The energy input mode influence on the efficiency of plasma water treatment in a bubble chamber

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Abstract. The optimal time interval was found for plasma treatment of liquid using distilled water as an example. The positive effect of plasma-active water on the agricultural crops growth is shown. The synchronization task of chemically active particles formation and their entry into the liquid has been revealed.

1. Introduction

It is that the non-thermal plasma treatment of liquid (depending on the conditions of the discharge) is based on the simultaneous influence of several physical and chemical factors on the initial liquid: ultraviolet radiation, shock waves, neutral, charged and chemically active particles [1]. The resulting liquid is generally referred to as «plasma-activated». There is a known method of water treatment with a high-voltage pulsed discharge created above its surface, where several combined needle electrodes or wire mesh are used as an anode [2]. There are also ways in which one of the electrodes represents a liquid surface or a liquid connected to a cathode [1, 3–5].

Various devices are used to obtain plasma-active liquids, in particular, based on the fact that when a voltage pulse is applied to the electrodes, a single-barrier discharge is ignited in the dielectric tube filled with air, where various chemically active particles are formed due to plasma-chemical reactions. These particles are displaced into the water, creating aqueous solutions of the desired chemical composition. This design intensifies the dissolution of chemically active substances formed in the discharge plasma in the volume of water in comparison with the methods and devices in which the discharge is ignited in the gas phase above the surface of the liquid phase [6, 7]. The corresponding class of technical means is called bubble discharge reactors.

A significant disadvantage of these approaches is the lack of synchronization between the process of chemically active species formation and their entry into the liquid. In other quarters the voltage pulses do not provide energy deposition into the bubble volume, consistent with the process of liquid bubbling. In addition, the discharge properties are not consistent with the properties of the treated liquid.

The purpose of the work is to determine how the synchronization of the energy input into the water in the bubbling mode impact on the productive bubble discharge chamber.
2. Methods and experimental setup
The experimental setup for study is represented in figure 1. The setup includes a pulse voltage source with an amplitude of 8–10 kV, a frequency from 2 to 50 kHz, a rise time from 20 to 900 ns. This source was connected to a wire anode with a diameter of 0.7–1 mm, located in a dielectric tube and having an internal diameter of 8–10 mm and a narrowing to 1.2–1.5 mm. This geometry excluded ignition of the discharge between the anode and the inner surface of the dielectric tube. Air was pumped through the dielectric tube (flow rate up to 5 l\textperiodcentered min\textsuperscript{-1}). The anode, dielectric tube and cathode were placed in water in a dielectric reservoir. For matching the deposited energy, the capacity was installed between the cathode and the voltage source.

![Figure 1. Experimental setup: 1 – pulse voltage source; 2 – anode; 3 – dielectric tube; 4 – liquid; 5 – air pump; 6 – second electrode, dielectrically isolated from the liquid; 7 – capacity; 8 – reservoir.]

Voltage pulses from the source were applied to the anode, at the same time there was an air supply into the dielectric tube, and the liquid was bubbled. As a result, a discharge was ignited between the anode and the interface between the liquid and gas, intensive ionization occurred. Then the chemical species form and saturate the water as the bubbles move to its surface.

At a given gas flow rate, the bubbles are under the action of an electric discharge for a limited period of time $t$ until they break away from the dielectric tube. During the time $t$, it is necessary to input an optimal (or close to optimal) portion of energy into the bubble, such that a maximum of chemically active particles is formed at its interface and in bubble volume. This energy portion should not be small; otherwise, it will reduce the productivity of the process. On the other hand, it should not be too high so that the particles formed at interface and in volume do not collapse. It should be taken into account that the bubble is inflated, and this leads to a change in the breakdown characteristics (the number of breakdowns per unit time and breakdown strength). At the low frequency $f$ of voltage pulses, it is necessary to increase the voltage pulse amplitude. Therefore, it can be assumed that there is an optimal period of time required for processing by the discharge of the bubble.

We tested this experimentally using the described setup in case of distilled water treatment. Water was bubbled with voltage pulses following with a repetition rate of up to 50 kHz. Processing was carried out for 2 minutes. The bubbles formation frequency $f_b$, which was set by the gas flow rate, was determined using an ultra-linear condenser microphone PMC-2 with a three-contact output and a frequency response of up to 20 kHz, close to linear, or using videorecording. Registration of absorption spectra was carried out by StellarNet EPP2000-C25 spectrometer. Measurements were also carried out
using an acidity level analyzer (range 0-14 pH) and an electrical conductivity level analyzer (range 0–9990 ppm).

3. Results and discussion

After discharge treatment, the water changed its chemical composition, turning into a solution with new optical absorption spectra. They consist of characteristic NO$_3^-$ absorption band in the wavelength range of 200–250 nm (figure 2).

![Figure 2. Optical absorption spectra of water solution with NO$_3^-$ after 10 minutes of discharge treatment and flow rate up to 1 l/min$^{-1}$.](image)

The described procedure was repeated at different bubble formation frequency $f_p$, noting differences in optical absorption of the obtained solutions, which indicated different water treatment efficiency. The obtained dependence of the optical absorption of solutions $A$ at a wavelength of 205 nm on the average bubbles lifetime values is shown in figure 3. It is seen that the dependence has an optimum, which confirms our hypothesis.

![Figure 3. An example of the dependence of the solutions optical absorption $A$ at $\lambda = 205$ nm on the average lifetime of bubbles $<t>$.](image)
In the described experiment, water solutions containing NO$_3^-$ ions were obtained. It is known that only this kind of ions provide nitrogen absorption in plants. Then the obtained solutions in tenfold dilution were used for irrigation of flax seeds ("TOST1" cultivar) and wheat ("Irgina" cultivar). Observation of the development of the root system of seeds showed that compared with irrigation with ordinary water, wetting with treated water leads to a 2.5–5 fold increase in the length of the roots of plants and a twofold increase in their dry weight. This is a strong evidence in favor of the industrial applicability of the obtained solutions to stimulate plant growth in agriculture.

It should be noted that for additional matching of energy deposition into the bubble with its life time, it is also necessary to coordinate the electrophysical properties of the liquid with the parameters of the voltage pulses. We assume that the value of the voltage pulse rise time $\tau$ must be consistent with the conductivity of the liquid $\rho$ as $\tau [\text{ns}] \sim 1/(1-10^\rho) [\mu\text{Sm}\cdot\text{cm}^{-1}]$ for $\rho$ values from 1 to $10^3 \mu\text{Sm}\cdot\text{cm}^{-1}$. For large values of $\rho$, the discharge treatment process will be inferior to electrolytic methods. This is a physical limitation on the efficiency of the energy input mode in the plasma treatment of water in the bubble chamber.

4. Conclusion

The literature analysis devoted to devices and methods for obtaining a plasma-active water, based on the discharge above water and in water, is fulfilled. It is revealed that the process of obtaining plasma-active water doesn’t provide synchronization between the formation of chemically active particles and their entry into the liquid. In addition, the discharge properties are not agreed with the properties of the treated liquid.

The proposed setup for water treatment discharge. It is shown that there is an optimal time interval required for processing by a bubble discharge (in a bubble discharge chamber). The water effect treated of discharge in the task of stimulating the plants growth in agriculture is demonstrated.

A remark about the need to match the electrophysical liquid properties with the parameters of the power supply voltage pulses of setup was made.

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