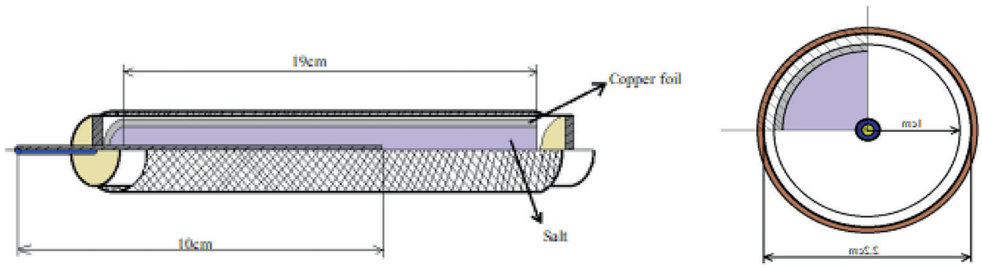


Figure 2. Ozonator based on corona discharge, (a) ozonator 4/1 part, (b) top view

$$E_{Max} = \frac{U}{r ln\frac{R}{r}} \quad (2)$$

Introduction of a geometric characteristic

$$p = \frac{r+a}{r} = \frac{R}{r} \quad (3)$$

for breakdown voltage

$$U_{breakdown\,voltage} = E_{breakdown} \cdot r \cdot l_{breakdown} \quad (4)$$

Since the geometric characteristics are constant and proportional to the radius of the inner cylinder, it can be traced from the expression below:

$$\alpha = r \cdot l_{breakdown} \quad (5)$$

To determine the efficiency of the ozonator, the following expression is used:

$$\eta = \frac{\alpha}{a} = \frac{r}{(a+r)-r} \ln p = \frac{1}{p-1} \ln p \quad (6)$$

In this case, the efficiency of the ozonator depends only on the geometric characteristics. Using the efficiency of the device, the breakdown through voltage can be found according to the formula below.

$$U_{breakdown\,voltage} = E_{breakdown} \cdot a \cdot \eta \quad (7)$$

The device works as follows: atmospheric air or oxygen (O_2) is supplied to the ozonator by means of a compressor, ozone (O_3) at the outlet of the ozonator enters a container with wastewater and interacts with an aqueous molecule (H_2O).

A new type of ozonator based on a special corona discharge was developed in the laboratory and theoretical and practical tests were carried out. The simplicity of the ozonator design with its energy efficiency was determined.

Experimental studies of the water ozonation plant were carried out. Ozone productivity and specific energy consumption were determined experimentally. Figure 3b shows a block diagram of a pilot plant for wastewater treatment. The technical parameters of the installation are given in Table 1 below.

Determination of the power density and temperature of the gas in the ozonator is the ratio of the active power propagating in the ozonator to the discharge region of the electrodes.

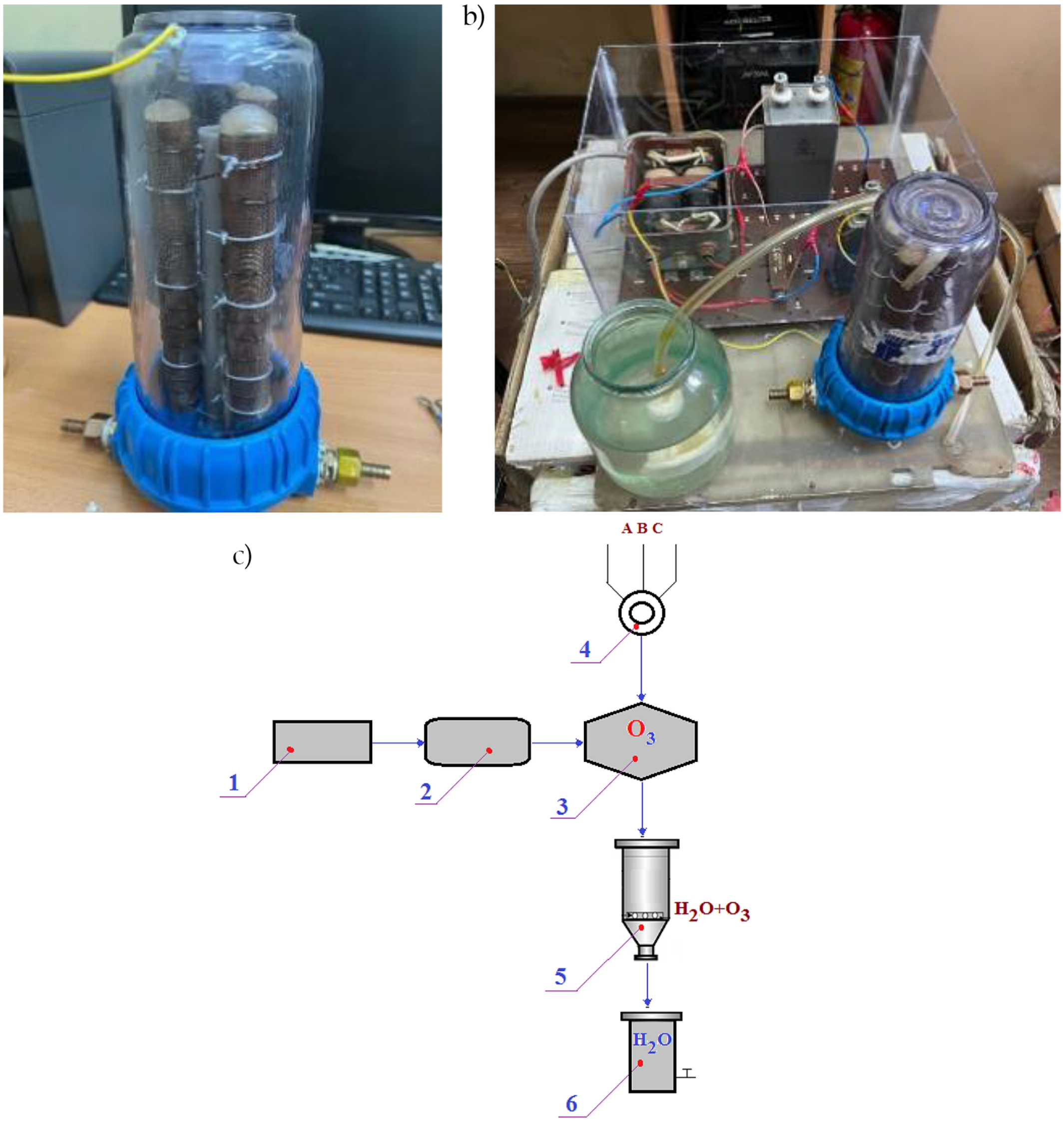
$$U_1(x,t) = A_1 + B_1 \times \Phi\left(\frac{x}{2a1\sqrt{t}}\right), kV \quad (8)$$

where: $U_1(x, t)$ is the distribution on the barrier surface in the ionized zone, A1 and B1 are the constant (Error integral) determined from the boundary conditions.

Table 1. Technical parameters of the installation

1	Voltage of the electrical network	3kV, 50 Hz
2	Power consumption	125 W
3	Volume of treated water	2 m^3
4	Single action time	10 min
5	Weight	10.5 kg

a) b)



c)

Figure 3. Experimental setup, (a) general image of the experimental setup, (b) block diagram of the experimental installation, where (1) part of the control of the installation; (2) the source of the high-voltage node (generator); (3) an ozonator based on an electric corona discharge; (4) a compressor; (5) a reservoir; (6) a reservoir of pure water

$$\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e - £^2 d \quad (9)$$

$$a_1 = \frac{1}{\sqrt{(Rp + Rэ)Cб}} \quad (10)$$

The situation at the ionization boundary x = ξ :

$$U + \mathrm{B1} \times \Phi\left(\frac{\xi}{2\sqrt{t}}\right) = U_1(\xi, t) \quad (11)$$

From this formula, it is possible to calculate the formation time of micro -discharges as follows:

$$t\phi = (\xi \,/\, \psi)^2 \approx 3.3 \cdot 10^{-9}\ s \quad (12)$$

Formation voltage under the action of micro-discharges (minimum):

$$U_{min} = I_m \cdot r_{mic} = 0.64 \cdot 2100 \approx 1.35\ kV \quad (13)$$

The voltage on the device (voltage on the active element) can be determined as follows:

$$U_{active\ voltage} = 1.35/\sqrt{2} = 0.96\ kV \quad (14)$$

During the research work, methods of ozonation and coagulation, precipitation and filtration of water, as well as traditional methods of Cathedral purification were additionally used. Therefore, in all scientific and experimental studies, it is possible to observe the effectiveness of water purification with ozone. (Table 2) [12, 13]. Water quality is often illustrated by spectrogram data at different wavelengths (for example, nitrates 220 nm, total organic matter 254 nm, color 400 nm, and turbidity of water 540 nm).

Figure 4 shows the results of UV spectrometry of various wavelengths. The figure shows that the content of organic substances after ozonation decreased by an average of 30%, after coagulation, bleaching in settling tanks and filtration through a sand filter – from 10 to 80% (on average by 45%). The sorption filter additionally reduces the organic matter content by another 50–70% (on average by 65%) [8].

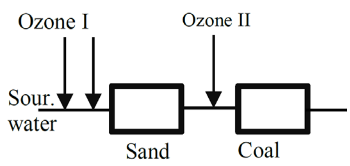
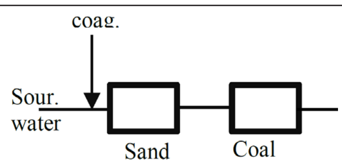
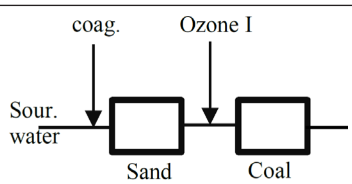
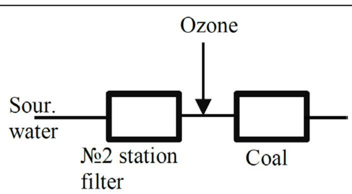
In the course of these studies, it can be noticed that harmful substances in terms of water quality have decreased by several percent (for example, there is no turbidity and color in purified and filtered water) [8,10].

To determine the results of the biological process using AG-3 grade coal, a special research work was carried out [10]. For 50 days, the river water treated with coagulant was continuously fed and filtered into two columns loaded with AG-3 grade coal. Ozone in the amount of 2 mg/l was sent to activated carbon filtration before water was supplied, and in the second case, water without ozone was sent to the carbon filter. As a result of the conducted experiments, it was found that when using ozone in front of a carbon filter, the content of organic pollutants increases by 30–35% [12, 13].

In the primary ozonation scheme, the percentage effect of obtaining organic substances, characterized by the UV absorption indicator D254, is somewhat lower (Fig. 5). Then, the purification efficiency changes among themselves: the purification effect according to the activated carbon scheme continues to decrease over time, and the purification effect according to the ozonation and sorption purification scheme is practically stabilized. The nature of the change in the effectiveness of the two options considered is an indirect proof of the course of an intensive biological process on coal in the pre-ozonation scheme. The location of the initial sections of the efficiency curves is explained by some deterioration in the absorption of organic substances as a result of ozonation. This leads to an increase in the polarity of the molecules and a decrease in their molecular weight.

It was found that the decrease in the sorption capacity of activated carbon after purification of ozonated water at the end of the filtration cycle is approximately halved compared to the purification of water not treated with ozone. This can be

Table 2. The effectiveness of the use of ozone and activated carbon in various technological schemes [10, 11]

No.	Water purification schemes	Name of samples	Ozone amount, mg/l	Transparency mg\l	Color, grad	Oxidation
1		Source water		37.6	93	5.39
		Ozonated water (1 time)	2.0	16.9	41	4.8
		After coagulation		0	14	4.48
		Ozonated water (2nd time)	2.4	0	0.5	3.22
		Coal filter		0	0	1.27
2		Source water		37.6	93	5.39
		After coagulation		1	7	4.2
		Coal filter		0.5	0	2.4
3		Source water		37.6	93	5.39
		After coagulation		0	7	3.2
		Ozonated water (2nd time)	2.4	0	0	3.06
		Coal filter		0	0	2.33
4		Second filtering		0	0	1.89
		Ozonated water (2nd time)	3.3	0	0	1.93
		Coal filter		0	0	1.0

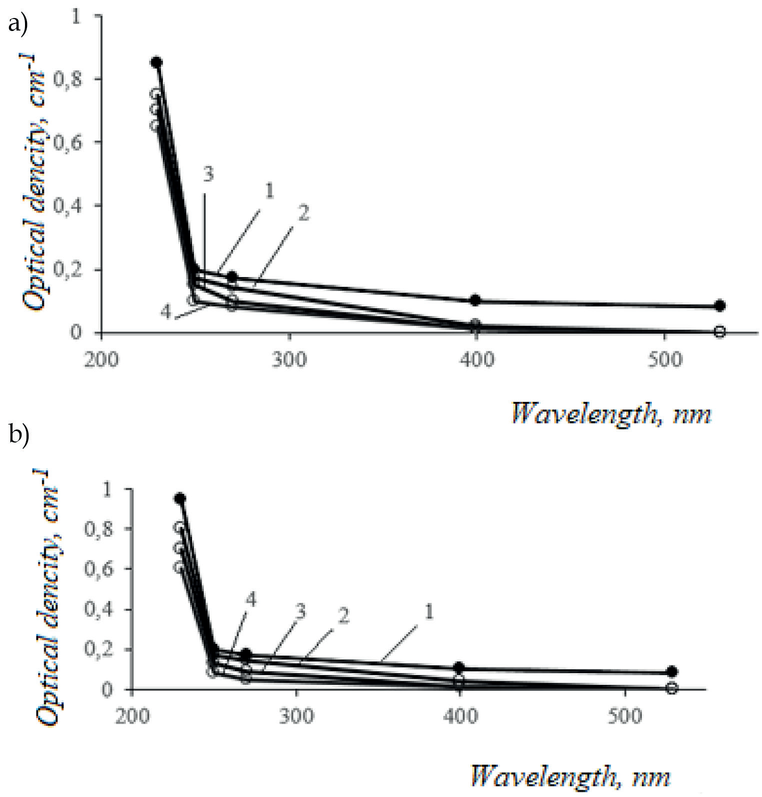


Figure 4. UV spectrogram data [8, 11], where (1) is source water, (2) is ozonated water, (3) is water after sand loading, (4) is water after coal loading

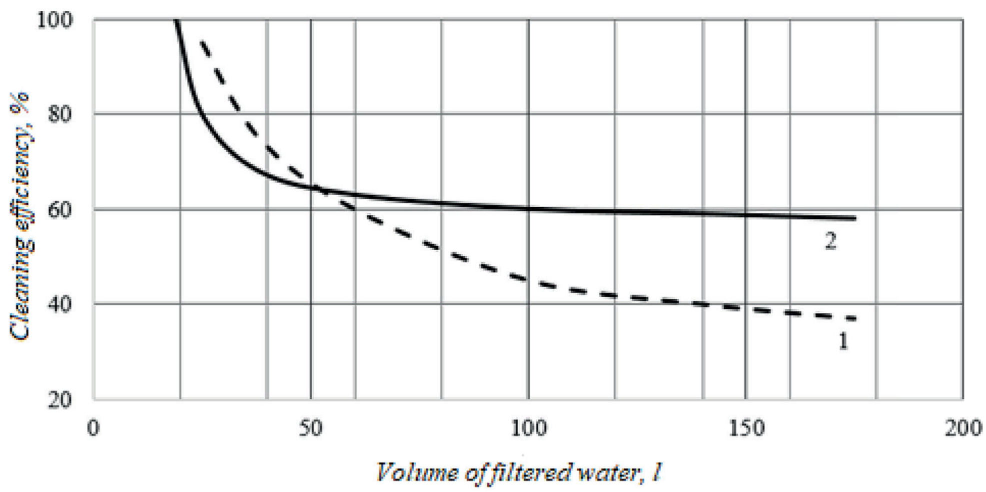


Figure 5. The effect of reducing the UV absorption of water after coagulation treatment, where: (1) is activated carbon, (2) is ozone together with activated carbon

Table 3. Efficiency of removal of organic pollutants at various stages of water purification

Indicators	Units	Water samples			
		Source water	Ozone	Sand filter	Coal filter
Total content of organic compounds (UV wave index 254 nm)		0.11–0.27	0.09–0.123	0.078–0.92	0.019–0.05
Petroleum products	mg/l	0.139–0.39	0.07–0.19	0.07–0.19	0–0.06
Phenols	mg/l	0.0017–0.0056	0–0.0035	0.002–0.0038	<0.001–0.002
COD (chemical oxygen demand)	mgO_2/l	25–45	15–27	18–29	12–23.4
BOD_5 (Biological oxygen demand)	mgO_2/l	1.32–3.03	2.3–2.7	0.55–0.57	0–0.32

explained by the process of bio-regeneration of activated carbon. It was also noted that the number of microorganisms detected in activated carbon during ozonation is 3.5 times greater.

The efficiency of water purification in the settlement of Kumkol is presented in Tables 3 and 4.

A large complex of works to determine the effectiveness of ozone and the presence of organic compounds before and after ozonation was carried out during the purification of the water of the Ili river (Almaty region, Kapshagai) [10.11]. During the experiment, the scheme of application of two-stage ozonation, reagent treatment and sorption water purification was considered. The results of experimental studies are presented in Table 5.

From the results obtained, it can be seen that after primary ozonation, the concentrations of chromium, oxidation of permanganate, iron, petroleum products, metal ions and other pollutants significantly decreased.

During further water purification, organic and inorganic pollutants are removed in the future (completely or up to the requirements of the

Table 4. Efficiency of removal of inorganic contaminants at various stages of water purification

Indicators	Units	Water samples			
		Source water	Ozone concentration 600mg	Sand filter	Coal filter
Iron	mg/l	0.25	0.20	0.15	0.11
Ammonium nitrogen	mg/l	0.8	0.47	0.3	0
Nitrites	mg/l	0.12	0.022	0.002	0.022
Nitrates	mg/l	16.4	15.0	15.5	15.5
Manganese	mg/l	0.55	0.17	0.0023	0.0014
Beryllium	mg/l	2000	0	0	0

Table 5. Qualitative indicator for water treatment stages [163–165]

Indicators	Source water	Subsequent water			
		Primary ozonation	Sand filter	Repeated ozonation	Sorption filter
Turbidity, mg/l	8	5	1.7	1	0
Color, grad.	10.5	6.5	5	0.1	0
Oxidation, mgO_2/l	2.2	2	2	1	0.4
Nitrates, mg/l	1.5	2	1.8	1.1	1
Common iron, mg/l	0.37	0.3	0.2	0.1	0
Ammonia, mg/l	1.8	0	0	0	0
Petroleum products, mg/l	0.12	0	0	–	–
Metals, mg/l					
Copper	0.025	0.019	0.018	0.018	0.018
Lead	0.007	0.007	0.005	0.003	0.002
Nickel	0.025	0.014	0.015	0.015	0.014
Cobalt	0.007	0.003	0.002	0.002	0
Chrome	0.02	0.004	0.002	0.002	0.002
Vanadium	0.004	0.003	0.002	0.001	0.001
Titan	0.049	0.038	0.027	0.027	0.027
Molybdenum	0.0015	0.0014	0.0011	0.0009	0.0007
Silver	0.0015	0.001	0.0002	0.0001	0.0001
Barium	0.039	0.038	0.036	0.036	0.036
Zirconium	0.025	0.014	0.014	0.009	0.009
Strontium	0.392	0.288	0.27	0.27	0.27
Manganese	0.074	0.038	0.027	0.023	0.018
Koli-index, cl/l	>1100	<3	<3	<3	<3
Total microbial number, CL / ML	200	80	98	85	98

Table 6. The effect of ozonation on the content of organic compounds in water

Indicators	MPC (maximum permissible concentration), mg/l	Water, mg/l		
		River	Ozonated	Purified
1	2	3	4	5
It is normalized according to general sanitary and organoleptic indicators				
Acetaldehyde	0.2	0.01	0.026	0.02
Acetone	2.2	0.035	0.035	0.035
Dichloromethane	7.5	0.4	0.4	0.035
1,3,5-trinitrotoluene	0.5	0.003	0.003	<0.001
Toluene	0.5	0.2	0.2	0.035
P-Xylene	0.05	0.035	0.035	0.003
M-Xylene	0.05	0.035	0.035	0.008
O-Xylene	0.05	0.008	0.008	0.003
Styrene	0.1	0.003	0.035	<0.001
Hexane	0.5	0.08	0.035	0.003
Isopropylbenzene	0.1	0.003	0.003	<0.001
α-Methylstyrene	0.1	0.003	0.003	<0.001
Vtorbutylbenzene	0.1	0.003	0.003	<0.001
Tretbutylbenzene	0.1	0.008	0.008	0.001
2-ethyl-1-hexane	0.15	0.035	0.003	0.008
Benztiazole	0.25	0.008	0.003	0.003
Di-n-butyl phthalate	0.2	0.4	0.4	0.2
Di-n-octyl phthalate	1	0.08	0.035	0.035
Acetaldehyde	0.2	0.08	0.08	0.08
2-butene	0.2	0.003	0.003	0.003
Acetonitrile	0.7	0.035	0.035	0.035
Akironitrile	2	0.001	0.003	0.001
2-methylfuran	0.5	0.003	0.003	0.003
3-pentanon	0.03	0.001	0.008	0.008
2,3-dimethylbutanol	0.01	0.008	0.008	0.008
2-methyl-2-pentanol	0.01	0.003	0.003	0.003
Benzaldehyde	0.003	0.003	0.008	0.008
Heptanol	0.005	0.008	0.003	0.08
Phenol	0.001	0.003	0.003	0.003
Naphthalene	0.01	0.003	0.003	0.003
Normalized by sanitary and toxicological indicators				
Formaldehyde	0.05	0.005	0.024	0.01
Furan	0.2	0.008	0.008	0.008
Croton aldehyde	0.3	0.001	0.003	0.003
Acetophenone	0.1	0.001	0.003	0.003
1,2-dichloroethylene	0.006	0.008	0.003	<0.001
Chloroform	0.06	0.2	0.2	0.035
1,2-dichloroethane	0.02	0.008	0.008	<0.001
Benzene	0.5	0.008	0.008	0.003
Trichloroethylene	0.06	0.008	0.003	<0.001
Lindane	0.004	0.035	0.035	0.003
Diphenyl	0.001	0.003	0.003	<0.001
Dimethyl phthalate	0.3	0.008	0.008	0.001

standard). However, calcium, magnesium, sulfates, chlorides, pH value, alkalinity and hardness practically do not change.

The water quality after primary ozonation met the requirements of the standard according to bacteriological indicators.

Such practical studies have been conducted in foreign scientific research. For example, to study the composition of organic pollution in natural water and its changes in the process of water purification using ozone, specialists of the Chemical Faculty of Moscow State University conducted special studies with the analysis of water quality by chromatography-mass spectrometry [14, 15].

In the studied water samples, 230 organic compounds of various chemical nature were detected, 27 of which were included in the category of hazardous pollutants from the list of the US Environmental Protection Agency. Table 6 presents the sanitary rules and data on changes in the composition of norms and normalized organic pollutants [10, 13].

As it can be seen from the table, the regulatory content of harmful substances in the river water sampled during the flood period exceeds MPC by a number of indicators.

After primary ozonation, the concentration of the proposed organic pollutants changes uniformly: some of them decrease, others increase. Further purification of water by coagulation, clarification and processing with ozone can significantly improve its quality in all organic compounds.

A complete analysis of changes in the composition of organic substances during ozonation of river water was carried out for all identified substances. As a result of the destruction of organic

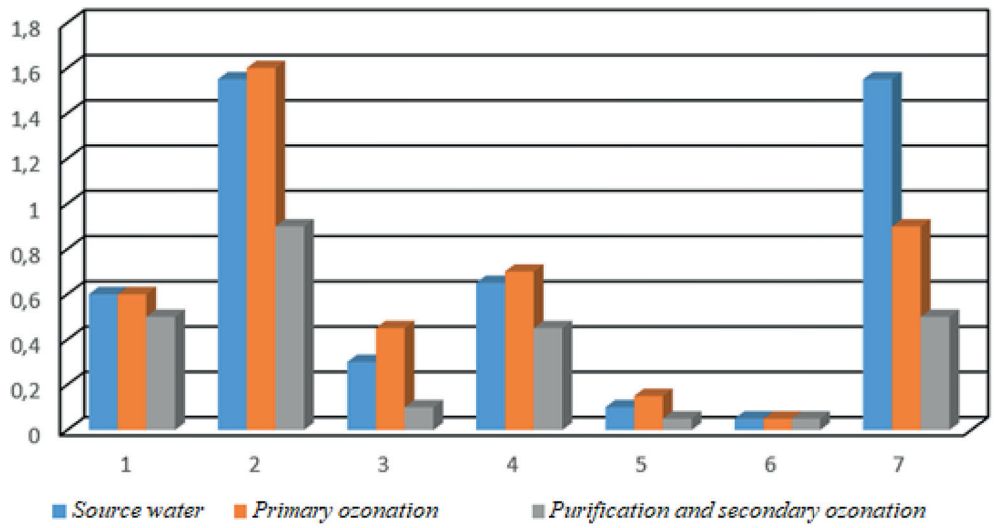


Figure 6. Changes in the concentration of various hydrocarbons during ozonation and purification of the water of the Ural River [10, 11]

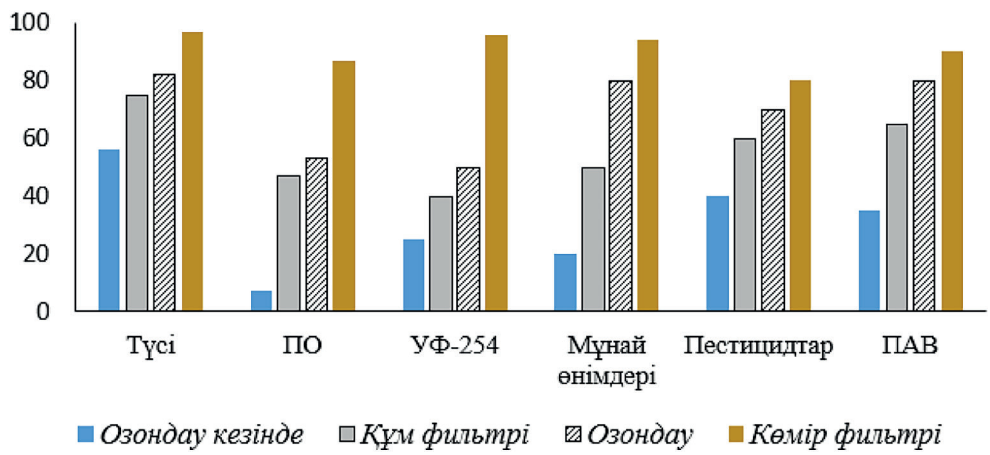


Figure 7. Efficiency of removal of various contaminants by stages of water purification (according to generalized data)

pollutants, oxidation by-products are formed, and the concentration of some compounds increases. Figure 6 shows the change in the qualitative and quantitative composition of organic pollution of untreated and purified river water (for visual representation, all identified organic compounds are conditionally divided into main classes) [16].

The generalized data on the effectiveness of water purification from pollutants for various periods are presented (Fig. 7).

During the primary ozonation of water, the concentration of alcohols, esters and halogen-containing hydrocarbons decreases, and the content of compounds of other classes increases. With secondary ozonation of purified water, the amount of all organic pollutants decreases.

The schematic diagram and dynamic conditions of the ozonation process in static form are shown in Figure 8. The figure shows all the similarities of static and dynamic modeling methods. A significant difference in determining the main parameters of the process is:

a) for the case:

$$G = G_O + G_R + G_B \quad (15)$$

$$G = [C_{O_3}] \cdot Q_B \quad (16)$$

$$G_0 = R_O \cdot Q \quad (17)$$

$$G_R = [R_{O_3}] \cdot Q_B \quad (18)$$

$$Q_B\,[C_{O_3}] = R_O \cdot Q + R_{O_3} \cdot Q + [R_{O_3}] \cdot Q_B \quad (19)$$

$$\eta = G - G_B/G = 1 - G_B/G = 1 - [R_{O_3}]/[C_{O_3}] \quad (20)$$

$$[C_{O_3}] \cdot Q_B\,\eta/Q = R_O + R_{O_3} \quad (21)$$

$$D_{O3} = [C_{O_3}] \cdot Q_B\,/Q = R_O + R_{O_3}/\eta \quad (22)$$

$$R_O = \eta\, D_{O_3} - R_{O_3} \quad (23)$$

b) for the case:

$$G = G_0 + G_R + G_B \quad (24)$$

$$G = [C_{O_3}] \cdot Q_B \cdot T_k \quad (25)$$

$$G_0 = R_O \cdot V \quad (26)$$

$$G_R = [R_{O_3}] \cdot V \quad (27)$$

$$Q_B = [R_{O_3}] = Q \cdot T_k \quad (28)$$

$$Q_B = [C_{O_3}] \cdot T_k = RO \cdot V + R_{O_3} \cdot V + [R_{O_3}] \cdot Q_B \cdot T_k \quad (29)$$

$$\eta = G - G_B/G = 1 - G_B/G = 1 - [R_{O_3}]/[C_{O_3}] \quad (30)$$

$$T_k \cdot [C_{O_3}] \cdot Q_B\,\eta/V = R_O + R_{O_3} \quad (31)$$

$$D_{O_3} = T_k \cdot [C_{O_3}] \cdot Q_B\,/V = R_O + R_{O_3}/\eta \quad (32)$$

$$R_O = \eta\, D_{O_3} - R_{O_3} \quad (33)$$

where: G – amount of introduced ozone;
G_O – ozone used for oxidation of pollutants;
G_R – ozone residue content in water;
G_B – residual ozone content in gas mixture;
Q – purified water consumption, m^3/h;
V – volume of purified water, m^3/h;
Q_B – consumption of ozone-air mixture, Nm^3/h;
R_O – ozone absorption by source water, mg/l;
$[C_{O_3}]$ – concentration of ozone mixture after the ozonizer (air with an admixture of ozone), g/Nm^3;
$[R_{O_3}]$ – concentration of ozone in the ozone-air mixture after the contact chamber, g/Nm^3;
n – efficiency of ozone use (efficiency);
D_{O_3} – ozone content, g/m^3;
T_k – time contact of ozone-air mixture with water, min.

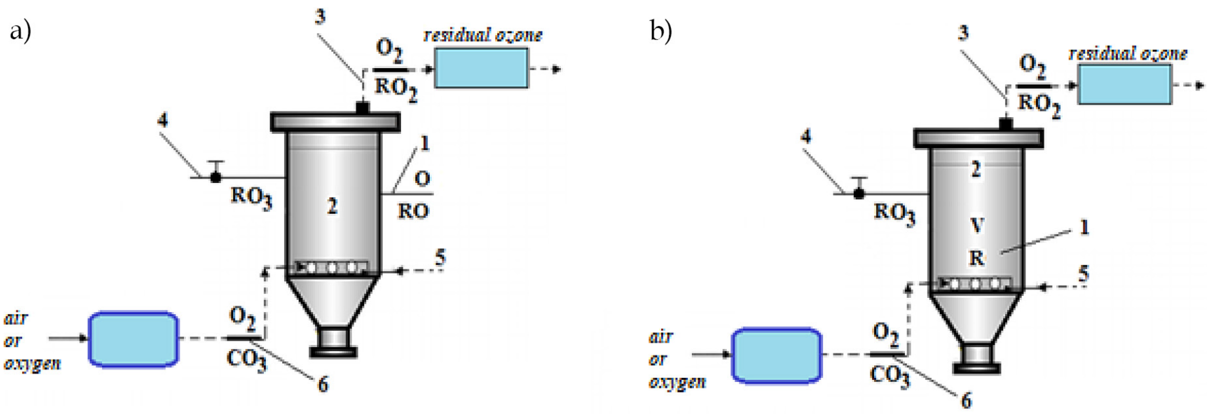


Figure 8. Block diagram of the water ozonation process; a) dynamic mode, b) static mode; 1, 4 – initial and ozone distilled water; 2 – contact chamber; 3, 6 – initial and spent ozone-air mixture; 5 – porous (porous) diffuser

The main error in the static modeling model is the inaccuracy of the contact time in the contact chamber, since the concentration of residual ozone $[R_{O_3}]$ in the Gas is independent.

In this case, water with ozone is an integral nature due to the tendency to saturation, the contact time $T_k = 60$ (V/Q), min (Q is measured in m^3/h, V-m^3), cannot be determined by the formula. This formula is used during a dynamic experiment. However, in any period of time, the supply of an ozone-air mixture from the ozonizer to distilled water does not take into account the formation of an amount of ozone from the contact chamber and the ozone-air mixture consumed along the way $[R_{O_3}] = 0$ ($n = 1$). At the same time, the value of n (efficiency) in the stationary dynamic mode is not described in dynamic modeling.

As established in the research work, the most effective in most cases is a two-stage ozonation scheme. This technology ensures the removal of organic pollutants by 80–85% by oxidation, by 95–99% by UV index, by 90-95% by petroleum products.

CONCLUSIONS

The research paper considered the study of the effectiveness of an ozonator in the process of water treatment based on a corona discharge. In the course of the review work on foreign literature, the economic losses of ozonators were considered when using methods of ozonation and sorption purification. For example, to obtain ozonator buildings, activated carbon or other filters, etc., the operating costs, the costs of providing electric power and continuous activated carbon were investigated.

During the study, technical and economic indicators of the ozone technology water purification process were presented. It was established that water treatment using activated carbon with ozone is effective. Experimental studies of the water ozonation plant were carried out. Ozone productivity and specific energy consumption were determined experimentally. UV spectrogram data were considered. During the research work, the devices corresponding to the range of ultraviolet radiation used for disinfection and the principle of their operation were considered. LED sources of ultraviolet radiation were selected as a research device. The principle of operation of UV LEDs has been studied. LEDs with a voltage of 12 V and a current of 720 mA were selected. It was found that the decrease in the sorption capacity of activated carbon after purification of ozonated water at the end of the filtration cycle is approximately halved compared to the purification of water not treated with ozone. This can be explained by the process of bio-regeneration of activated carbon. It was also noted that the number of microorganisms detected in activated carbon during ozonation is 3.5 times greater.

In the research work, a small ozonator device was developed, theoretical and experimental studies were carried out. The ozonator is designed for disinfection and purification of natural water. As established in the research work, the most effective in most cases was a two-stage ozonation scheme. This technology ensures the removal of organic pollutants by 80–85% by oxidation, by 95–99% by UV index, by 90–95% by petroleum products.

REFERENCES

1. Bahtaev S.H.A., Tojgozhinova A.Z.H., Kodzhabergenova A.K. 2014. Fizika processov obrazovaniya i poteri ozonov otricatel'noj korone Vestnik Nacional'noj Akademii Nauk Respubliki Kazahstan, Almaty, 4, 36–41.
2. 2. Bahtaev SH.A., Tojgozhinova A.Z.H., Sydykova G.A. 2014. O raspredelenii plotnosti ozona v razryadnoj zone otricatel'noj korony. Doklady Nacional'noj Akademii Nauk Respubliki Kazahstan, Almaty, 4, 41–46
3. Yavorovskij N.A., Sokolov V.D., Skolubovich Y.U. A, Li I.S. 2000. Ochistka vody s primeneniem elektrorazryadnoj obrabotki. Vodosnabzhenie i Santekhnika, 1, 12–14.
4. Ivanov V.G., Dikarevskij V.S. I Dr. 2000. Obezzarazhivanie pit'evyh i stochnyh vod produktami elektrohimicheskoj aktivacii. Vodosnabzhenie i Santekhnika, 10, 26–28.
5. Mnuhin A.G., Bryuhanov A.M., Nasonov S.V., Mnuhin V.A. 2020. Obezzarazhivanie poverhnostnyh i stochnyh vod s pomoshch'yu elektrogidravlicheskogo vozdejstviya. Vodosnabzhenie i Santekhnika, 11, 18–19.
6. Goncharuk V.V., Potapchenko N.G. i dr. 2001. Obezzarazhivanie vody ozonom. Vliyanie neorganicheskih primesej na kinetiku obezzarazhivaniya vody. Himiya i Tekhnologiya Vody, 23(2), 198–208.
7. Baryshnikov V.V., Hmara V.F. i dr. 2000. Primenenie ozono-fil'troval'nyh ustanovok dlya ochistki prirodnyh vod. Vodosnabzhenie i Santekhnika, 1, 15–16.

8. Draginskij V.L., Alekseeva L.P. 2002. Obrazovanie toksichnyh produktov pri ispol'zovanii razlichnyh okislitelej dlya ochistki vody. Vodosnabzhenie i Sanitarnaya Tekhnika, 2, 9–12.
9. Sokolov V.D., Usol'cev V.A., Skolubovich Y.U-.L., Alekseeva L.P., Draginskij V.L. 2001. Podgotovka vody pit'evogo kachestva v gorode Kemerovo. M.
10. Draginskij V.L., Usol'cev V.A., Sokolov V.D., Alekseeva L.P. 1994. Primenenie ozona na Kemerovskom vodoprovode. Vserossijskaya Konferenciya "Ozon-94", Tezisy Dokladov. Ufa Reaktiv.
11. Draginskij V.L., Alekseeva L.P., Sabel'fel'd A.V., Gridasov G.G., Usol'cev V. A., Sokolov V. D. 1999. Podgotovka vodoochistnyh stancij k rabote usloviyah trebovanij SanPiN 2.1.559-96 (na primere gorodov Kuzbassa). Vodosnabzhenie i Sanitarnaya Tekhnika, 11.
12. Belyh I.A. 2009. Toksicheskoe dejstvie ozona na bakterii Escherichia coli. I.A. Belyh, I.P. Vysekancev, A.M. Grek, A.V. Sakun, V.V. Marushchenko, 1, 48–53.
13. Bozhko I.V. 2006. Elektrodnaya sistema dlya razryadnyh ustrojstv s polozhitel'noj strimernoj koronoj. I.V. Bozhko, I.S. Petuhov, N.I. Fal'kovskij (Eds.). Tekhn. Elektrodinamika, 3, 49–53.
14. Vlasov V.V. 2008. Elementarnye processy v plazme gazovogo razryada. H.: HNU, 175.
15. Bahtaev S.H.A., Sydykova G.K., Tojgozhinova A.Z.H. 2010. Razrabotka istochnika vysokovol't-nyh impul'sov dlya ozonatornoj yachejki. Mezhd. Nauchprakt. Konf. "Perspektivnye napravleniya al'ternativnoj energetiki i energosberegayushchie tekhnologii", Shymkent, 2, 63–65.
16. Bahtaev S.H.A., Tojgozhinova A.Z.H., ZHirnova O.V., Wojcik W., Sulejmenov B.A., Koshimbaev S.H.K. 2017. Modelirovanie processa ozonirovaniya vozduha v rabochem obeme pri szhiganii biogaza. Vysshaya Shkola Kazahstana. Mezhdunarodnoe Nauchno-Pedogogicheskoe Izdanie, 1(1), 280–289.