Application of Microsecond Voltage Pulses for Water Disinfection by Diaphragm Electric Discharge

S V Kakaurov[1,4], I F Suvorov[1], A S Yudin[2], T L Solovyova[3], N S Kuznetsova[1]
[1] Transbaikal State University, Chita, 672039, Russian Federation.
[2] Tomsk Polytechnic University, Tomsk, 634050, Russian Federation.
[3] Chita State Medical Academy, Chita, 672000, Russian Federation.

[4] E-mail: blackhawkserg@yandex.ru

Abstract. The paper presents the dependence of copper and silver ions formation on the duration of voltage pulses of diaphragm electric discharge and on the pH of treated liquid medium. Knowing it allows one to create an automatic control system to control bactericidal agent's parameters obtained in diaphragm electric discharge reactor. The current-voltage characteristic of the reactor with a horizontal to the diaphragm membrane water flow powered from the author`s custom pulse voltage source is also presented. The results of studies of the power consumption of diaphragm electric discharge depending on temperature of the treated liquid medium are given.

1. Introduction
Electric discharge water processing technologies both in industry and in everyday life are increasingly used. This is clearly linked with the improvement of both the technologies themselves and the components and circuitry of the power supplies that are an integral part of any modern electric installation equipment. There are many ways of water treatment by different kinds of electrical discharges: arc, spark, corona, glow, barrier, multi-channel, edge, diaphragm discharges and their subspecies. Each discharge has its own advantages and disadvantages. For example, arc, spark, corona, glow and edge discharges generate a significant amount of H_2O_2 but have high specific electricity consumption for water disinfection [1-5]. Barrier discharge allows one to generate large amount of ozone at relatively low specific energy consumption for water disinfection. But it requires fairly complex and expensive technological equipment [6]. Diaphragm electric discharge (DED) has a number of features due to which it can be used for water disinfection. However, the lack of knowledge of the DED poses a number of questions to researchers, without answering them it is impossible to create a competitive technology. Particularly the question remains unsolved in terms of specific power consumption which is 0.35 kWh/m^3 that reduces the market attractiveness of this water disinfection method [7].

The DED water treatment technology described in [8] consists of the special switching power supply (SPS) and the reactor [9] divided by a diaphragm membrane into two chambers, each of them being equipped with metal electrodes and nozzles. The SPS of the reactor converts the sinusoidal voltage mains 380/220 V in to bipolar pulses with a pulse amplitude of up to 3 kV and a duration of from 0.8 to 16 microseconds. Method of water disinfection by the DED technology is complex and depends on many conditions. The uniqueness of water treatment by the DED is that water is disinfected due to the complex effect of hydrogen peroxide H_2O_2, copper ions Cu^{2+} and Ag^+ silver ions, atomic oxygen O and ozone O_3. The yield of bactericidal agents is affected by a number of factors: the amplitude of the voltage pulses, their duration; conductivity [10], pH and temperature of the treated water; the spatial orientation of the diaphragm membrane.

2. Experiment

Analysis of current-voltage characteristics (CVC) of DED was conducted in the static mode of the reactor operation with water temperature of 30 °C, its pH of 7.4 and conductivity of 0.45 mS/cm. The listed physical quantities were determined by water parameters tester Hanna HI 9813-6. The duration of the voltage pulses was 7 μs, duty cycle was 2.02 and a slew rate was of about 200 V/s. The parameters of the electric signals were recorded by oscilloscope Tektronix TDS 2022B. The voltage was measured by a resistive divider connected to the electrodes of the reactor. The current was calculated as the ratio of measured voltage dropped on resistance connected in series with the reactor and the active nominal value of its resistance. The experiments were carried out with the diaphragm membrane of 5 mm thickness with 72 holes and 1.2 mm of holes diameter. The volume of the reactor chamber is about 1300 cm^3.

Analysis of the dependence of the reactor power consumption of DED on water temperature was carried out under the same conditions as the analysis of DED CVC described in previous para only with constant voltage pulse amplitude of 2150 V and with changing water temperatures from 2 to 100 °C during the experiment.

The experiments of determination of the most effective pulse duration were carried out under the similar conditions as the analysis of DED CVC wherein the amplitude of the voltage pulses was set of 1970 V and the water flow mode was implemented. The model solution of distilled water and NaCl was used as the test fluid. The initial temperature of the test fluid was 20 °C and the final temperature at the end of the experiment was 21 °C. The flow rate was 4 liter/min. At each test point 50 W·h was spent that was defined by the electricity meter with accuracy class of 1.0.

The dependence of copper and silver ions formation on pH of the treated liquid medium was defined in identical conditions as the analysis of DED CVC with constant voltage pulse amplitude of 2150 V and varying pH from 2.5 to 9.5. It was done with a help of liquid conditioners for aquariums «TetraAqua» «pH Minus» and «pH Plus». The model solution was produced from distilled water, liquid conditioners and NaCl to set the conductivity at the level of 0.45 mS/cm.

3. Results and discussion

The pulses amplitude and their duration force on the penetrating ability of the acting voltage which generates a discharge in the vapor bubbles formed in the holes of the diaphragm membrane. Bubbles occur in the holes of the diaphragm membrane due to the Joule heating of water. The electric current density in the holes of the membrane in hundreds of times greater than outside. As a result, the CVC of the DED reactor powered by the SPS with bipolar pulses are highly nonlinear and has a crescent-shaped character (figure 1). Most of all it depends on steam-air mixture formation than on water resistance. In the range of voltages pulse amplitudes from 0 to 525 V the current increases in proportion to the voltage since the discharge under this voltage is absent.

Between the points of curve from 525 V to 755 V the current decrease is observed. Such effect of negative differential resistance is caused by the beginning of the DED formation. The gas-vapor mixture starts to occur in the holes of membrane and thus the resistance of the reactor increases. After the point of pulses amplitude of 755 V the CVC monotonically increases and one can see that after 1.7 kV the current starts rise faster than the voltage because of intensive formation of steam-gas mixture.

The temperature in the holes of the diaphragm membrane rises up to 5000 °K [5] which leads to nonlinear increase of conductivity.

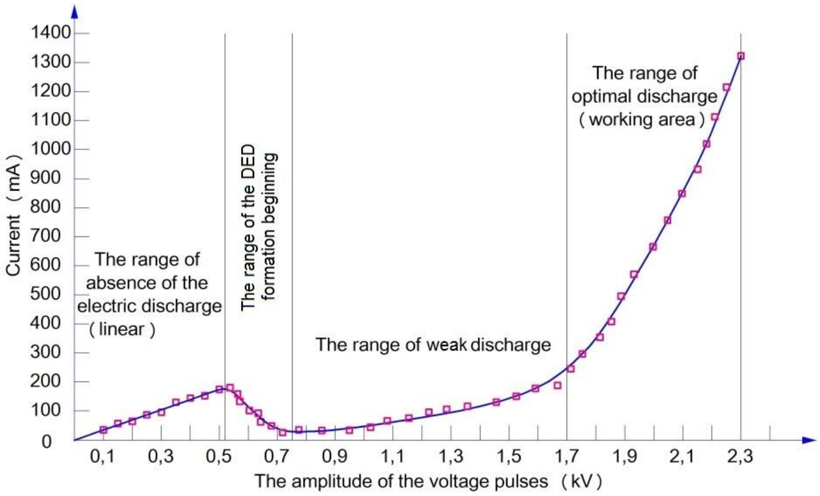

Figure 1. Volt-ampere characteristic of the diaphragm electric discharge.

The CVC of the DED has the same shape of the graph at the temperatures from 2 to 60 °C which confirms the assumption about its dependence mainly on the formation of the gas mixture and not on water resistance which depends from temperature nonlinearly. At higher liquid temperature from 60 to 100 °C more intense evaporation in the holes of the diaphragm membrane takes place and as a result, the power consumption level falls sharply without changing visual intensity of the discharge (figure 2). Based on these results the reactor with a horizontal to diaphragm membrane flow of water was designed [9] instead of the reactor where the water passes through the holes in the diaphragm membrane [7, 11]. In this case water in the upper part of the chamber does not flow and heated almost to the boiling point. Water in the lower part of the chamber moves continuously and heated slightly. As the result one has higher yield of bactericidal agents with the same power consumption [8, 9, 12].

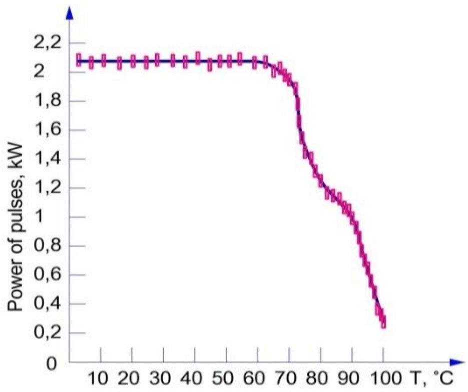

Figure 2. Dependence of the power consumption of the DED reactor from the temperature of the treated water

The yield of bactericidal agents depends on the duration of the voltage pulse. The amount of formed hydrogen peroxide H_2O_2, copper ions Cu^{2+} and silver ions Ag^{+} is changed with the pulse duration changing during the experiments. These dependences are shown in figure 3. The optimal pulse duration with the highest bactericidal agents yield is determined within the range from 4 μs to 8 μs. When the pulse duration is less than 4 μs the poor bactericidal agents yield is observed. This is due to the insufficient time of voltage exposure which is required for the development of the discharge. Bactericidal agents yield decline is also observed in the cases of pulse duration of more than 8 μs. The reason of the bactericidal agents yield lowering is the decrease of the pulse repetition frequency.

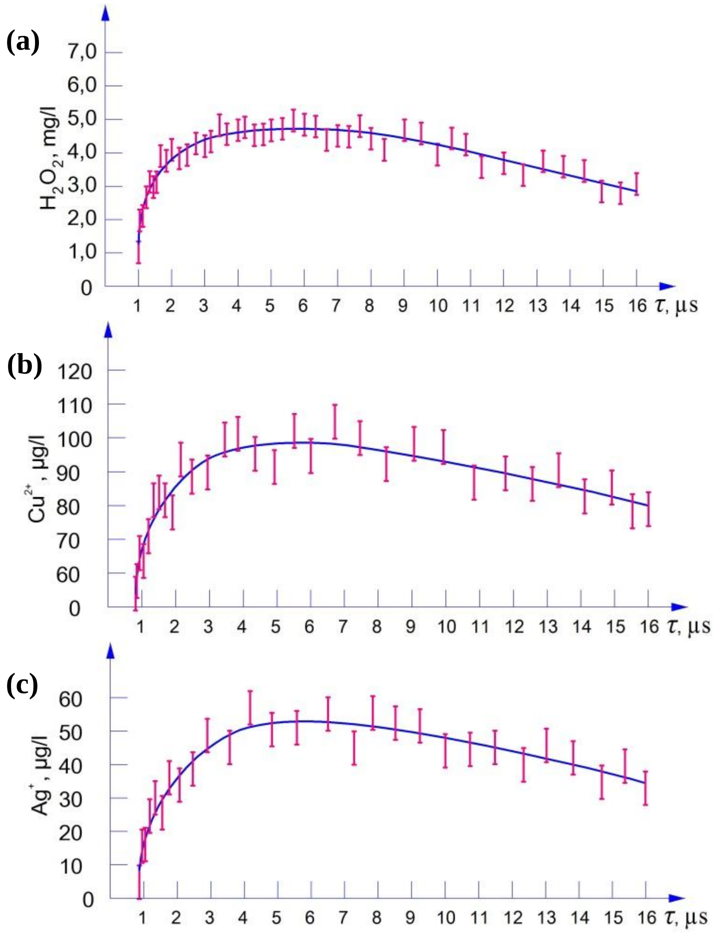

Figure 3. Dependence of the yield of hydrogen peroxide and metal ions from the duration of the voltage pulses. (a) hydrogen peroxide H_2O_2. (b) copper ions Cu^{2+}. (c) silver ions Ag^+.

The efficiency of the process of water disinfection is also significantly depends on pH of the treated liquids [11, 13]. However, it is difficult to determine what pH factor of liquid is better for the combined use of silver and copper electrodes: acid, alkaline or neutral. In the case of the copper electrodes using only the yield of copper ions Cu^{2+} increases with acid medium increasing (figure 4a). But on the contrary if the silver electrodes are used only, the yield of silver ions Ag^+ increases with alkaline medium increasing (figure 4b). That is why in acid medium it is better to use copper electrodes and in the alkaline medium – silver ones.

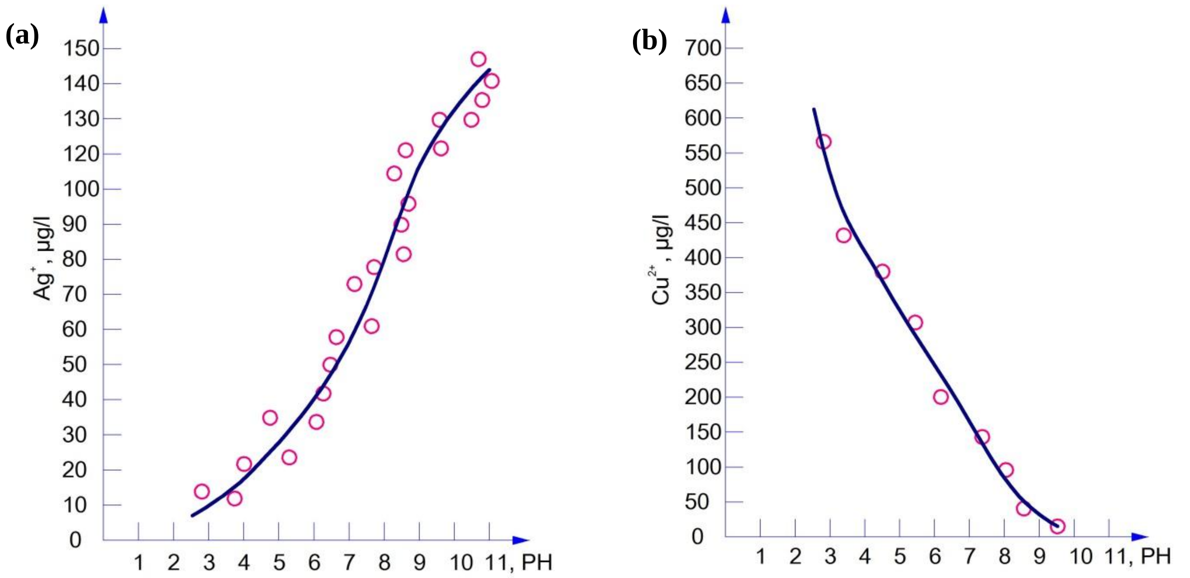

Figure 4. Dependence of yield of metal ions from water Ph. (a) silver ions Ag^{+}. (b) copper ions Cu^{2+}

4. Conclusions

The knowledge of the optimal pulse parameters for water disinfection by DED will help to create a more perfect and economical system of water disinfection since it is possible to reduce the consumption of electric energy in water treatment process by DED significantly. The investigated range of current pulse duration parameters is not completed yet. It is not clear what results of water disinfection in the pulse duration of less than 0.8 μs and more than 16 μs could be obtained. Dependency of bactericidal agents yield from pulse ratio (used SPS has no capability to regulate pulse ratio) is unknown. In the investigated range of pulse durations from 0.8 μs to 16 μs it is possible to allocate the range with durations from 4 μs to 8 μs. In this range there is a maximum yield of bactericidal agents with a deviation not exceeding the error of methods of determining the amount of these agents. It was found that the most productive amplitude of the voltage pulses is 2.3 kV when the thickness of the diaphragm membrane is 5 mm and the diameter of the holes in it is 1.2 mm. At a higher voltage than 2.3 kV the yield of hydrogen peroxide decreases and the method of water treatment by DED become ineffective. The dependence of the power consumption of the DED reactor on the temperature of the treated water was determined, and based on it a new type of reactor was constructed. This dependence indicates that the electric discharge is more intensive and productive at higher temperatures of liquid media. The new reactor design allows raising the yield of bactericidal agents and decreasing the power consumption.

References

[1] Tverskoj V S and Tverskoj A V 2006 Method of surface treatment: patent № 2286866 Russian Federation
[2] Piskarev I M, Ivanova I P and Trofimova S V 2013 *J. High Energy Chemistry* **47 5** 247-250
[3] Ivannikov A A, Lelevkin V M and Tokarev A V 2002 Application of glow discharge for disinfection of water *Proceedings of the 3rd International Symposium on theoretical and applied plasma chemistry Ivanovo* pp. 463-469
[4] Hljustova A V, Maksimov A I and Panova D S 2013 The Influence of an electric discharge and oxidizing agents in aqueous solutions of a mixture of two organic dyes *Electronic processing of materials* **49 4** 6-11

[5] Kuznecov V V 2011 Development of mathematical models of radiation processes in plasma accelerators torch capillary discharge *J. Physico-chemical kinetics in gas discharge* **11 1** 1-6
[6] Kornev Ja I 2005 Water treatment by pulsed discharge in water - air flow: thesis of candidate of technical Sciences. Tomsk Polytechnic University, Tomsk, 162 p
[7] Lapshakova K A 2009 Disinfection of domestic wastewater in small settlements diaphragm electric discharge: thesis of candidate of technical Sciences. Irkutsk State Technical University, Irkutsk, 115 p
[8] Gajsin A F, Suvorov I F, Kakaurov S V and Judin A S 2013 Electrical discharges with liquid electrodes *Bulletin of the Kazan Technological University* **16 23** 199-201
[9] Suvorov I F, Kakaurov S V, Judin A S and Rahlecova T V 2014 The device for water purification and disinfection: patent № 137284 Russian Federation
[10] Kakaurov S V 2013 Features of copper and silver ions formation for water disinfection by diaphragm electric discharge *Bulletin of the Transbaikal State University* **11** 22-27
[11] Judin A S 2010 Development of reactor and system for automatic process control of wastewater disinfection diaphragm electric discharge: thesis of candidate of technical Sciences. Irkutsk State Technical University, Irkutsk 121 p
[12] Son E E, Suvorov I F, Kakaurov S V, Gaisin A F, Samitova G T, Solovyeva T L, Judin A S and Rakhletsova T V 2014 Electrical Discharges with Liquid Electrodes Used in Water Decontamination *J. High Temperature* **52 4** 490–496
[13] Kul'skij L A 1987 *Silver water* (Kiev: Naukova Dumka) 136 p