

Purification of bacterially contaminated water using non-thermal plasma

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Abstract. The article presents the results of disinfection of *E. coli*-contaminated water using non-thermal plasma. It is shown that at an initial concentration of *E. coli* up to $8 \cdot 10^8$ CFU/cm³, which corresponds to the characteristic of 'heavily contaminated water', after 30 seconds of treatment, the concentration of *E. coli* decreased by four orders of magnitude, and after 60 seconds, the *E. coli* concentration decreased to 5.2 CFU/cm³, which corresponds to practically clean water. The effectiveness of disinfecting liquids with a concentration of microorganisms significantly exceeding the maximum permissible limits using non-thermal plasma reaches 95-99%. The bacterial content before and after treatment was determined by the limit dilution method of samples followed by sowing on a nutrient medium in Petri dishes.

Keywords: water, disinfection, bacteria *E. coli*, non-thermal plasma, electric discharge.

Freshwater shortages caused by seasonal weather fluctuations, climate change and excessive construction have led to serious consideration of its reuse, which involves the direct treatment of surface water, wastewater and bacterially contaminated water to drinking quality. Advanced water treatment technologies will be needed to achieve the latter. There is also concern about micropollutants (pharmaceuticals, bacteria, personal hygiene products, etc.) present in drinking water that have not been removed by traditional means [1].

The impact of these pollutants on health at low concentrations has not been sufficiently studied. Therefore, the removal of these pollutants is a pressing issue and can be based on water purification using non-thermal plasma.

The paper [2] presents data on the generation of non-thermal plasma in liquids using various devices, identifies the optimal conditions for its generation, clarifies the mechanism of stable plasma generation as a new source of plasma energy, and provides examples of the synthesis of nanomaterials for wastewater treatment.

According to [3], plasma in contact with liquid water generates a multitude of reactive particles (Fig. 1) that attack and ultimately mineralise contaminants in solution. This interaction occurs in the boundary layer or interaction zone concentrated at the plasma-liquid water interface. Understanding the physical processes occurring at the interface, although poorly studied, is key to optimising plasma-based water purifiers. This multiphase region is dominated by high electric field conditions, large density gradients, plasma-driven chemical processes, and hydrodynamic effects. This region is also the source of long-lived reactive particles that ultimately purify the water.

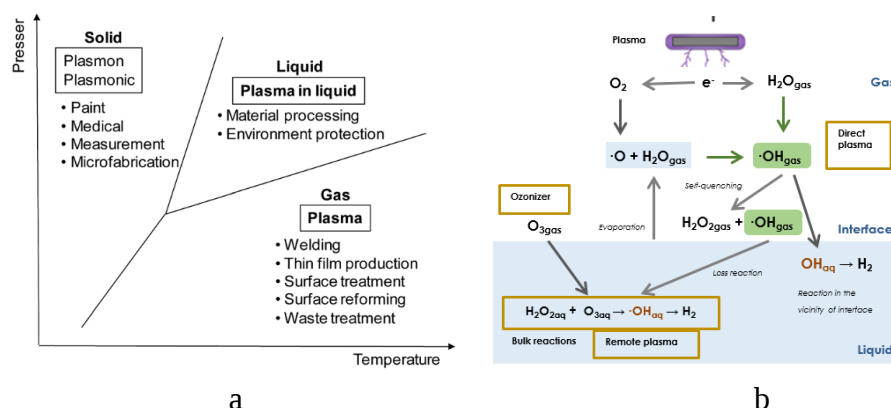


Fig. 1. Relationship between plasma and the three states of matter (a) and physical and chemical phenomena in spark discharges arising during water treatment with non-thermal plasma (b)

The authors [4] note the importance of plasma-treated water for inactivating microorganisms and show that the presence of $N_2 + 0.5 \text{ wt.}\% \text{ HNO}_3$ vapours in plasma contributes to greater deactivation of *E. coli*. In [5], it is noted that to achieve a satisfactory antimicrobial effect, plasma-activated water was used against native microbiota (total mesophilic count (TMC) and total psychrotrophic count (TPC)) and inoculated bacteria (*Escherichia coli*, *Listeria innocua* and *Pseudomonas fluorescens*). The positive effect of plasma-activated water, including pH, oxidation-reduction potential (ORP), conductivity, and active forms of oxygen and nitrogen (PON) in achieving higher inactivation rates, with the highest inactivation of 0.72, 0.62, and 0.5 log CFU/g for *L. innocua*, *E. coli*, and *P. fluorescens*, respectively. The positive effect of plasma-activated water (PAW) as a rinsing solution for microbial decontamination has also been noted [5]. The decontamination efficiency exceeded that of mimic solutions with equivalent concentrations of reactive substances and pH (log reduction of 3.0 vs. 1.7), indicating that the entire spectrum of reactive substances obtained from plasma is involved in decontamination, rather than just a few reactive substances. Treatment with PAW by washing achieved a reduction in the number of *Bacillus cereus*, *Salmonella* sp. and *Escherichia coli* O157:H7 by 6.89 ± 0.36 , 7.49 ± 0.40 and $5.60 \pm 0.05 \text{ log}_{10} \text{ CFU/g}$, respectively, inoculated on the surface of the products [6].

The above data confirm the effectiveness of using non-thermal plasma for disinfecting both water and food products.

Regardless of the data from works [2, 3], a pilot plant was constructed at the State Institution ‘Institute of Environmental Geochemistry’ of the National Academy of Sciences of Ukraine, which is part of the general technology for the purification of technical water PLASMA-SORB [7, 8], with the help of which it was possible to purify surface water contaminated with bacteria. The diagram of the pilot plant is shown in Fig. 2.

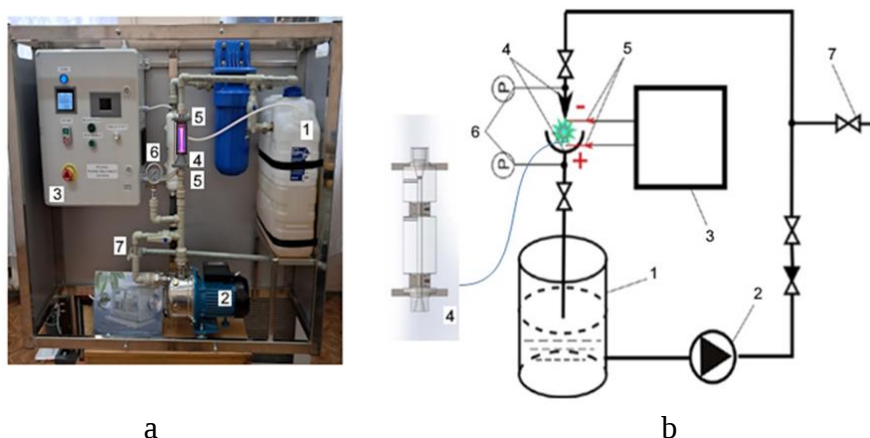


Fig. 2. Appearance (a) and hydraulic diagram (b) of a non-thermal plasma water treatment unit: 1 - water tank; 2 - water pump; 3 - high-frequency pulse current generator; 4 - ejector (disinfection reactor); 5 - electrodes; 6 - pressure gauges; 7 - sampling tap

The installation provides a cyclic flow of water into the reactor, where the disinfection process takes place with the help of a circulation pump. The disinfection reactor and, at the same time, the device for creating a heterogeneous water-air environment is an ejector with electrodes inserted into it, to which electrical current pulses are applied.

During the generation of non-thermal plasma by electrical discharges in a water-air environment, a number of physical and chemical factors arise that can contribute to water disinfection. Discharges initiate a whole range of different physicochemical phenomena, such as a strong electric field, intense ultraviolet radiation, shock waves of excess pressure and, in particular, the formation of various highly active chemical compounds, such as radicals ($\text{OH}\cdot$, $\text{H}\cdot$, $\text{O}\cdot$, $\text{HO}_2\cdot$) and molecules (H_2O_2 , H_2 , O_2 , O_3) [1, 3].

All these physicochemical processes that occur during the discharge itself, such as the formation and action of short-lived radicals, as well as the action of relatively long-lived oxidants such as H_2O_2 and O_3 , cause the disinfection of water from microorganisms: viruses, bacteria, fungi, algae, cysts, protozoa, etc., which are subjected to such treatment.

To determine the effect of non-thermal plasma on the nature of water disinfection, an increased amount of *E. coli* test culture was added to the technical water. This provided an initial concentration of *E. coli* cells of up to $8 \cdot 10^8$ CFU/cm³, which corresponds to the characteristic of ‘heavily contaminated water’. After 30 seconds of treatment of such water with non-thermal plasma, the concentration of *E. coli*

decreased by four orders of magnitude, and after 60 seconds, the concentration of *E. coli* decreased to 5.2 CFU/cm³, which corresponds to the indicators of practically pure water [1] (Fig. 3).

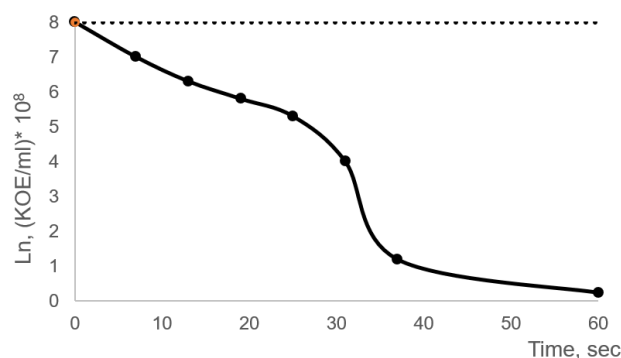


Fig. 3. Change in the content of viable *E. coli* colony-forming units over time after treatment of water samples in a non-thermal plasma device: before treatment; _____ after treatment

After treating biologically contaminated water with non-thermal plasma for 60 seconds, the inactivation rate of *E. coli* bacteria reached 95-99%, confirming the effectiveness of this approach in disinfecting water from bacterial contamination.

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