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OZONE DISINFECTION OF WATER INTAKE WELLS AND PIPELINES OF DRINKING WATER SUPPLY SYSTEMS

In the article on the basis of analysis and laboratory technologies offered disinfecting water supply wells and pipelines for drinking water using ozone. The data confirming the significant effectiveness of the proposed method in comparison with existing ones. Marked their economic efficiency and environmental safety.

Introduction. Viruses and bacteria get into the groundwater with infiltration aquifer recharge, ie, slowly passing through rock. Such a method of contamination is most typical for shallow wells and for those bodies which are drilled near the surface water.

Not only wells, but also water supply networks – new or refurbished are exposed to microbial contamination. The pollution data are associated with infection episodes transmitted by water, through urban water supply systems.

The need to disinfect wells and pipelines is determined by the State Sanitary and Epidemiological Surveillance and is implemented according to [1]:

1) according to epidemiological indications (at the outbreak of intestinal infections in the populated area or when put into water of wells sewage, feces, spoils, etc.);

2) as a prophylactic measure (on completion of new or after cleaning and repairing of existing wells).

Currently the disinfection of boreholes, wells and drinking water pipes is accomplished by treatment with liquid chlorine, chlorine bleach or calcium hypochlorite [2]. Active chlorine solution is prepared by dissolving in water of chlorinated disinfectants approved for use in drinking water supply.

The well must be treated with a solution of chlorine-containing disinfectants after mechanical cleaning with flushing discharge. Well treatment with active chlorine solution for the disinfection purpose is performed immediately in two stages.
Initially the well cavity from the mouth to the static level is chlorinated by its filling with a solution of active chlorine concentration of 50–100 mg/l, with a pneumatic packer (plug) pre-set 1–2 m below the static level.

Duration of curing period of the active chlorine solution must be not less than 6 hours at an active chlorine concentration of 75–100 mg/l and not less than 24 hours at its concentration of 40–50 mg/l. After processing the upper part the well cavity is chlorinated from the static level to the bottom. Treatment must be carried out by bringing active chlorine solution in the water column through the filler pipe (hose) in such a way that after mixing the active chlorine concentration would be not less than 40 mg/l. After chlorination, pumping on the discharge is performed to reduce the residual active chlorine concentration in water to 0.3 mg/l and the bacteriological analysis of water is conducted. When the results of the analysis correspond to the normative sanitization requirements, the well is allowed to be put into operation. When obtaining negative analysis results the well disinfection is repeated with elevated active chlorine concentrations increased in 1.5–2 times in comparison with the initial doses.

The methods of continuous dosing, of pelletized chlorination and the method using a highly concentrated chlorine solution are considered when processing the inner surface of water pipes.

When using the method of continuous dosing water pipe is firstly washed with a large flow of highly concentrated chlorine solution, then it is filled with a chlorine solution with a concentration of 25 mg/l. This solution is held in the pipeline as long as the residual chlorine concentration retains at a level of at least 10 mg/l after 24 hours. While using the method of pelletized chlorination, calcium hypochlorite tablets are attached to an inner surface of the conduit in multiple axial locations, after which the pipeline is filled with water for the dissolution of tablets as long as the residual chlorine concentration in the pipeline will remain at a level of at least 25 mg/l for 24 h. In the latter method, large chlorine solution flow with concentration more than 100 mg/l is slowly passed through the conduit in such a manner that the entire inner surface would be exposed to highly concentrated chlorine solution for at least 3 hours.

Disadvantages of the chlorination process are:

– inadequate disinfection efficiency;

– formation of highly toxic chlorine-containing compounds;

– high doses of active chlorine;

– high toxicity of the chlorine and of many chlorine-containing agents;

– high corrosion activity of the solution , which leads to a rapid deterioration of networks and stop valves;

– the duration of the exposure time for effective chlorine disinfection (disinfection of pipeline inner surface requires at least 24 hours), which leads to long delays; when using a method of pelletized chlorination for disinfecting inner surface of water pipes tablets are not fully dissolved , and since the water is static by this method of chlorination, tablets not fully dissolved may cause inefficient disinfection in some places of pipelines;

– each chlorination method requires dechlorination of solutions used for the desinfection so that you can reset the solutions in household or storm sewers;

– methods of chlorination are not related to scientific and rational fundamental principle of disinfection.

It should be noted that while conducting borehole disinfection in the RB, the used solutions are not recycled and are usually dumped on the adjacent territory, in rare cases, the used solution is passed through the pipeline to the second lift station. What concerns the processing pipelines for drinking water, here it is carried out only after the repair and preventive treatments and in most cases are only reported in the log book. Chlorine used in solutions often exceeds the norm in several times. In order to solve the problems and to remove deficiencies of mentioned above pipeline disinfection methods used today, ozone may be applicated an alternative disinfectant.

Table 1 based on the analysis of various literary sources gives an estimate of application schemes with using various disinfectants.

Currently when evaluating the effectiveness of one or another disinfectant the so-called C×T-criteria, ie, the product of the reactant concentration for operating time are used. According to various experiment results presented in literature, ozone exceeds such disinfectants as chlorine, chlorine dioxide and chloramine. In accordance with its bactericidal effects ozone is 3–6 times stronger than UV radiation and 400–600 times stronger than chlorine.

Table 2 based on an analysis of various literary sources provides an estimate of the effective application of different disinfectants. Nevertheless today chlorination is applied more often than ozonation. There are several reasons that were formed in the last century.

The first one is easiness of work with chlorine and chlorine-containing reagents as compared with working with ozone. And the second reason is the complexity of using ozone equipment, low level of automation and, as a consequence, the need for highly qualified staff. However, modern ozone generators are practically deprived of all of these and other shortcomings.

Main part. In the world there are many systems of water treatment, which are working today using ozonation: in France, Canada, Switzerland, Italy, Germany, Saudi Arabia, etc. However, these systems are used only for water disinfection. In 2005 in the U.S. there was patented the method of water networks disinfecting using ozone [3]. It is suggested to conduct pipeline disinfection by impacting on their inner surface with a disinfection solution obtained by dissolving ozone in the drinking water. The use of ozone for disinfection eliminates the need for disinfection of the solution after application, as the dechlorination, because ozone decomposes in water into oxygen within a short period of time, usually less than 1 hr. The rate of decay depends on the water temperature, pH, ozone concentration, substances containing in the water.

Such a phenomenon as ozone decay with formation of oxygen, allows to develop ozone disinfection process, which will enable the residual ozone concentration inside the pipeline to be decomposed with formation of oxygen before discharging the disinfection solution from the conduit.

In this regard, the utilization of this solution is simplified, thereby avoiding damage to the environment. Depending on the residual ozone concentration in the disinfectant solution the water after ozone disinfection may also often be discharged directly to the streets, in sewages or in water courses. Low residual ozone concentration in this solution (less than 1 mg/l) is quickly spent when contacting pollutants with the pavement surface, and on exposure to the UV sun radiation.

Table 1

Comparative analysis of disinfection methods

Technology	Ecological compatibility	By- product	Effectiveness	Capital expenditure	Current expenditure
Ozonation	+	+	++	+/–	+
UV processing	++	++	+	+/–	++
Chlorine dioxide	+/–	+/–	++	++	+
Chlorine gas	– –	– –	–	+	++
Hypochlorite	– –	– –	–	+	++

Table 2

Comparative analysis of different disinfectants

Technology	Protozoa	Bacteria	Viruses
Chlorination	Doesn't destruct	Destruct completely	Destruct incompletely
Ozonation	Destruct completely	Destruct completely	Destruct completely
UV processing	Destruct incompletely	Destruct completely	Destruct completely

The use of ozone-containing disinfectant solution also allows to avoid the storage, transportation and preparation in situ disinfection of hazardous chemicals commonly used in the processes of chlorination (hypochlorites and hydrosulfites). Ozone can be prepared in situ disinfection by electrical discharges using oxygen (which in turn is generated in place from the oxygen separation system or is taken from cylinders), or air as the feed gas. Necessary equipment for this process is compact and can be applied in the field conditions without the need for large storage facilities or large vehicles.

Since ozone is the most powerful disinfectant of drinking water, pipeline ozone disinfection process may last a minute, and not at least an hour, as a chlorination. Ozone is able to remove protozoa, bacteria and viruses from the water at a value of C×T-the indicator two orders of magnitude lower than those required by chlorination.

Thus, the flowing process is possible. Ozone consumption is 0.5–5 mg / (l·min), depends on water temperature, and bacteria sensitivity to ozone.

Taking in consideration the above, the schemes of using ozone for disinfection boreholes and piping drinking water have been proposed: three options for well disinfecting and one – for water pipe disinfection.

Schemes must be equipped with ozone analyzer for determining the decay rate of the residual ozone concentration in water. Adjustment device must control the rate of ozone bringing in the water, depending on the information supplied by the analyzer which reflects ozone decomposition rate to provide a specified ozone concentration in water to meet the disinfection requirements.

To control the system it provides a logic controller, which is programmed to determine the necessary combination of initial ozone residual concentration and its decay rate constant in order to maintain the planned ozone concentration not more than 0.3 mg/l at the exit from the treated pipeline area.

It is sufficient to select one point for ozone input for a relatively small length of the pipeline. For long pipelines or pipes of large diameter, in which there are most likely higher decomposition rates of ozone, it is possible to make several ozone entry points along the entire length of the pipeline in order to achieve the desired disinfecting effect.

It was picked up a laboratory plant for research (Fig. 1), which allows determining the effect of processing time, the ozone concentration in water and the water movement mode on C×T-indicator.

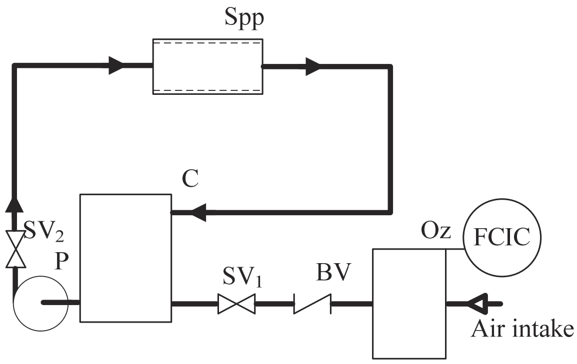

Fig. 1. The scheme of the laboratory setup to determine the parameters of waterpipe disinfection:
Oz – ozone generator, C – Capacity, P – pump;
Spp – studied part of the pipeline;
SV1-2 – shut-off valve; BV – back flow valve air intake

Determination of the residual ozone concentration in the gas mixture and a residual content in water in the selected procedure is based on the oxidation of iodide to iodine with ozone, which was titrated with a solution of sodium hyposulfite [4, 5]. Determination of the gas mixture consumption was performed using flowmeter CFC-15 / G (ΔP = = 0.1 MPa, T_{max} = 90 ° C, *Q norm* = 1.5 m^3/h, №035832). Determination of energy consumption of installation was performed using the single-phase meter (type DC1, OST 6225, № 456891).

Based on the studies of disinfection of drinking water pipelines will be carried out pilot tests of the proposed technologies. To accomplish this task a certain diameter plumbing was selected. It will be divided into ten sections of equal length. After processing the selected area with water saturated with ozone, the following indicators will be identified for each segment: initial and residual ozone concentration in water, the values of microbial contamination. It is also necessary to select the optimum mode of water flow in the pipeline. The value of indicators in the last section of the pipeline is monitored to determine whether the disinfection purpose is achieved since this site is subjected to the least impact.

To determine the ozone solubility in water at a height of liquid column the experimental setup has been picked up. It is a plastic tube 2 m high. Five holes are made in the pipe for sampling every 0.5 m. Connection for ozone supply is located at the bottom of the column (Fig. 2).

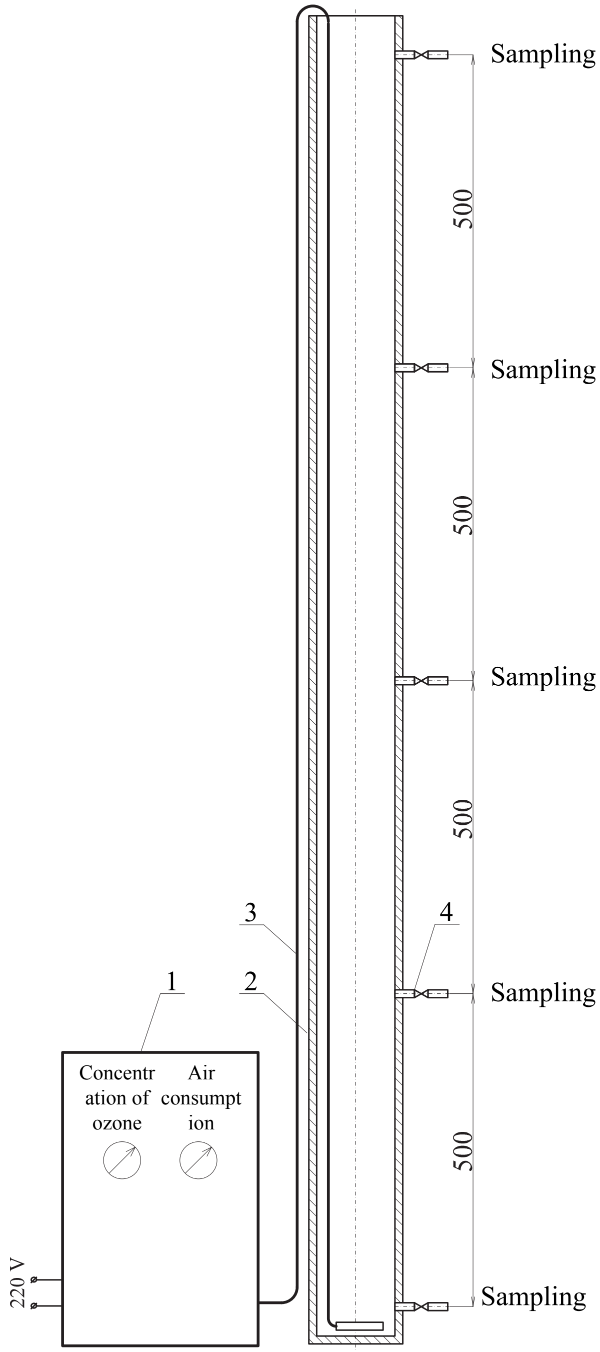

Fig. 2. Scheme of the laboratory setup to determine the parameters of borehole disinfection: 1 – ozonator, 2 – pipe, 3 – gas flue; 4 – Connection for sampling

To determine the ozone solubility in water various consumption of air gas mixture was used (at an ozone rate of 14 g/h): 3.3, 6.6 and 13.2 l/min, the treatment time 10, 30, 60 min. It was found experimentally that the ozone solubility considerably reduces at the height of the liquid column (Fig. 3 and 4).

This is due to a decrease of ozone concentration in the gas phase, the collapse of the bubbles in the gas mixture and it confirms the known patterns. It has been found that ozone water saturation is affected by its concentration in the gas mixture and by the mass transfer surface (size of the gas bubbles created by air "dispersant"). Maximum water saturation is created at a higher ozone concentration in the gas mixture and its lower consumption, at an increase of the processing time, and thereby it confirms the known laws. The obtained data testify that using the well disinfection by passing gaseous, air ozone mixture the ozone dispersants must be placed at a distance of 5–10 m from each other in height. At ozone saturation of the tap water (temperature 17 °C) to a concentration of 4 mg/l its 50% decomposition was observed in 40 min. In this case it is also necessary to study the influence of the treatment duration, the ozone concentration in water and of water motion mode on C×T-indicator.

As noted above, the disinfection requirements for water supply networks must be based on meeting the disinfection effect 99.99% inactivation.

For ozone input in water and its dissolution varied aeration eequipment can be used, which differs with sizes of the contact area of the gaseous and liquid phases, with pressure in the system and with reaction duration:

1) Injection aeration with static mixers: water aeration is achieved using injectors and two static mixers installed on the ozone suction pipe and the main pipe; and after mixing there should be the time for the reaction within the conduit or additional tank;

2) small-bubble aeration: small-bubbling ozone bringing in water is carried out through porous metal-pipe or wheels on the bottom of the tank;

3) aeration column: Gas input takes place in the aeration tower by means of the oncoming water stream;

4) the aeration with means of stirrers is used at continuous water flow and a small control range of ozone supply. Agitators rotating in the water and mixing ozone with water are used to apply this method.

In the water being treated at a steady input process and ozone mixing of order 5–25% it remains undissolved. Residual undissolved ozone must be neutralized before being discharged into the atmosphere. The ozone MPCmn 160 g/m^3. When working with an air ozone mixture it should also be considered LEL equal to 10 vol.

Elimination of residual ozone can be carried out by the following methods:

– thermal (temperature above 310 °C and treatment time of not less than 2);

– catalyst (palladium and metal oxide, based on CuO/MnO are used as catalysts for ozone deposition; plate working temperature of the catalyst must be from 60 to 80 °C;

– reagent (ozone neutralizing suitable chemicals include ascorbic acid, sodium disulphate and calcium thiosulfate).

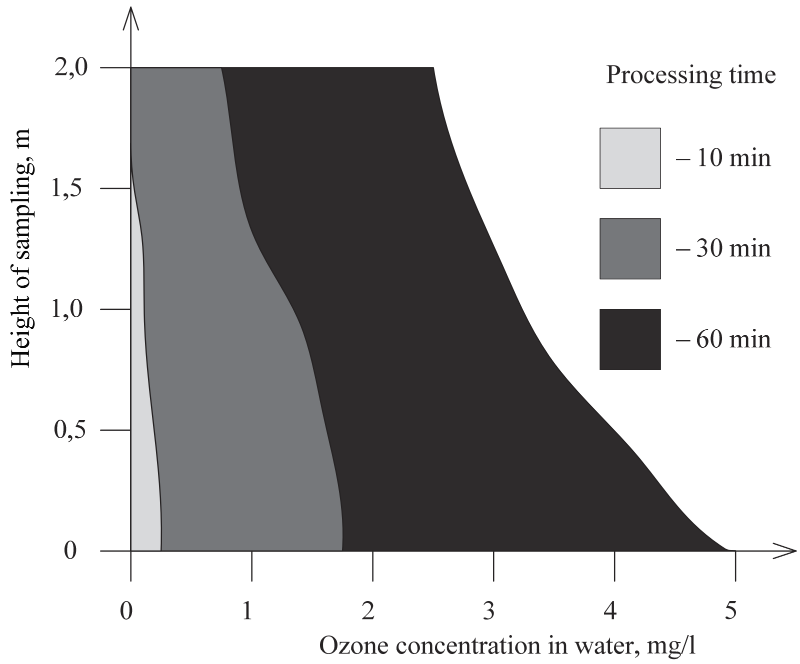

Fig. 3. Dependence of the ozone concentration in the treated water mg/l on the treatment time at a an ozone rate of 14.0 g/h, gas mixture – 3.3 l/min

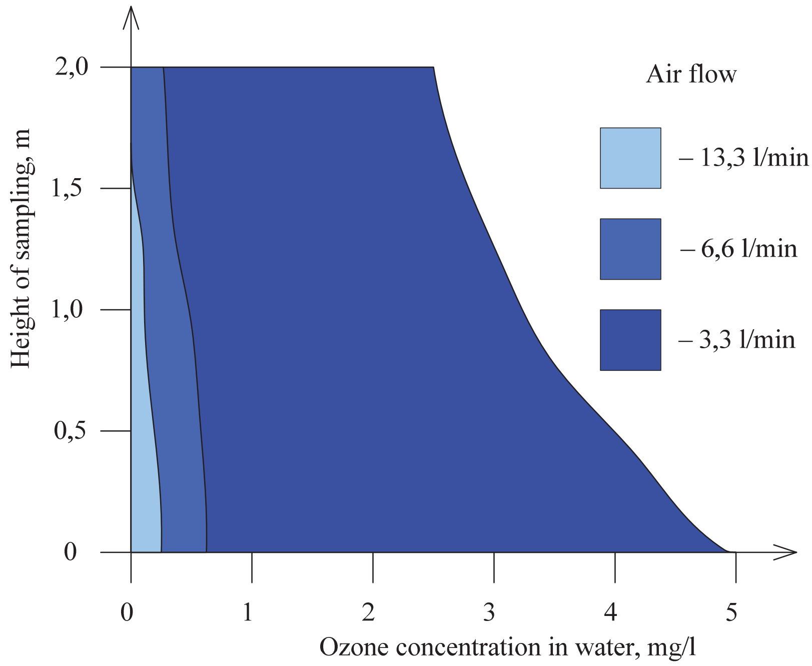

Fig. 4. Dependence of the ozone concentration in the treated water mg/l on the gas mixture flow at an ozone flow rate of 14.0 g/h and the treatment time 60 min.

The ozone dose in the pipeline section, which is to be disinfected or in the well being treated must be at least 0.2–0.3 mg/l. This residual concentration is sufficient to meet the disinfection requirements and it is also sufficiently low in order to be able to discharge the ozonated water from the sanitized pipeline section into the environment without causing any harm.

Conclusion. Fully equipped stationary plants for ozonation, consisting of elements producing ozone, mixing equipment, reaction and resonator tanks removing residual ozone from the system must be installed in isolated, locked locations. The proposed schemes of disinfection devices can be movable and installed on a truck or trailer for transportation. Ozone generating system which is a system being air cooled generates ozone from oxygen, brings ozone in a water stream under pressure and delivers the ozonated water to the pipe section to be sanitized. The ozone generator is to be with air cooling. These ozone generators are designed in our country by the Ltd company "Rovalant Special Service" [6]. These generators are also distinguished by a low specific energy consumption of ozone 4–5 W/g. Additionally, the system can be equipped with a mobile generator to provide the necessary power.

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