

DIAPHRAGM DISCHARGE IGNITION BY CONSTANT DC VOLTAGE IN ELECTROLYTE SOLUTIONS

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The paper deals with diaphragm discharge ignition in water solutions of selected electrolytes (NaCl, NaNO₃, Na₂SO₄, Na₃PO₄) using constant DC voltage. Time resolved as well as mean electric characteristics were measured during the discharge ignition. Substantial influence of electrolyte concentration on breakdown parameters was estimated. Breakdown voltage was decreased by the electrolyte concentration enhancement while breakdown current slightly increased. Emission spectra of the diaphragm discharge were recorded with respect to the electrode polarity and the influence of electrolyte concentration was observed.

Key words: diaphragm discharge, electric measurements, breakdown in electrolyte, optical emission spectroscopy

1 Introduction

Electrical discharges in liquids have been in a serious focus of researchers for mainly last three decades. Especially formation of various reactive species such as hydroxyl and hydrogen radicals, some ions and molecules with high oxidation potential (hydrogen peroxide) has been investigated in order to utilize this process in water treatment and removal of organic compounds from water [1, 2].

Diaphragm discharge configuration consists of two electrode spaces divided by the dielectric barrier with a central pin-hole. Ratio of the pin-hole diameter to the diaphragm thickness is approximately 1:1. Discharge ignition starts in the pin-hole when sufficient power is applied and breakdown moment is probably related to the bubbles formation [3]. By the application of constant DC voltage, water solution is significantly heated due to the strong electric field and bubbles of water vapour create in the pin-hole region. It is assumed that the discharge breakdown starts in these bubbles because of high potential gradient between the outer and inner bubble region [3]. Moreover, application of DC voltage initiates creation of two kinds of plasma channels (streamers) on both sides of the diaphragm (see Fig. 1 left) [4].

The presented contribution describes diaphragm discharge creation by the means of electrical characteristics and discusses the influence of electrolyte kind and concentration (providing particular solution conductivity) on the breakdown moment. The results are completed by optical emission spectra of the discharge with respect to the electrode polarity.

2 Experimental

The photograph of the batch discharge reactor used in experiments is given in Fig. 1 right. The device used the diaphragm made of PET (thickness of 0.25 mm) with a central pin-hole (initial diameter of 0.4 mm). High voltage source gave the constant DC power up

to 1 kW. Diaphragm discharge was generated in water solutions of electrolytes NaCl, NaNO₃, Na₂SO₄ and Na₃PO₄ with conductivity in the range of 300–1300 μS·cm⁻¹.

Oscilloscope Tektronix TDS 1012B operating at 100 MHz with the high voltage probe Tektronix P6015A were used to obtain time resolved characteristics of discharge voltage and current with the focus on the breakdown moment. Mean values of breakdown parameters (voltage, current, power and resistance) were estimated and subsequently, current-voltage characteristics were evaluated for each experiment. Emission spectra were detected by the optical spectrometer Jobin Yvon TRIAX 550.

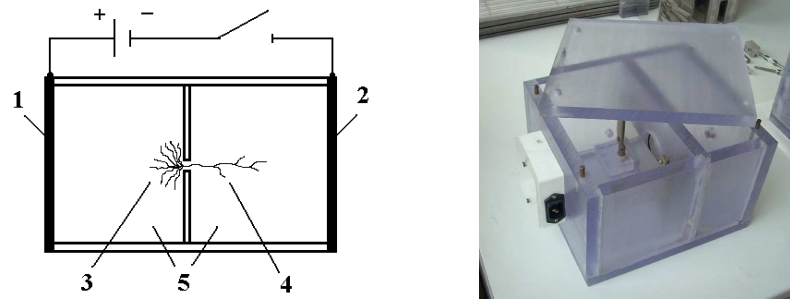


Fig. 1. Simplified scheme (left) and photograph (right) of diaphragm discharge reactor: 1 – anode, 2 – cathode, 3 – negative plasma streamers, 4 – positive plasma streamers, 5 – electrolyte solution.

3 Results

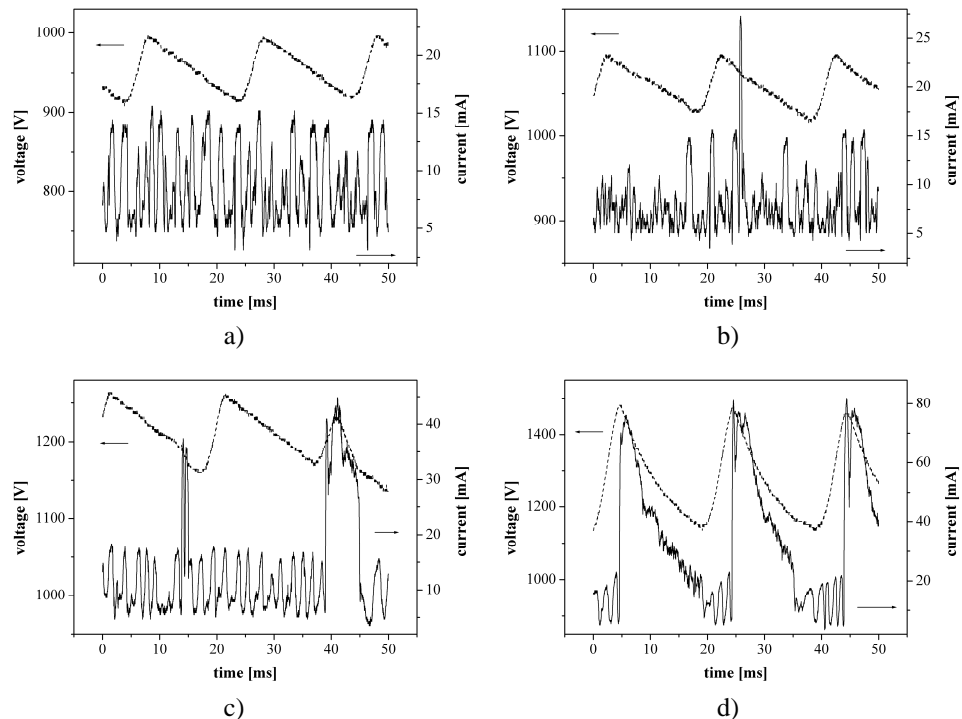


Fig. 2. Time resolved characteristics of voltage and current in Na₃PO₄ solution around the breakdown moment: mean voltage values of a) 950 V, b) 1060 V, c) 1205 V, d) 1280 V.

Note: The y-axis ranges for a) – d) differ according to the mean value.

Time resolved characteristics measured in Na_3PO_4 solution (conductivity of $500 \mu\text{S}\cdot\text{cm}^{-1}$) are given in Fig. 2. Presented images show the time behaviour of voltage and current at the different mean voltage value around the breakdown point. Fig. 2 a) demonstrates regular voltage and current oscillations corresponding to the bubble formation in the pin-hole. Increasing the mean applied voltage, irregular higher peaks of current appears on the record related to the random discharge breakdown in the bubble (Fig. 2 b) and c)). If the input power is sufficient, regular current and voltage oscillations during the discharge are observed (Fig. 2 d)). The breakdown of water vapour bubble induces the decrease of system resistance and therefore rapid current enhancement appears connecting to the simultaneous drop of voltage.

Mean values over 50 ms (i.e. over 2.5 period) of voltage and current were estimated from time resolved characteristics and subsequently, current-voltage curves were constructed. Fig. 3 demonstrates the comparison of current-voltage characteristics obtained in Na_3PO_4 solution at three conductivities ($500, 900$ and $1300 \mu\text{S}\cdot\text{cm}^{-1}$). The discharge ignition is characterised by the significant breakpoint on the curve. It is evident that the increasing solution conductivity (electrolyte concentration) decreases the breakdown voltage while the breakdown current slightly increases. The more or less same effect was observed in other tested solutions. The comparison of breakdown voltage as a function of solution conductivity in selected electrolytes is given in Fig. 4.

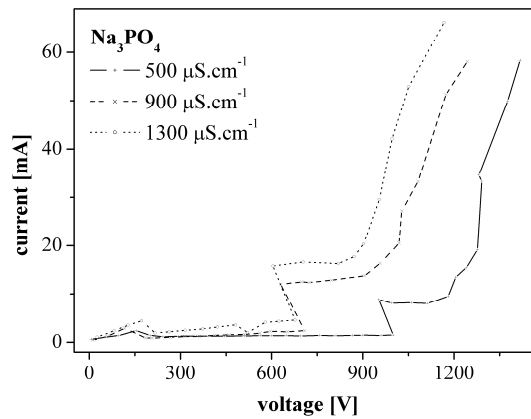


Fig. 3. Current-voltage characteristics of diaphragm discharge in Na_3PO_4 solution – comparison of three conductivities ($500, 900$ and $1300 \mu\text{S}\cdot\text{cm}^{-1}$).

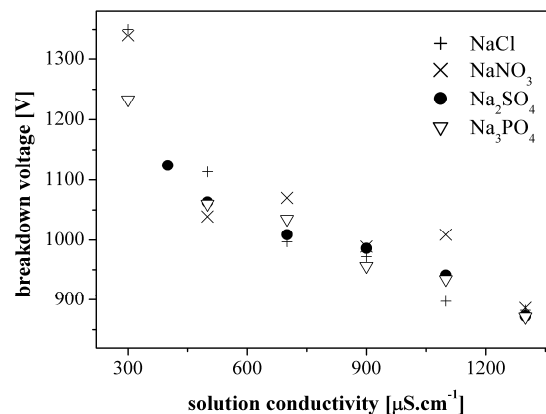


Fig. 4. Breakdown voltage of the diaphragm discharge as a function of solution conductivity – comparison of four electrolytes ($\text{NaCl}, \text{NaNO}_3, \text{Na}_2\text{SO}_4, \text{Na}_3\text{PO}_4$).

Emission spectra of the diaphragm discharge were recorded with respect to the polarity of plasma channels on each side of the diaphragm. Spectra of OH radicals obtained in Na_2SO_4 solution (conductivity of $600 \mu\text{S}\cdot\text{cm}^{-1}$) are shown in Fig. 5 left. The recorded emission intensity was significantly higher in the cathode space, i.e. on the diaphragm side where longer positive streamers were created. The intensity was influenced by the radiating volume that was probably related to the bubble size which could differ on each side of the diaphragm. However, exact description of bubble creation is still a subject of our research.

Influence of solution conductivity on OH radical emission intensity is demonstrated in Fig. 5 right for Na_2SO_4 electrolyte and two conductivities, 300 and $600 \mu\text{S}\cdot\text{cm}^{-1}$. It is evident that the emission intensity was enhanced by the increase of solution conductivity, i.e. by the enhanced amount of electrolyte in the solution.

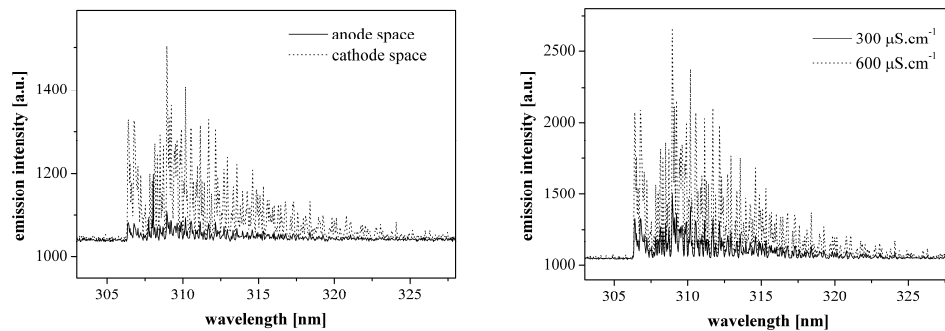


Fig. 5. Comparison of OH emission spectra in diaphragm discharge (Na_2SO_4) – comparison of electrode space polarity (left) and solution conductivity (right). Input power of 120 W.

4 Conclusion

Ignition of diaphragm discharge generated by constant DC voltage in water solutions of selected electrolytes (NaCl , NaNO_3 , Na_2SO_4 and Na_3PO_4) was clarified by time resolved characteristics. Relation between discharge creation and formation of bubbles (water vapour) was discussed. Significant influence of electrolyte concentration (solution conductivity) on breakdown parameters was observed. Increasing the solution conductivity, discharge appearance started at lower mean voltage as well as a slightly higher mean current was detected. Comparing results obtained in water solutions of all tested electrolytes, we achieved more or less the same trends in breakdown parameters.

Emission spectra of OH radicals produced in the diaphragm discharge were recorded and compared with respect to the electrode polarity and solution conductivity. Remarkably higher emission intensity was observed in the cathode space where longer positive streamers were created. Enhancement of solution conductivity affected the increase of OH emission intensity in Na_2SO_4 solution.

Acknowledgements

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