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METHOD OF DISINFECTION AND PURIFICATION OF WATER USING PULSED ELECTRIC DISCHARGES OF NANOSECOND DURATION IN GAS BUBBLES IN IT

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The method of disinfection and purification of water using pulsed electrical discharges in gas bubbles formed inside the water makes it possible to use all high-intensity factors from discharges for its disinfection and purification. This method is a logical continuation of the development of the water ozonation method for the same purpose. The ozonation method is widespread in the developed countries of the world as it is more progressive in comparison with the chlorination method. However, the water ozonation method has a number of serious disadvantages. Ozone as an active factor is obtained in industrial ozonation plants by means of electrical discharges, mainly by means of barrier discharges, which provide the highest concentrations of ozone in an oxygen-containing gas. Reactors that generate ozone using electrical discharges provided by appropriate high-voltage pulse generators are located outside of water and away from water. Ozone is delivered to water using ozone-resistant pipelines. All high-intensity factors from electrical discharges, except ozone, are not used. Such factors, which are more intense than ozone, include: OH radicals, atomic oxygen O, high-energy electrons. Also, hydrogen peroxide H_2O_2 and broadband radiation from electrical discharges, containing ultraviolet light in their frequency spectrum, are not used. Ozone can be transported from the generator to the water for its purification, since the molecules of this gas are quite long-lived (minutes or more) due to lower activity (lower electrochemical, oxidative potential) than that of OH radicals, atomic oxygen O. To use all high-intensity factors from discharges, they must be carried out in a gas directly at the water surface, since the lifetime of OH radicals of atomic oxygen O is less than one millisecond. It is energetically unprofitable to carry out electric discharges in the water itself for the purpose of its disinfection and purification, since the electric strength, specific electrical conductivity and dielectric constant of water are much higher than those of gases.

There are many variants of discharges in gas directly at the water surface. The advantage when choosing more rational options are those in which most (or all) of the accumulated high-intensity factors enter the water and carry out its disinfection and purification. One of these options is the method of disinfection and purification of water using pulsed electrical discharges in gas bubbles in it. A gas bubble in water is surrounded by water along its border. Under conditions of a pulsed electric discharge in a bubble, the flow of a pulsed current through the gas-discharge plasma in it and through water, high-intensity factors from the discharge, including electrons, ions, and broadband radiation, enter the water through the area of contact of the discharge plasma with water, having time to start a chain of reactions leading to disinfection and water purification. Since all factors from the discharge are used, not only ozone, the energy efficiency of this method is significantly higher than that of the ozonation method of water. But the advantage of this method is not only and not so much in this, but also in the fact that this method allows solving those problems of disinfecting and purifying water, which, in principle, cannot be solved by the ozonation method due to the lower value of the oxidizing potential of ozone molecules.

Treated, for example, river water, from the point of view of electrical engineering, is a fairly well conductive dielectric barrier (a dielectric with a relative permittivity of 81 and a specific volume resistance of about 10 Ohm × m) and a load for a high-voltage pulse generator, in which a strong pulsed electric field is created and stored and electromagnetic energy is released, turning into thermal energy.

We use a discharge in a highly inhomogeneous field. A high-voltage pointed electrode, for example in the form of a «whisk», is located inside a gas bubble in water. Discharge plasma channels close the tips of the «whisk» needle branches to the interface between a gas bubble with a characteristic diameter of about 1 cm and water. Inside the bubble, in the immediate vicinity of the water surface and on the water surface, as a result of discharges with a frequency of 2000 pulses / s or more, active particles, including OH hydroxyl radicals, and broadband radiation are created. Active particles, including OH radicals, which have got into the water as a result of diffusion, ensure its disinfection and purification. An important role in the process of disinfection and purification of water is played by broadband radiation from pulsed discharges in a gas bubble, which penetrates into water. Under the influence of quanta of this radiation, photodecomposition of water molecules $H_2O \rightarrow H + OH$ occurs [1]. Thus, OH radicals are formed inside the water (in addition to OH, which got into the water from the gas-discharge plasma in the bubble). The water in the reactor in the treatment zone with the help of discharges in gas bubbles is in a sufficiently strong electric field with an average value of ~ 30 kV / cm. The disinfected water contains microorganisms to be inactivated. The cytoplasmic membrane of each of the microorganisms (bacteria, yeast, etc.) is a dielectric. Therefore, at the interface between the membrane and water, the electric field strength increases sharply, being distributed inversely proportional to the ratio of the relative permittivities of water and cell membranes, and can reach 600 kV / cm = 60 kV / mm in membranes with pores at nanosecond fronts and durations of voltage pulses from generator. Such an increase in the electric field strength at micro-inhomogeneities inside the water can lead to additional ionization processes, including impact ionization by electrons formed in a local strong field. It should be noted that with pre-breakdown voltages at various inhomogeneities in non-degassing water, gas bubbles with characteristic sizes of 10-6-10-5 m can form from micro-nuclei both inside the water and in the area of its contact with plasma and metal electrodes [2]. In these bubbles, the growth and life time of which is much longer than the duration of nanosecond voltage and current pulses, during the application of a pulsed voltage to the water layer during the combustion of nanosecond discharges in a gas bubble in front of the water layer, micro-discharges appear similar to partial discharges in gas inclusions in solid dielectrics. These micro-discharges in numerous small bubbles inside the water lead to the formation of active particles in them, including OH hydroxyl radicals. In addition, in a strong field, microparticles are excited inside the water, water molecules dissociate into OH and H, and a complex chain of reactions is triggered, which ultimately provides a high degree of disinfection and water purification. OH radicals having a lifetime of ~ 300 μs at a concentration of ~ 10^{14}-10^{15} cm^{-3} [3], being in water, participating in chaotic thermal motion, can provide energy-efficient disinfection and purification of water, acting synergistically with other high-intensity factors.

Nanosecond discharges in a gas bubble are energetically significantly more favorable than microsecond ones, since with less power consumed from the source, they provide higher working electric field strengths and, therefore, better production of high-intensity factors for disinfection and water purification. As the results of our experimental studies show, complete and irreversible inactivation of representative E-coli microorganisms at their initial concentration of 106 cm-3 in a flow-through mode can be achieved without noticeable heating of water by the released energy from nanosecond current pulses, following with a frequency of about 2000 pulses /s [4, 5].

Thus, it can be concluded that the considered method of disinfecting and purifying water using pulsed electrical discharges of nanosecond duration in gas bubbles is promising for use on an industrial scale and can replace or substantially supplement the widely used method of ozonation.

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