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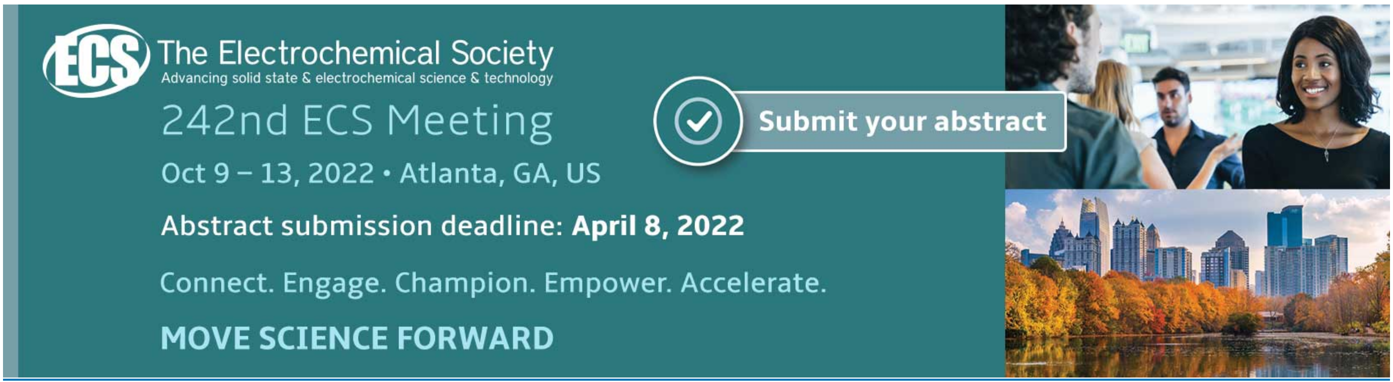

Disinfection of drinking water with ozone by the method of electrodispersion

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Abstract. This article analyzes the existing methods for disinfecting drinking water with ozone and identifies their disadvantages. The substantiation of the method of water disinfection with ozone using electrodispersion is given. The description of the technological scheme of water disinfection using the method of electrodispersion is given. The description of the design of the electric spray is given. The results of production tests of a device for water disinfection on the water of open reservoirs and artesian wells are presented.

1. Introduction

Since its discovery at the end of the 18th century, ozone has attracted great interest among specialists in various fields and researchers due to its unique properties, first of all, its high oxidizing and disinfecting capacity [1]. Ozone is the second relatively stable (metastable) simple molecular compound, which, along with the O_2 form, forms oxygen. In total, seven simple oxygen compounds are known, including the O_4 and O_6 complexes [2]. Ozone (O_3) is an allotropic modification of oxygen which, under normal conditions, is a gaseous colorless substance with a pungent odor. Ozone is one of the most powerful oxidants used to degrade organic pollutants from drinking or waste water [3].

There are many methods for generating ozone, including electrical barrier discharge, ultraviolet radiation, thermal, chemical, electrolytic, and chemo-nuclear methods [4].

The ozone molecule, due to the splitting of the third oxygen atom, is a strong oxidizing agent. This property makes it very effective in killing microorganisms. It has been proven that ozone destroys viruses that cause hepatitis A, influenza A, vesicular stomatitis and infectious rhinotracheitis in cattle. Inactivation occurs mainly as a result of damage to protein and peptidoglycan molecules in the virus capsid. It is equally effective in killing several strains of bacteriophages. The bactericidal properties of ozone have also been demonstrated in the case of gram-positive and gram-negative microorganisms (Yersiniaenterocolitica, Pseudmonasaeruqinosa, Salmonellatyphimurium); both in spores and in vegetative cells [5].

The reactions of ozone with aromatic compounds formed the basis of modern technologies for deodorization of various environments, rooms, drinking and waste waters [6]. Today, the advantages of using ozone in the processes of purification and disinfection of water are generally recognized.

Ozonation is an effective alternative to the treatment of waste water containing metals in organic complexes. Ozone is an unstable gas, so it must be generated before direct use. Commercially available ozone generation technology is based on the corona discharge process, which involves the use of a high voltage discharge in a cooled and dried gas phase containing oxygen (O_2 or air) [7].

There are many water treatment systems operating in the world today that use ozonation: in France, Canada, Switzerland, Italy, Germany, Saudi Arabia, Belarus, etc. However, these systems are used only for water disinfection. In 2005, the USA patented a method for disinfection of water supply networks using ozone [8, 9].

In industrialized countries, ozone is widely used in many sectors of the economy, including the dairy industry, medicine, wastewater treatment, chemical and petrochemical processes, agriculture, electronics, paper and textile industries, microbiological and food industries, mechanical engineering, and in utilities [10-16].

Despite the numerous patents for inventions aimed at increasing the efficiency of the process of ozone electrosynthesis [17, 18], they have not found industrial use. For the electrosynthesis of ozone on an industrial scale, sinusoidal voltages with a frequency of about 50 Hz and high-frequency ozonizers with a frequency of 1000 Hz and higher are mainly used [19].

When the ozone generator is powered from a sinusoidal EMF source, the current i in the circuit has a complex harmonic composition [20, 21]. The averaged curve of the instantaneous current value contains discontinuities at the moments of the onset of the discharge. The discharge on the period of the supply voltage occurs twice and stops. The existence of a discharge is possible if the operating voltage across the ozonator exceeds a certain minimum voltage. In this case, the operating voltage is chosen less than the voltage of the complete electric breakdown of the discharge gap. When powered by a sinusoidal voltage, the dielectric barrier is heated due to high-frequency discharges during the achievement of a sinusoidal voltage, both positive and negative polarity (Fig. 2), of the amplitude value, which leads to a decrease in the ozone yield. The frequency of these oscillations lies in the range of 300-500 kHz (Fig. 3). Therefore, the ozone generators provide for the cooling of the electrode covered with the barrier by running water.

When using periodic pulses with a crest factor of more than 5 to power the ozone generator, the electric field strength of the discharge gap is higher than the electric field strength when using a sinusoidal voltage. The amplitude of the voltage applied to the potential electrode is 3.55 times greater than the amplitude of the sinusoidal voltage, which significantly exceeds the strength of the electric field both in the gas space of the ozone generator and in the dielectric barrier. The magnitude of this intensity is sufficient for the formation of a low-temperature plasma. The presence of low-temperature plasma is proved by the presence of glow in the ultraviolet region of the spectrum and energy absorption. The latter factor is especially important because it eliminates the operation of cooling the dielectric barrier and the need for air preparation before processing.

The existing stations for treating drinking water with ozone provide for a cyclic method of treating water in contact chambers and have a number of significant disadvantages. Inefficiency of the design of the reaction vessel and the contact column, as a result of which the mixing of the purified and ozonized water in the reaction vessel is carried out "by selecting the ratio of the pump feed and the volume of the vessel." This is a laborious operation that requires the constant presence of maintenance personnel (technologist). When the ozone bubbles of the air mixture move through the contact column from bottom to top, they become larger and the dignity of fine dispersion achieved with the help of the ejector is lost. Due to the counteraction of a column of water equal to the height of the column, as well as the passive process of water ozonization, it becomes necessary to increase the pump power and increase the height of the contact column, without which the station does not allow achieving high efficiency of mixing ozone bubbles of the air mixture with the treated water, and therefore a high degree of its cleaning and disinfection.

The irrational location of the ejector (in the lower part of the contact column) leads to the fact that in the event of an unexpected stop of the pump, water from the contact column under the influence of its pressure can flow through the ozone wire into the electronic unit of the ozonizer and thereby disable it.

2. Theoretical Basis and Results

Based on the identified shortcomings of the existing methods of water treatment by the cyclic method in contact chambers, we have developed a method of flow-through treatment using the method of electrodispersion (Figure 1). The method provides for pneumatic spraying of the treated water using ozone-containing air and electric charging with supply of a mixture of water aerosol and ozone-containing air to the contact chamber. The detailed schematic diagram of the pneumatic sprayer is given in Figure 2.

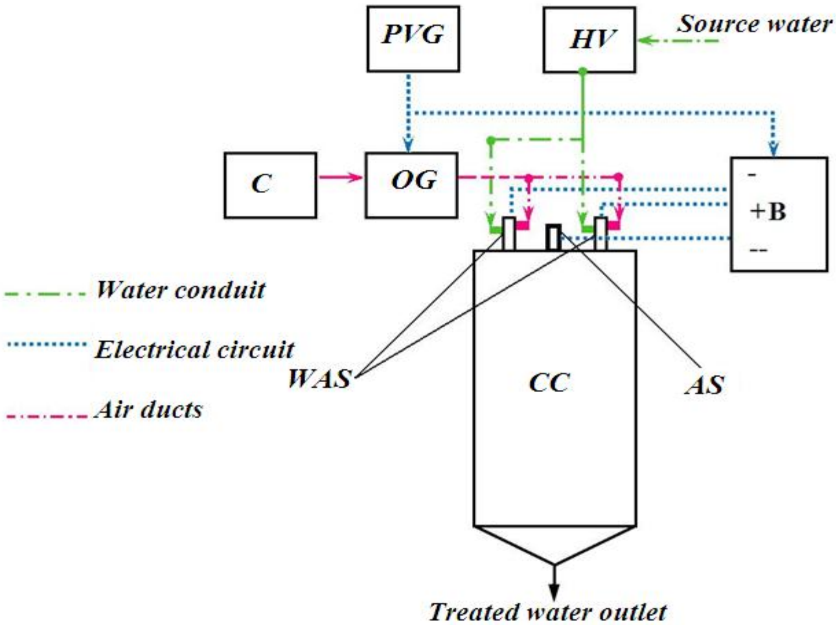

Figure 1. Technological scheme of water treatment with ozone

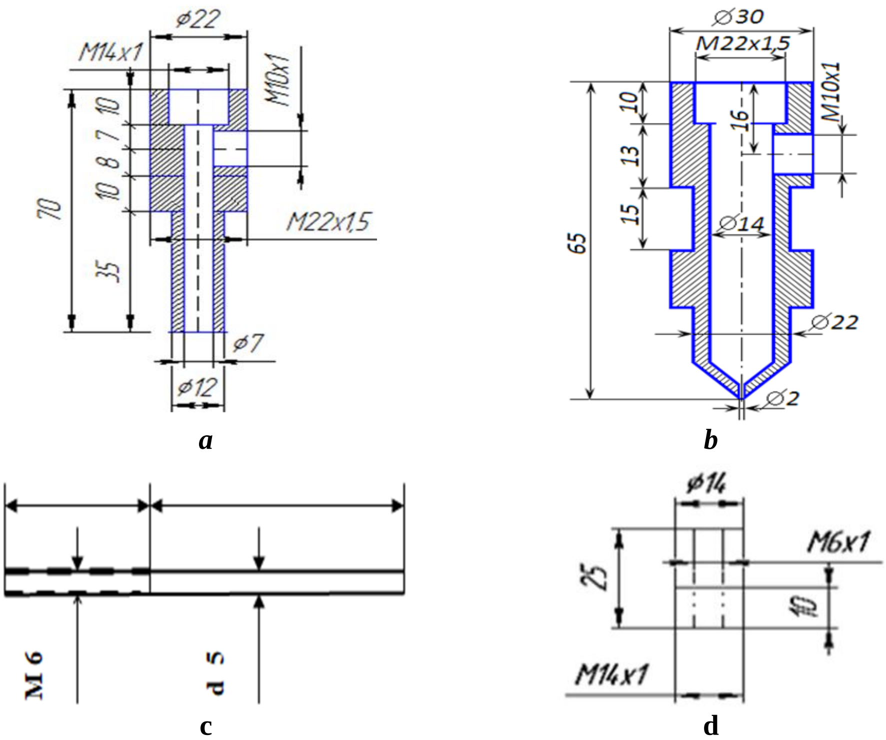

Figure 2. Detailing of the pneumatic sprayer: a - inner cage; b - outer cage; c - inducing axis; electrode; d - contact control sleeve

The device (Figure 1) consists of a compressor C, a OG ozone generator, a generator of periodic voltage pulses of the WAS, a HV water pump, a rectifier unit B, electrostatic sprayers of water aerosol WAD, an aerosol separator AS, a contact chamber CC.
The ozone generator with tubular electrodes is powered by periodic voltage pulses of an acute-angled shape from the generator of periodic high-voltage pulses of the GIN with an amplitude factor of more than 5, which makes it possible to increase the voltage amplitude in the discharge gap by 3.55 times greater than the sinusoidal voltage amplitude and significantly increase the ozone output.
Air was supplied to the ozone generator by a TSN ZZ1130 compressor. The compressor design prevents lubricating oil from entering the forced air. After processing the air from the ozone generator, the ozone air mixture is supplied to the electrostatic spray of water aerosol WAD, to which the treated water is simultaneously supplied. Water is supplied from a VN water pump of the WATER PUMP type.
An ozone generator was connected to one output, and a rectifier unit for powering electrostatic nebulizers and an aerosol separator was connected to the second.

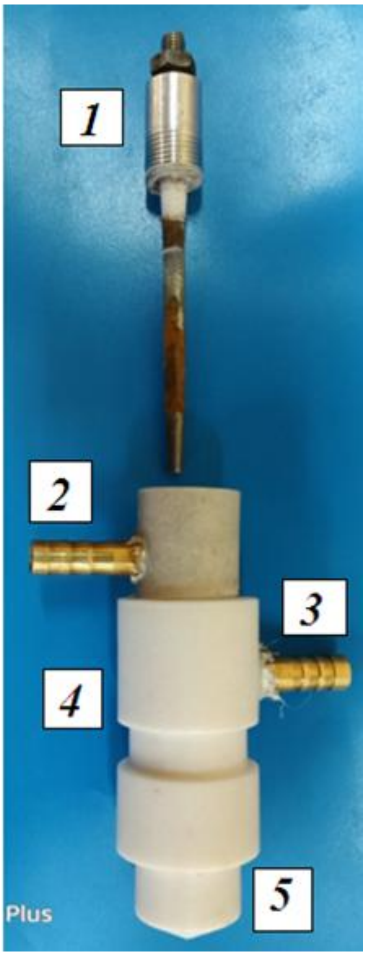

Figure 3. General view of the sprayer

There are several ways to charge sprayed materials. These methods are based on the use of corona discharge or electrostatic induction and operate from sources of rather high voltage (80-140 kV), cumbersome and complex in design.

The University of Tartu studied the possibility of using pneumatic spray guns for electro-painting and developed several samples of special spray guns. These devices use low voltages and are simple in design.

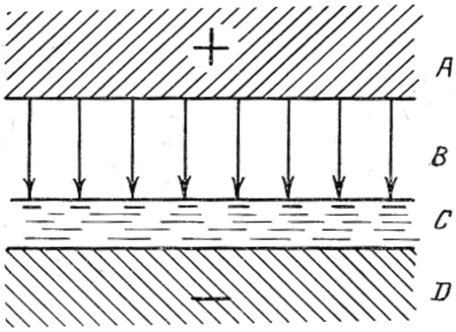

Figure 4. Zones of electrostatic induction: A, D - electrodes; B - air layer; C - sprayed liquid layer

During induction charging, particles of the sprayed liquid acquire a charge in the induction zone. The induction zone is a layer of air B and sprayed liquid C, located between the surfaces of the electrodes A and D (Figure 4). If a potential difference is applied to electrodes A and D, then under the action of the created electric field in the liquid layer, a distribution of free charges occurs - surface charges are induced with a density

$$\sigma = \varepsilon_0 \varepsilon E, \quad (1)$$

where ε_0 – electrical constant, 8,82x10^{-12} F/m;
ε - relative dielectric constant of a liquid;
E – electric field strength near the surface.
When the particles are detached from the liquid layer under consideration, charges remain on them. To assess the degree of electrification of particles, it is advisable to introduce the concept of the value of the average charge density of the sprayed liquid, determined by the formula:

$$\rho = \frac{I}{F_L}, \quad (2)$$

where I – charge carried away by particles per unit time;
F_l – liquid atomization volumetric rate.
Based on the continuity equation for the volume charge density, it can be shown that

$$\rho = \rho_0 \left[1 - \exp\left(- \frac{t}{\varepsilon_0 \varepsilon \rho_V} \right) \right], \quad (3)$$

where ρ_0 – the density of charges of such a density of the liquid for which the distribution of free charges at a given electric field strength has practically ended;
t - charge distribution time;
ρ_V – fluid resistivity.
Based on equation (3), it follows that the degree of electrification by induction depends on the properties of the sprayed liquid.
The time t, during which the distribution of charges occurs in a certain portion of the liquid, depends on the device of the atomizer and is limited by the volumetric spray rate.
The strength of the current I can practically be measured with a microammeter, through which a special collector is grounded, to which a torch of atomized and electrified liquid is directed.
Below is the design of our developed axial induction electrode atomizer.

Ozone is generated using periodic high-voltage pulses with an amplitude factor of at least 5, which are fed to a gas-discharge plasma ozone generator.

The process of ozone electrosynthesis takes place in two stages. At the first stage, the processed air, through the branch pipe, enters the zone of ultraviolet radiation. Ultraviolet radiation enters zone from the zone of low-temperature plasma through a potential electrode made of a mesh with 2x2 mm cells, and a dielectric barrier. The voltage is supplied to the potential electrode through the bushing insulator.

At the second stage of ozonation, partially ozonized gas enters the zone of action of low-temperature plasma. Ozonized gas is removed from the ozone generator through a branch pipe 16.

Ozone-containing gas is supplied to the nozzles of sprayers of water aerosol. The treated water is supplied to the fittings. To obtain a mono dispersion of an aqueous aerosol, a constant electric field is created in the nebulizer. In this case, two atomizers are charged positively, and the other two negatively. After entering the contact chamber, oppositely charged water aerosols interact with each other and form a foggy environment in the lower part of the contact chamber, which significantly increases the efficiency of water disinfection.

The ozone generator, aerosol separator and water aerosol nebulizers are powered from a source of periodic voltage pulses with an amplitude factor of more than 5 after increasing on a transformer with two outputs 2x10000 V (Figure 5). One of the 10,000 V terminals is connected directly to the potential electrode of the GO ozone generator. To the second terminal, electrostatic sprayers of water aerosols of positive and negative polarity are connected through high-voltage diodes V1 and V2. Power to the aerosol separator is supplied from a rectifier with voltage multiplication, collected on diodes V3, V4 and capacitor C, therefore a voltage is supplied to the separator, the effective value of which is 20,000 V.

Charged particles of water aerosol of negative and positive polarity and ozone containing gas simultaneously enter the contact chamber, where the second stage of processing takes place. The interaction of aerosol particles of different polarity leads to the formation of a foggy environment in the lower part of the contact chamber, which significantly increases the efficiency of water treatment.

Production tests of the device were carried out with the participation of employees of the Tashkent Regional Center for Sanitary and Epidemiological Control and showed the high efficiency of water treatment in artesian wells and water in open reservoirs.

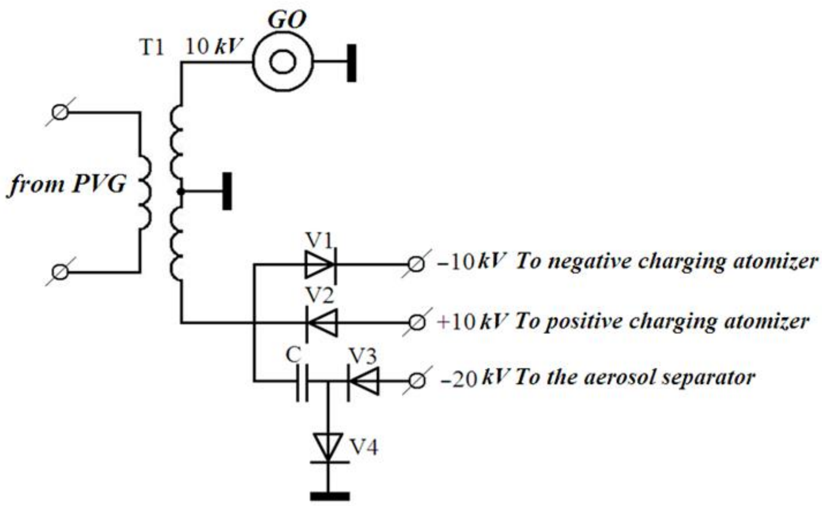

Figure 5. Schematic diagram of the power supply of the ozone generator, electrostatic nebulizers and aerosol separator with high pulse and periodic voltage

Production tests were carried out on September 22 and 23, 2020 at the drinking water pumping station of the OO "Toshkent Suv Taminoti" of the Kibray region. Analysis of the research results of the disinfection process of water in open reservoirs (Table 1) and artesian wells (Table 2) shows that the best disinfection process is observed with bipolar charging of water aerosol. When an uncharged aerosol is fed into the contact chamber, disinfection is weak, due to the fact that aerosol particles have different dispersion. The best indicators were obtained with a bipolar charged aerosol, which is due to the fact that the interaction of a vaso-polarly charged aerosol takes place already in the contact chamber. These are visually observable hazy formations at the bottom of the contact chamber.

Table 1. Results of bacteriological analysis of water in an open reservoir treated with ozone

Sample name	Treatment type	CCB, TCB in 100 ml	CCB, GCB in 100 ml	Pathogenic microbes, including salmonella
Kurgazma street Boz-su canal water before treatment	The control	585	8955	Not found
Kurgazma street Boz-su canal water after treatment	Conventional spraying	370	7982	Not found
Kurgazma street Boz-su canal water after treatment	(+) aerosol	207	575	Not found
Kurgazma street Boz-su canal water after treatment	(-, +) aerosol	117	275	Not found
Kurgazma street Boz-su canal water after treatment	(-) spray can	153	252	Not found

Notice: Conclusions of the head of the department of the Tashkent regional CSEC Musabekov G: The tested water samples after processing according to bacteriological indicators meet the requirements of San KMi 0318 – 15

Table 2. Results of bacteriological analysis of water from an artesian well treated with ozone

Sample name	Treatment type	Total microbial count at 1.0	ITBG (leftover)	Pathogenic microbes, including salmonella
Water is taken from the 29 homes before processing	The control	TMC = no growth	n/i = 7	Not found
Water taken from 29 houses after processing	Conventional spraying	TMC = no growth	n/I = 4	Not found
Water is taken from the 29 homes before processing	The control	TMC = no growth	n/i = less than 3	Not found
Water taken from 29 houses after processing	(-, +) aerosol	TMC = no growth	n/i = less than 3	Not found
Water is taken from the 29 homes before processing	The control	TMC = 100	n/i = 9	Not found
Water taken from 29 houses after processing	(-) spray can	TMC = no growth	n/i = less than 3	Not found
Water is taken from the 29 homes before processing	The control	TMC = no growth	n/i = 4	Not found
Water taken from 29 houses after processing	(+) aerosol	TMC = no growth	n/i = less than 3	Not found

3. Conclusions

According to the conclusion of the employees of the Tashkent Regional CSEC, after the treatment of water in an open reservoir (Boz-Su canal), according to the bacteriological indicators, they meet the requirements of San KMi 0318, and after the treatment of the water of an artesian well, the bacteriological indicators meet the requirements of OiDSf -950! 2011 (Copies of the analysis results are attached).

A real assessment of the efficiency of ozone use for the process of disinfecting drinking water can be assessed by economic indicators while taking into account the improvement in the quality of treatment, the reduction of the effects of chlorine compounds and residual chlorine on the human body. The latter indicators can be determined on the basis of statistical processing of the results of these impacts. In our case, the determination of the efficiency of the ozone water treatment process was determined by economic criteria.

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