DOI: https://doi.org/10.31073/mivg202202-340
Available at (PDF): http://mivg.iwpim.com.ua/index.php/mivg/article/view/340

UDC 53.047 + 628.16

INVESTIGATION OF WATER DISINFECTION PROCESSES USING PULSE ELECTRIC DISCHARGE

Ye.M. Matselyuk[1], Ph.D., D.V. Charny[2], Doctor of Engineering Sciences, V.D. Levitska[3]
[1] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, 03022, Ukraine; https://orcid.org/0000-0001-9960-6333; e-mail:evgen1523@ukr.net;
[2] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, 03022, Ukraine; https://orcid.org/0000-0001-6150-6433; e-mail:dmitriych10@gmail.com
[3] Institute of Water Problems and Land Reclamation of NAAS, Kyiv, 03022, Ukraine; https://orcid.org/0000-0003-2213-1696; e-mail: veral@ukr.net

Abstract. *As a result of Russian military aggression in the south-eastern region of Ukraine, water supply pipes and structures of centralized water supply systems were destroyed, and therefore water supply was practically stopped. The solution to the problem can be the use of mobile water treatment stations which use local sources of water: canals, lakes, ponds, or underground water. A feature of water treatment technologies in the field is the need to reliably ensure the process of water disinfection. Existing water disinfection technologies have low efficiency, taking into account the growing number of chlorine-resistant microorganisms, therefore, the implementation of alternative methods of disinfection during water treatment is urgent. One of these methods is liquid disinfection by electric current discharge. The results of the research on disinfection of different types of surface water in Kyiv and water contaminated with E. coli (Escherichia coli (E. coli)) are described. The research was carried out on a laboratory setup with a circulation pump and an ejector-type reactor with integrated electrodes where a water-air mixture is formed through which an electric discharge passes. The discharges initiate the formation of various highly reactive chemicals such as radicals (OH•, H•, O•) and molecules (H_2O_2, H_2, O_2, O_3). All physical and chemical processes that occur during discharge ensure the formation and action of short-term radicals and relatively long-term oxidants. The study of the influence of the concentration of microorganisms on the speed and completeness of water disinfection was carried out on technical (tap) water with the addition of washings from two tubes with test culture to the reaction tank, which provided the initial concentration of E. coli equal to $3.4 \cdot 10^6$ CFU/cm^3. Water treatment for 30 seconds reduced the number of microorganisms to $5.4 \cdot 10^4$ CFU/cm^3. After 1 minute of treatment this indicator decreased to $1.7 \cdot 10^2$ and after 3 minutes the value of 5.2 CFU/cm^3 was recorded in the samples, that is, the treated water had indicators of practically pure water. Experiments have proven the effectiveness of plasma disinfection for liquids with high concentration of microorganisms.*

Key words: *water, water supply, disinfection, bacteria, plasma, electric discharge*

Relevance of the problem. As a result of the military aggression of Russian Federation in the south-eastern region of Ukraine, water pipes and structures were destroyed, and, as a result, water supply in Donbas, Zaporizhzhia, Luhansk, Mykolaiv, and Kherson regions was practically stopped. First of all, rural settlements were affected to which water was transported tens of kilometers by big group agricultural water pipelines that include water intake and treatment facilities, transfer pumping stations, water discharge facilities. Such powerful objects, due to their considerable dispersion, are prone to damage and therefore to the cessation of functioning.

An effective alternative solution for restoring water supply can be mobile water treatment stations which can use existing local water sources: canals, lakes, rivers, ponds, or underground (especially mineralized) water. A specific feature of water treatment technologies under war conditions is the need to reliably ensure the process of effective water disinfection.

Analysis of recent research and publications. In recent years, studies on the quality of tap drinking water in Ukraine have revealed a tendency towards an increase in the frequency of deviations from hygienic requirements in terms of sanitary-chemical and bacteriological indicators [1–4]. The increase in the number of samples that do not meet the regulatory sanitary and chemical parameters is due to organochlorine compounds (OCs). Trihalomethanes, the marker of which is chloroform (CH), are considered prioritized among OCs. The largest share of tap drinking water samples (according to the data of the laboratory of natural and drinking water hygiene of the State Enterprise «Institute of Public Health named after O.M. Marzeev of the National Academy of Medical Sciences of Ukraine») [5; 6], the quality of which does not meet the hygienic requirements according to sanitary and toxicological indicators, belongs to CH (36.6%).

The current sanitary-epidemic situation is caused by a number of factors including the decrease in the effectiveness of classic chlorine-containing disinfectants. This is explained by the mass spread of chlorine-resistant forms of pathogenic microorganisms. The problem is currently being solved by using new water treatment technologies [5–7] as well as increasingly expensive, toxic, but insufficiently effective disinfectants [8–10]. Therefore, it is necessary to develop new technological principles that guarantee stable disinfection of a wide range of microorganisms in natural waters.

One of the possible technological directions is the use of high-energy water treatment during electric discharge. The authors of the paper proposed water purification technology when using local water sources. The schematic diagram of the water treatment station is shown in Fig. 1. In this technological solution the question of the efficiency of the generator of complex oxidizers is insufficiently investigated.

The goal of the work is to experimentally determine the effectiveness of the method of inactivating microorganisms in water using the influence of cold plasma of pulsed electric discharge in a heterogeneous water-air environment.

Materials and methods. The research was carried out on a laboratory setup (Fig. 2) at the Institute of Environmental Geochemistry of the National Academy of Sciences together with the employees of the Institute of Water Problems and Land Reclamation of NAAS [11; 12]. The setup ensures a cyclic flow of water into the reactor where the decontamination process takes place. The decontamination reactor is served by an ejector with inserted electrodes to which electric current pulses are transmitted.

The electrodes are located in the vacuum zone of the mixing chamber of the ejector. Cavitation «boiling» of the treated water flow occurs in the ejector ensuring the formation of a water-air mixture in the ejector's vacuum zone. The water-air mixture formed in this way makes it possible to significantly reduce the cost of electricity for the generation and maintenance of plasma compared to discharges in a purely aqueous environment [2–4].

Discharges initiate a large spectrum of different physicochemical phenomena, such as a strong electric field, intense ultraviolet radiation, shock waves of excess pressure, and, especially, the formation of various highly active chemical compounds such as radicals (OH•, H•, O•, HO_2•) and molecules (H_2O_2,

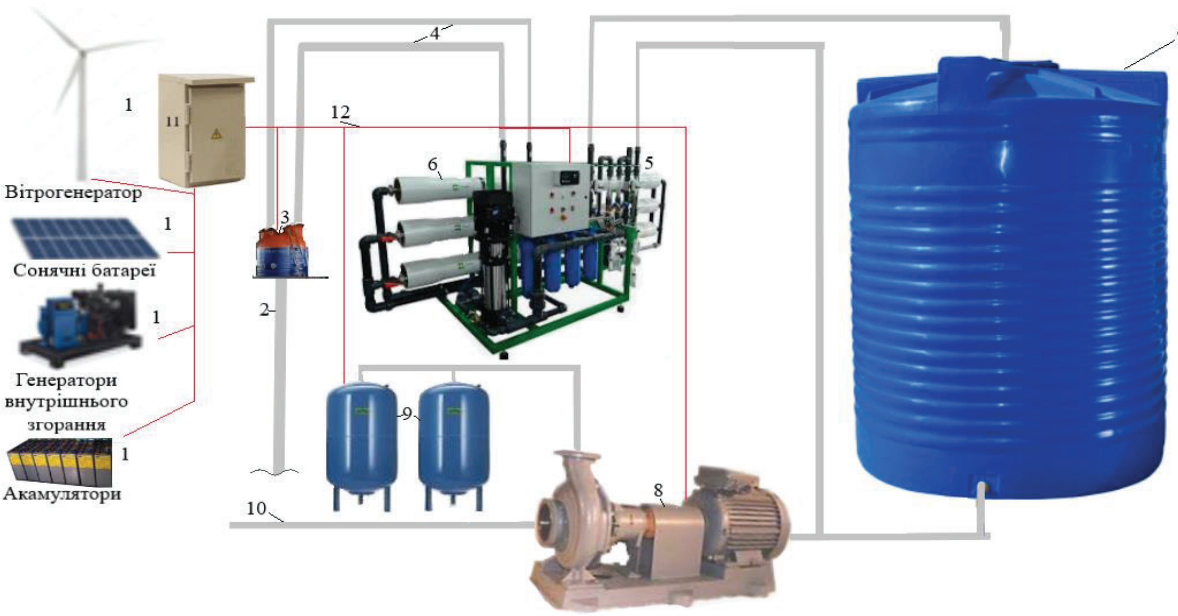

Fig. 1 Schematic diagram of a mobile water treatment station:
1 – power sources; 2 – line of input water supply; 3 – pump; 4 – lines of water supply for treatment; 5 – generator of complex oxidizers; 6 – microfiltration module; 7 – tank of clean water; 8 – pump of second lift; 9 – hydropneumatic accumulators; 10 – line of clean water supply; 11 – automated power supply cabinet with ARS, inventor, and stabilizer; 12 – line of power supply

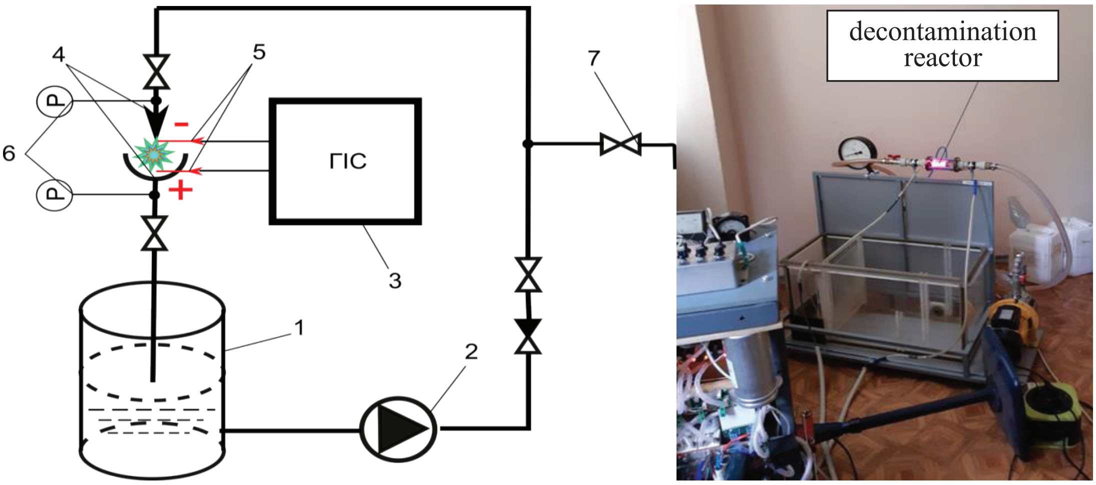

Fig. 2 Scheme of the experimental electric discharge installation for water disinfection:
1 – tank of input water; 2 – circulation pump; 3 – power supply unit; 4– discharge chamber – ejector; 5 – electrodes; 6 – manometers; 7 – tap for sampling

H_2, O_2, O_3) [3; 5; 7]. These physic-chemical processes, which occur during the discharge itself, determine the effect of disinfecting water from microorganisms. Accordingly, there is an assumption that the use of such processing will ensure high efficiency in disinfecting water from virtually all types and forms of microorganisms: viruses, bacteria, fungi, algae, cysts, protozoa, etc. The productivity of the experimental setup was Q = 0.45 m^3/h at the working pressure at the ejector inlet equal to 0.3 MPa. The volume of treated water was 5 liters. The total duration of the output pulses of the current generator was 5 ÷ 7 μs, the frequency of the pulses was 15 kHz, the amplitude of the pulses was about 5 kV.

The test object was the culture of E. Coli, strain B-926, from the collection of the Institute of Microbiology and Virology named after D.K. Zabolotny National Academy of Sciences of Ukraine.

Experiments were carried out on model samples of tap water (here and further referred to as «technical») with the sowing of E. coli culture grown on meat peptone agar (MPA), as well as on natural water: river water – the Dnipro River, which was collected in mid-July in the coastal zone of park named after Primakov, and from lake Seredne, which is part of the cascade of Holosiiv Lakes in Kyiv.

For tap water, cultures were washed in a sterile vial and shaken thoroughly. After introducing the bacterial culture, the content of the container was mixed well and a sample was taken aseptically to determine the initial concentration of the test culture in the water. The initial concentration of the microbial culture, as well as the content of microorganisms after exposure to plasma in the experiments was determined by the method of water limit dilutions.

The effect of the concentration of microbial contamination was studied on technical water samples, where the washings from two test tubes of E. coli B-926 culture on MPA were added.

The total microbial number of the initial water samples and after exposing them to plasma was calculated by the method of limiting dilutions, i. e., in all conducted experiments, tenfold dilutions were prepared from the selected samples. Next, 0.1 cm^3 of water of each dilution was sown on the appropriate medium (Endo or MPA) with three repetitions. The cultures were incubated for 24 hours at the temperature of 37 °C. After incubation, the total number of colonies was counted and the total microbial number was calculated according to the formula:

$$X = \frac{AB}{C}, \qquad (1)$$

where X is the total microbial number of colony-forming units of viable microorganisms (CFU)/cm^3; A is the average colony count from replicates; B is the sample dilution; C is the amount of seed material, cm^3.

Technical water was inoculated on E. coli-selective Endo medium and natural water samples were inoculated on MPA to determine total microbial numbers, as well as on Endo medium to record the presence of fresh faecal contamination.

Samples were coded as follows: total microbial number – ZM; D – a sample of river water from the Dnipro river; O – sample from the lake; T – technical water sample; content of E. coli – Ecol.

Results and discussion. The study of the influence of the concentration of microorganisms on the speed and completeness of water disinfection was carried out on technical (tap) water with the addition of washings from two test-culture tubes to the reaction tank. This provided an initial E. Coli concentration of $3.4 \cdot 10^6$ CFU/cm^3. Water treatment for 30 seconds reduced the concentration of microorganisms by two orders of magnitude (down to $5.4 \cdot 10^4$). After 1 minute of treatment, this indicator decreased to $1.7 \cdot 10^2$ CFU/cm^3, and after 3 minutes, the value of 5.2 CFU/cm^3 was recorded in the samples, that is, the treated water corresponded to the parameters of practically pure water [13].

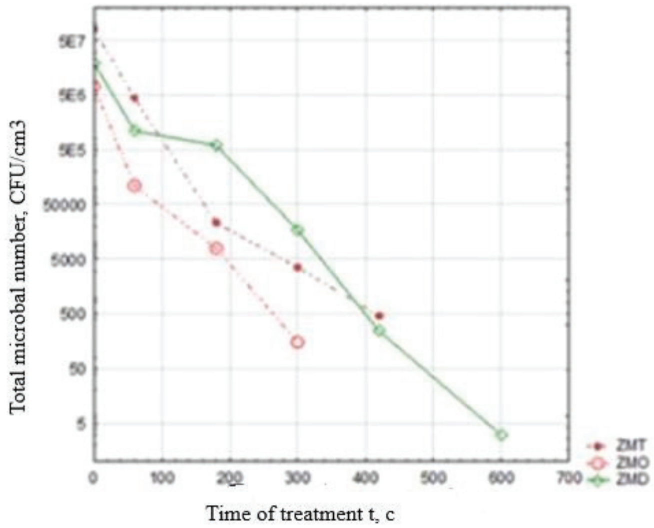

Fig. 3. Change in the total microbial number of CFU in the process of water treatment by electrical discharges

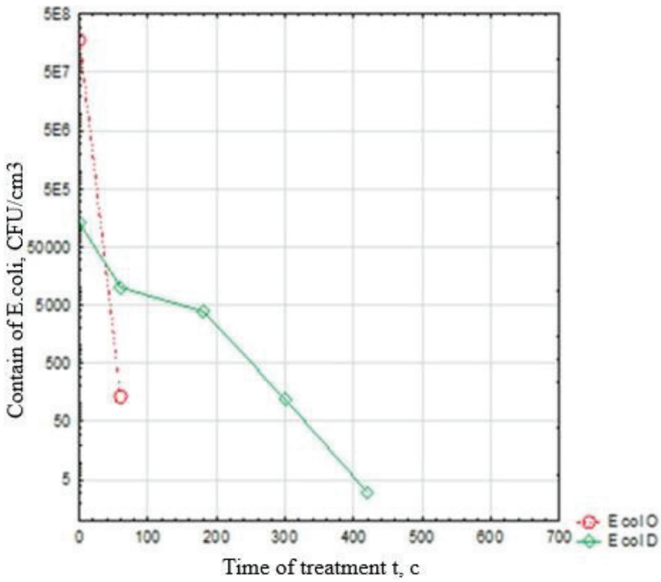

Fig. 4. Trends in changes in the CFU content of E.coli in the process of water treatment by electric discharges

To find out the influence of the degree of pollution on the nature of water disinfection, an increased amount of test culture was introduced into the technical water. This provided an initial cell concentration of $8 \cdot 10^7$ CFU/cm^3, which corresponds to the characteristic of «heavily polluted water» [14]. This led to a decrease in the speed of water disinfection. The results of the experiments are presented in the form of graphs (Figs. 3, 4) of the dependence of the change in the amount of CFU in the studied samples on the time of exposure to the electric discharge plasma.

Lake water samples were tested for total microbial numbers. Analyzes showed that the water sampled in the park zone far from the sources of pollution was quite clean according to microbiological indicators, the CFU in the samples was not many orders of magnitude higher than the requirements for drinking water – 100 CFU/cm^3 [13].

Experiments have established that 7–12 colonies of different species could be observed on one cup when sowing fresh river water. On Endo's medium, Escherichia coli ceases to germinate quite quickly; the growth of gram-negative, oxidase-positive microorganisms was observed, however, for a final conclusion about the belonging of these bacteria to the intestinal group additional studies must be conducted.

At the same time, water treated with plasma and stored for 7 days in the laboratory without sterile conditions showed a spike in insemination, including E. coli. Sowing of this water on MPA showed the value of $1.9 \cdot 10^5$, on Endo medium – $4.1 \cdot 10^5$ CFU/cm^3.

Conclusions. 1. A significant relationship between the time of plasma treatment and the amount of CFU was confirmed, regardless of the genesis of the sample, species and type of microorganisms.

2. The water treatment time is influences not only by the initial concentration of microorganisms, but also by the presence of an additional organic component. This can be explained by the fact that significant part of the synthesized oxidants is activated to oxidize the organic component.

3. Under the studied conditions, the use of high-energy water treatment proved its high water disinfection efficiency and, therefore, confirmed the hypothesis about the feasibility of using this method of water disinfection in mobile water purification plants in modern conditions.

References

1. Belinskiy, V.V., (2010). Impulsnyy koronnyy razryad na poverkhnost elektroprovodyashchey zhidkosti i yego ispolzovaniye dlya obrabotki vody – [Pulsed corona discharge on the surface of an electrically conductive liquid and its use for water treatment]. *Tekhnichna elektrodynamika*, 3, 21–27. [in Russian]
2. Bozhko, I.V., & Charnyy, D.V. (2013). Issledovaniye effektivnosti ochistki vody ot organicheskikh primesey impulsnymi razryadami – [Investigation of the efficiency of water purification from organic impurities by pulsed discharges]. *Tekhníchna elektrodynamíka*, 3, 81–86. [in Russian]
3. Bereka, V., Boshko, I., Kondratenko, I., & Zabulonov, Yu., Charny D. (2021). Efficiency of plasma treatment of water contaminated with persistent organic molecules. *Journal of Environmental Engineering and Science*, Vol. 16, Iss. 1, 40–47. https://doi.org/10.1680/jenes.20.00028 [in English]
4. Bozhko, I.V., Zozulev, V.I., & Kobylchak, V.V. (2016) SOS-henerator dlya elektrorozryadnykh tekhnolohiy na osnovi impul′snoho bar″yernoho rozryadu – [SOS generator for electrical discharge technologies based on pulsed barrier discharge]. *Tekhnichna elektrodynamika*. 2, 63–68. [in Ukrainian]
5. Charnyy, D.V., Matselyuk, Ye.M., & Kharchenko, M.Yu. (2016). Doslidzhennya efektyvnosti roboty kontaktnoho filtra z pinopolistyrolnym filtruvalnym zavantazhennyam pry ochyshchenni pryrodnykh poverkhnevykh vod – [The study of the influence of the contact filter with polystyrene filter loading on the concentration of residual aluminum during the purification of natural surface]. *Melioratsiya i vodne hospodarstvo*, 104, 26–31. [in Ukrainian]
6. Charnyy, D.V. (2016). Obhruntuvannya mozhlyvosti ochyshchennya pidzemnykh vod iz ponadnormovym vmistom Fe_{2++} i Mn_{2+} za dopomohoyu sproshchenoyi aeratsiyi po bezreahentniy skhemi – [Justification Substantiation of the treatment possibility of groundwater with an excess content of Fe_{2+} and Mn_{2+} by simplified aeration using a reagent-free scheme]. *Melioratsiya i vodne hospodarstvo*, 104, 48–57. [in Ukrainian]
7. Matselyuk, Ye.M., Charnyy, D.V., & Levytska, V.D. (2021). Novi tekhnolohichni rishennya dlya system vodopidhotovky v suchasnykh umovakh. – [New technological solutions for water treatment systems in modern conditions]. *Melioratsiya i vodne hospodarstvo*, 2, 201–209. https://doi.org/10.31073/mivg202102-303. [in Ukrainian].
8. Dolina, L.F. (2003). Novyye metody i oborudovaniye dlya obezzarazhivaniya stochnykh vod i prirodnykh vod – [New methods and equipment for the disinfection of wastewater and natural water]. Dnepropetrovsk : Kontinent. [in Russian]
9. Mokiyenko, A.V. (2020). Obezzarazhivaniye vody. Gigiyenicheskiye i mediko-ekologicheskiye aspekty. Tom 4: Ul'trafioletovoye oblucheniye i kombinirovannyye metody – [Disinfection of water. Hygienic and medical-ecological aspects. Volume 4: Ultraviolet irradiation and combined methods]. Odessa : Feníks. 378 p. [in Russian]
10. Grudinkin, A.P., & Piskareva, V.M. (2021). Tekhnologicheskiye i tekhnicheskiye osobennosti metoda obezzarazhivaniya vody ul'trafioletom – [Technological and technical features of the method of water disinfection by ultraviolet light]. *Santekhnika*, 5, 52–56. [in Russian]
11. Charnyy, D.V., Yaroshchuk, D.A., Puhach, O.V., Smirnova, H.F., Musich, O.H., Stokolos, M.O., Nikolenko, V.A., Tishchenko, I.V. & Chernova, N.M. (2021). Znezarazhennya pytnoyi vody za dopomohoyu plazmy elektrychnoho rozryadu – [Disinfection of drinking water using electric discharge plasma]. *Heokhimiya tekhnohenezu*, 6(34), 99–104. [in Ukrainian]
12. Zabulonov, Yu.L., Charnyy, D.V., Odukalets, L.A., Yaroshchuk, D.A., Puhach, O.V., Arkhypenko, O.M., & Chernova, N.M. (2021). Vyznachennya neobkhidnykh umov dlya efektyvnoho ochyshchennya pytnoyi vody z pidvyshchenym vmistom khloroformu za dopomohoyu obrobky plazmoyu v aerozoli – [Determining the necessary conditions for effective purification of drinking water with an increased content of chloroform using aerosol plasma treatment]. *Heokhimiya tekhnohenezu*, 5(33), 71–76. [in Ukrainian]
13. Derzhavni sanitarni normy ta pravyla “Hihiyenichni vymohy do vody pytnoyi pryznachenoyi dlya spozhyvannya lyudynoyu” (DSanPin 2.2.4-171-10). (2010) – [State sanitary norms and rules “Hygienic requirements for drinking water intended for human consumption” (DSanPin 2.2.4-171-10)]. Zatv. nakazom MOZ Ukrayiny vid 12.05.2010 za № 400; za reyestr. v Minyusti Ukrayiny nakazom vid 01.07.2010 za № 452/17747. *Ofitsiynyy visnyk Ukrayiny* vid 16.07.2010. Kyiv. № 51, stor. 99, stattya 1717, kod akta 51857/2010. [in Ukrainian]
14. DSTU 4808:2007 (2007). Dzherela tsentralizovanoho pytnoho vodopostachannya. Hihiyenichni ta ekolohichni vymohy shchodo yakosti vody i pravyla vybyrannya – [DSTU 4808:2007 Sources of centralized drinking water supply. Hygienic and ecological requirements for water quality and selection rules]. Kyiv. [in Ukrainian]

УДК 53.047 + 628.16

ДОСЛІДЖЕННЯ ПРОЦЕСІВ ЗНЕЗАРАЖЕННЯ ВОДИ ПРИ ЗАСТОСУВАННІ ІМПУЛЬСНОГО ЕЛЕКТРИЧНОГО РОЗРЯДУ

Є.М. Мацелюк[1] канд. техн. наук, Д.В. Чарний[2] докт. техн. наук, В.Д. Левицька[3]

[1] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0001-9960-6333; e-mail:evgen1523@ukr.net;
[2] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0001-6150-6433; e-mail:dmitriych10@gmail.com;
[3] Інститут водних проблем і меліорації НААН, Київ, 03022, Україна;
https://orcid.org/0000-0003-2213-1696; e-mail: veral@ukr.net

Анотація. *Внаслідок військової агресії рф у південно-східному регіоні України відбулось руйнування водоводів і споруд централізованих систем водопостачання, а отже практично припинено водопостачання. Вирішенням проблеми може стати застосування мобільних станцій водопідготовки з використанням місцевих джерел водопостачання: каналів, озер, ставків або підземних вод. Особливістю технологій водопідготовки в польових умовах є необхідність надійного забезпечення процесу знезараження води. Існуючі технології знезараження води мають низьку ефективність, враховуючи зростаючу кількість хлоррезистентних мікроорганізмів, отже актуальним є впровадження альтернативних методів знезараження при водопідготовці. Одним із таких методів є знезараження рідини розрядом електричного струму. Описано результати досліджень знезараження води різних типів із поверхневих джерел м. Києва та води, зараженої кишковою паличкою (Escherichia coli (E. coli)). Дослідження здійснені на лабораторній установці з циркуляційним насосом і реактором ежекторного типу з інтегрованими електродами, де формується водоповітряна суміш, через яку проходить електричний розряд. Розряди ініціюють утворення різних високоактивних хімічних речовин, таких як радикали (OH•, H•, O•) та молекули (H_2O_2, H_2, O_2, O_3). Усі фізико-хімічні процеси, які відбуваються протягом розряду, забезпечують утворення та дію короткотермінових радикалів і порівняно довготривалих окислювачів. Вивчення впливу концентрації мікроорганізмів на швидкість і повноту знезараження води проводили на технічній (водопровідній) воді із внесенням до реакційної ємності змиву з двох пробірок тест-культури, що забезпечило початкову концентрацію E. coli 3,4 · 106 КУО/см^3. Обробка води протягом 30 секунд знизила кількість мікроорганізмів до 5,4 · 104 КУО/см^3. Через 1 хвилину обробки цей показник знизився до 1,7 · 102, а після закінчення 3 хвилин у пробах реєстрували 5,2 КУО/см^3, тобто оброблена вода мала показники практично чистої води. Досліди довели ефективність знезараження плазмовим методом для рідин із високою концентрацією мікроорганізмів.*

Ключові слова: *вода, водопостачання, знезараження, бактерії, плазма, електричний розряд*