DC Underwater Capillary Discharge With Symmetrical Hole: Diagnostics and Pumping Effect

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Abstract. Capillary discharge investigated by this work was created in the reactor using positive half-cycle of AC high voltage up to 2 kV. Electric field created between two electrodes which were separated by the dielectric ceramic barrier with a symmetrical cylindrical hole (diameter of 1 mm, length of 5 mm) in it. When voltage reached the value sufficient for liquid breakdown, the discharge appeared initially in bubbles of evaporated solution in the hole vicinity and spread further into the liquid volume. After the rise of discharge, two kinds of plasma channels (streamers) propagated towards electrodes from the pin-hole: longer positive streamers on the side with the cathode (analogically as in the positive corona discharge) and shorter negative streamers (like negative corona discharge). These streamer kinds differed especially in the energy dissipation originating from different electron velocities in plasma channels due to electron collisions with positive particles accelerating or decelerating electron avalanches and it gave rise of a significant pump effect.

1. Introduction

Electrical discharges in electrically conductive liquids can be generated in several ways and various electrode configurations have been studied. Among the various configurations to generate plasma in a conductive water solution only the diaphragm and the capillary discharge scheme allow generation of plasma which is not in contact with electrodes. In these discharge configurations plasma is generated in one or more holes in a dielectric separating two water vessels. In capillary discharges, the length-to-diameter ratio of the holes is >> 1 [1]. If this ratio is about 1, the discharge is called diaphragm discharge [2].

Recent research showed that periodic plasma generation in an asymmetrical capillary induces a flow of liquid between the two vessels, which might be utilized to design a micro pump [3]. It is assumed that these underwater electrodeless discharges are initiated by the breakdown of a water vapour bubble inside the hole, the bubble being nucleated due to Ohmic heating of the conductive liquid filling the dielectric hole [4].

This work presents our research focused on the pump effect using the symmetrical geometry of the capillary. Parameters such as initial solution conductivity or input power on this effect as well as diagnostics by optical emission spectroscopy and electrics characteristics have been investigated.

2. Experimental

The experimental apparatus consisted of an AC high-voltage power supply and a batch reactor (Figure 1, left). The high-voltage power supply gave the AC output voltage (up to 3.5 kV) directed by diode for using only positive or negative half-cycle of voltage. Two circle electrodes made of stainless steel were separated by the dielectric barrier thickness of 5 mm and made from shapal ceramic. Both electrode spaces were connected by only a small hole (diameter of 1 mm) in this ceramic diaphragm (Figure 1. right). Discharge breakdown appeared just in this orifice and plasma channels propagated from this spot towards electrodes. Due to the application of voltage, two different kinds of plasma streamers appeared on the opposite sides of the dielectric barrier [4]. On the side with the positive electrode, shorter plasma channels fill a spherical volume around the orifice. In the other reactor part containing the cathode, longer plasma channels propagated from the pin-hole towards the negative electrode. [3][5]
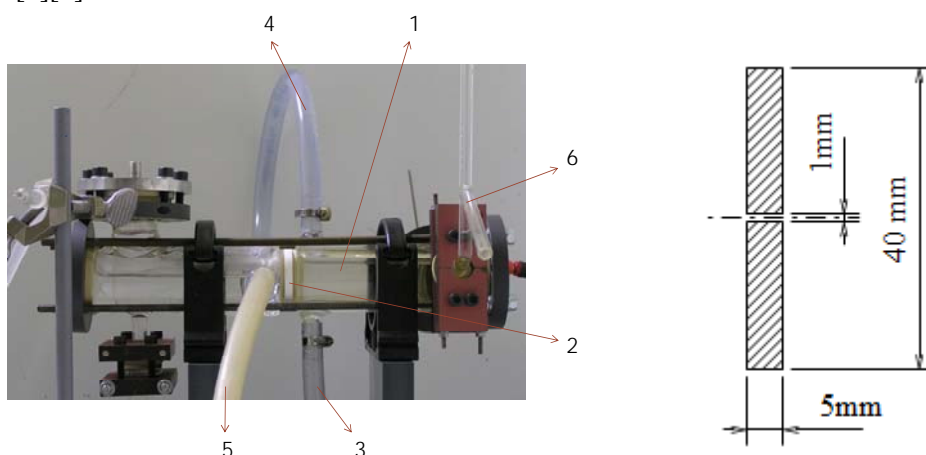

Figure 1. Photo of discharge reactor (1 – reactor vessel, 2 – ceramic dielectric barrier with symmetrical capillary hole, 3 – cooling inlet, 4 – cooling, 5 – cooling outlet, 6 – aqueous solution outlet) and scheme of ceramic symmetrical capillary.

Each part of the reactor contained 100 ml of treated solution. Water solutions contained distilled water and a definite amount of supported electrolyte NaCl providing particular solution conductivity ($50 - 1000$ μS·cm^{-1}). There was provided the weighing of flowing drops of aqueous solution during the pump effect. Parameters such as initial solution conductivity or input power on this effect as well as diagnostics by optical emission spectroscopy and electrical characteristics have been investigated.

3. Results and discussion

Emission spectroscopy was used to identify the various species that are formed. Spectroscopic measurements of the plasma induced emission performed without time resolution indicate that the discharge might be an efficient source of OH, H and O radicals, which are among the strongest oxidants available. Figure 2 shows emission radiation produced by the discharge in spectral range of 200–900 nm for three different conductivities of water solution.

The average electrical characteristics of discharge, featuring values of power and voltage, are presented in figure 3 for different initial conductivities of aqueous solution. There was observed similar results for positive half-cycle and negative half-cycle of applied voltage.
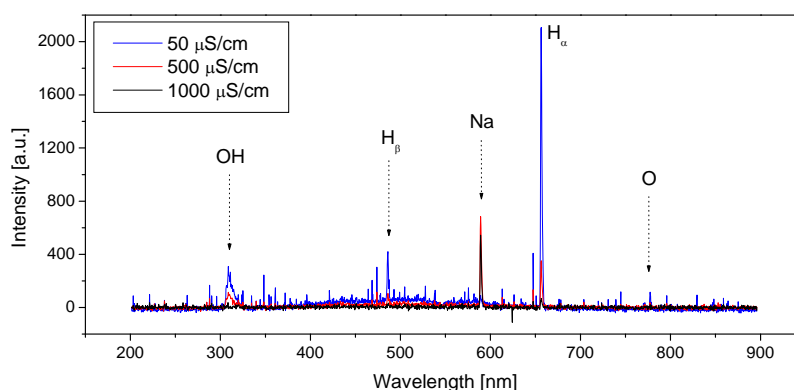
Figure 2. Optical emission spectra of the underwater discharge emission for different solution conductivities (50 µS/cm – blue line, 500 µS/cm – red line, 1000 µS/cm – black line) containing NaCl electrolyte and obtained for electric output 33 W using positive half-cycle of passing voltage.
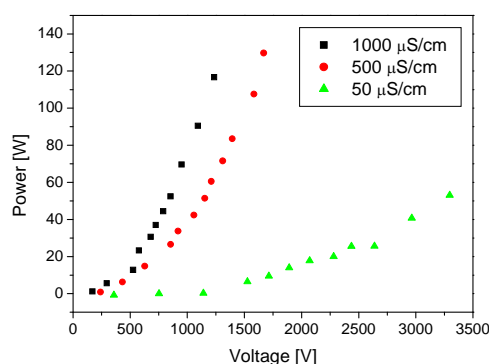

Figure 3. Electrical characteristics for three different water solution conductivities during the positive half-cycle of passing voltage.

Typical examples of the time evolution of the amount of discharge treated aqueous solution coming out at highest outlet during 20 minutes after switching on the discharge for various solution conductivities are displayed in figures 4, 5 and 6.

There was obtained only one pumping effect for output power 10 W for solution conductivity of 50 µS/cm and for glowing discharge (with plasma formation). There was no pumping effect for lower values of applied voltage without plasma (Figure 4).
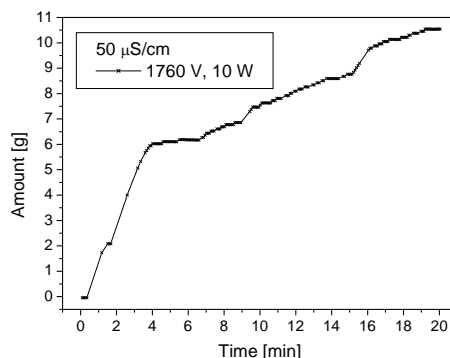
Figure 4. Time evolution of the amount of discharge-treated aqueous solution coming out at the outlet for positive half-cycle of voltage. Used solution conductivity of 50 µS/cm (electrolyte NaCl).
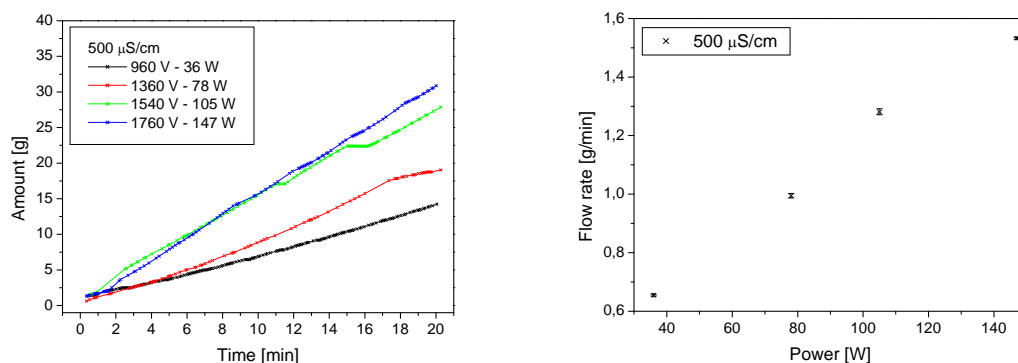
Figure 5. Time evolution of discharge-treated aqueous solution amount coming out at the outlet for positive half-cycle of voltage on the left and dependence of aqueous flow rate on applied power on the right side. Used solution conductivity of 500 µS/cm (electrolyte NaCl).
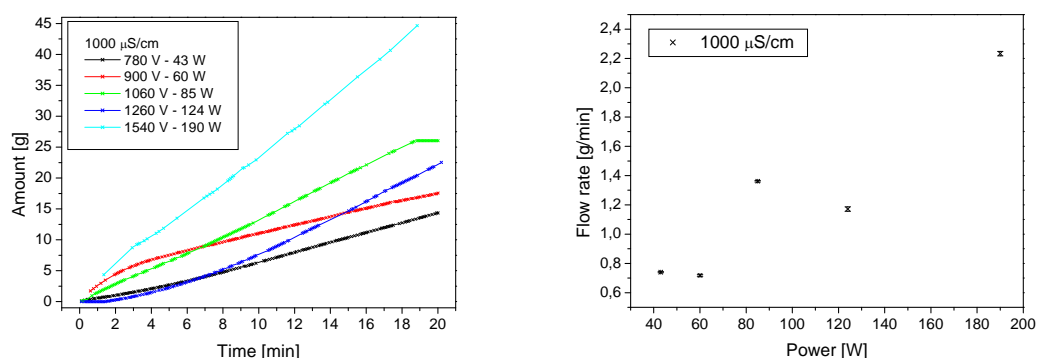
Figure 6. Time evolution of discharge-treated aqueous solution amount coming out at the outlet for positive half-cycle of voltage on the left and dependence of aqueous flow rate on applied power on the right side. Used solution conductivity of 1000 µS/cm (electrolyte NaCl).

The dependences of outlet amounts of aqueous solution on applied power for solution conductivity of 500 µS/cm (Figure 5, left) and 1000 µS/cm (Figure 6, left) were measured. Presented plots were realized for different values of applied voltage with formation of plasma and it indicates that higher used voltage gives larger outflow and it records a linear dependences. There is no major modification between results for positive and negative half-cycle of voltage.

Figures 5 and 6 (right) show the dependence on applied power of the aqueous flow rate resulting from the DC plasma generation in symmetrical capillary. Among these two different conductivities (500 and 1000 µS/cm), the highest and most stable plasma-induced aqueous flow rate is obtained for a solution conductivity of 1000 µS/cm and used power of 190 W in figure 6 right.

Acknowledgements

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