

BREAKDOWN OF DC DIAPHRAGM DISCHARGE IN SOLUTIONS OF ALKALINE METALS

J. PROCHAZKOVA, Z. STARA AND F. KRCMA

*Faculty of Chemistry, Brno University of Technology, Purkynova 118, 612 00 Brno, Czech Republic,
e-mail: xcprochazkovaj@fch.vutbr.cz*

Received XXX

Abstract. This contribution shows results obtained from the electrical measurements of the DC diaphragm discharge with the focus on the discharge ignition. The determined breakdown voltage beheld into the range of 1100-1300 V in wide range of studied solution conductivities (50-1400 $\mu\text{S}\cdot\text{cm}^{-1}$) more or less independently on the electrolyte kind. The current at the breakdown was 20-50 mA and it linearly increased with the increase of solution conductivity.

Key words: discharge ignition, breakdown voltage and current, alkaline metals

1 Introduction

Generation of electric discharge in gases has been an object of many studies focused on the application of different high voltage sources and in various electrode configurations [1]. However, discharge creation in liquid, particularly in water, is limited to only a few suitable electrode geometries together with the application of a sufficient energy source. In all cases, it is important to accumulate energy of the applied electric field on some edge or tip in the system. The most convenient and also by many authors the most investigated configuration is point-to-plane electrode geometry where the discharge is ignited using the DC pulsed high voltage [2]. Further the coaxial, diaphragm or capillary configurations have been already studied [3-4]. This contribution is focused on the generation of the diaphragm discharge by the application of the DC high voltage.

Diaphragm discharge is created in the small pin-hole in the dielectric diaphragm which divides the discharge reactor into two electrode spaces, each filled with a definite volume of electrolyte solution. Intensity of electric field between two planar electrodes accumulates just in the pin-hole. If the electric field is sufficient, the discharge is formed in the bubbles of evaporated water in and near the pin-hole. These bubbles are nucleated due to the ohmic heating of the conductive liquid. Similar mechanism of the discharge creation has been observed in the underwater capillary discharge [4].

2 Experiment

The batch discharge reactor divided into two parts by the dielectric diaphragm was used in our experiments. The stainless steel electrodes were installed in the distance of 2 cm from the dielectric diaphragm (PET - the thickness of 0.25 mm) with a small pin-hole in its centre (initial diameter of 0.4 mm). The DC non-pulsed high voltage source up to 5 kV was used for the discharge ignition [5]. The electric circuit with the discharge reactor and HV source is given according to the scheme in Fig. 1.

Generation of the diaphragm discharge was investigated in water solutions containing various electrolytes. This paper presents results of the breakdown in following selected

electrolytes: NaCl, KCl, Na₃PO₄, Na₂HPO₄·12H₂O, KH₂PO₄ and NaNO₃. Solutions of alkaline metals were selected because of their very good solubility in water and only a small amount (0.02 - 1.00 g/litre) was needed for the adjustment of the definite conductivity. According to the concentration of electrolyte dissolved in deionised water, particular conductivity of the solution was adjusted in the range from 50 to 1400 μS·cm⁻¹.

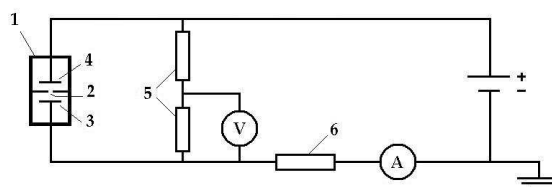


Fig. 1: Simplified scheme of experimental set-up:
 1 – discharge reactor, 2 – dielectric diaphragm with pin-hole, 3 – grounded cathode, 4 – anode,
 5 – resistances (ratio of division 1:33), 6 – source ballast resistance (5.5 kΩ).

3 Results and discussion

Initial conductivity of the solution is one of the most important parameters for the diaphragm discharge creation in liquids. When conductivity is low (until 50 μS·cm⁻¹) there are only few charge carriers in such system, the resistance is high and subsequently, current initiated by the applied electric field is too weak for the discharge creation. Moreover, the weak electric field is not sufficient for water heating necessary for bubble creation and thus the discharge can not be initiated in the gas phase. On the other hand, very high conductivity (over 1500 μS·cm⁻¹) also enables discharge ignition because the system resistance is low as well as the voltage between electrodes. Therefore a special caution should be paid to the adjustment of solution conductivity. Based on this fact, the influence of solution conductivity on the breakdown characteristics (voltage, current) of the diaphragm discharge has been investigated [6].

An example of V-A characteristics measured in water solutions containing NaCl electrolyte of various concentrations is given in Fig. 2.

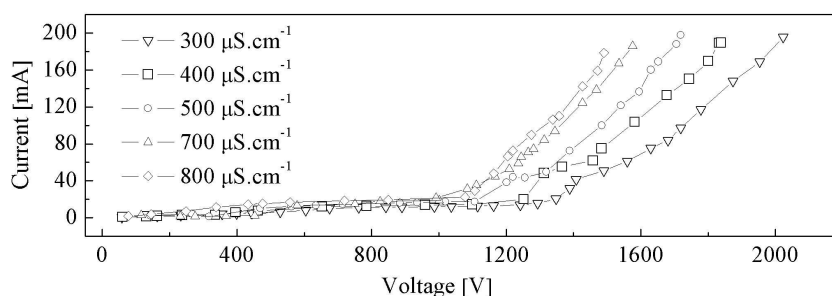


Fig. 2: Selected V-A characteristics of DC diaphragm discharge as a function of NaCl solution conductivity.

Each characteristic showed a similar evaluation of current as a function of voltage – at lower voltage, current increased only slightly. However, after the transcendence of a particular breaking point, current started to rapidly increase with the further increase of voltage. This breaking point indicated the ignition of the diaphragm discharge in the pin-hole. From the comparison in Fig. 2 it is obvious that these breaking points were highly dependent on the solution conductivity, it means the rapid increase of current related to the discharge creation started at various voltage magnitudes for different solution conductivity.

The results presented in Fig. 3 compare the breakdown phenomenon in various electrolytes according to their chemical structure. Thus it transparently shows that there was only a negligible difference in the discharge ignition in electrolytes with the same anion group. Study of breakdown voltage dependence on the initial solution conductivity showed following tendency: at a very low conductivity (until approximately $100 \mu\text{S}\cdot\text{cm}^{-1}$), significantly high voltage up to 4 kV was needed to ignite the discharge in water solutions of all studied electrolytes. With further conductivity enhancement, the breakdown voltage rapidly dropped to the value of about 1-1.5 kV only. Subsequently in the range between 200 and $1400 \mu\text{S}\cdot\text{cm}^{-1}$, it decreased only slightly or even remained constant with the conductivity increase. In general, current estimated during the discharge ignition slightly increased with the increasing solution conductivity in the studied region ($50\text{-}1400 \mu\text{S}\cdot\text{cm}^{-1}$) and no significant change in this tendency was observed, except in chloride electrolytes. In NaCl and KCl solutions, the highest studied values of solution conductivity provided a remarkable higher increase in current than at lower conductivities. This phenomenon was probably related to the reaction mechanism of chloride anions or some other effects.

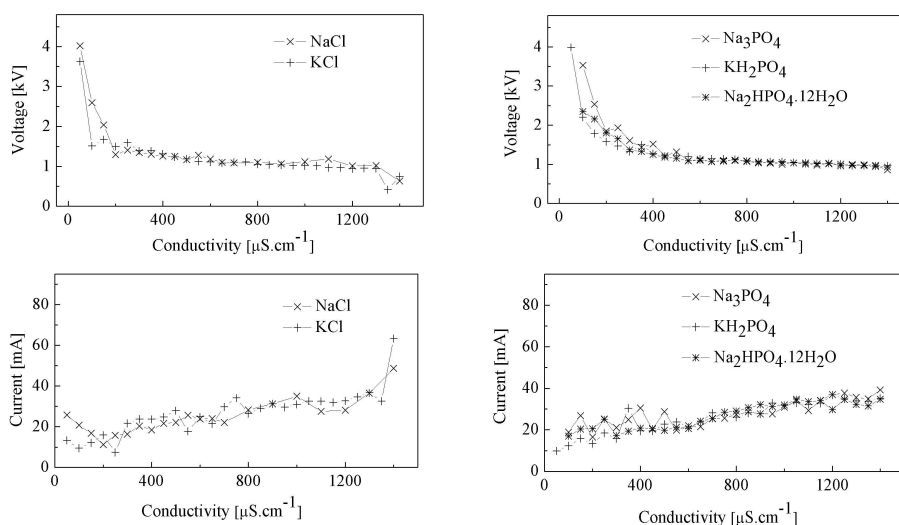


Fig. 3: Dependence of breakdown voltage and current on conductivity of the NaCl, KCl and Na_3PO_4 , KH_2PO_4 , $\text{Na}_2\text{HPO}_4\cdot 12\text{H}_2\text{O}$ solutions.

An important parameter of observed breaking point is also the corresponding discharge power. It was calculated as a product of breakdown voltage and current for each electrolyte solution. Dependence of discharge power on the solution conductivity (Fig. 4) of studied electrolytes showed that discharge power slowly increased with increasing conductivity. Unstabilities obtained at low conductivities ($50\text{-}350 \mu\text{S}\cdot\text{cm}^{-1}$) were probably given by the unstability of the discharge operation.

Obtained results demonstrated a slight difference between the discharge power enhancements caused by the increasing conductivity of electrolytes consisting of ions with different size (Fig. 4).

When smaller ions (Cl^-) were contained in the solution, discharge power increased more intensively with the increasing conductivity, probably due to the higher mobility of these anions (these ions particularly increase total current made mainly by flow of the electrons). On the other hand, presence of bigger anions (PO_4^{3-}) did not cause so significant power enhancement as a function of the increasing conductivity because such anions were much slower. However, this fact will be an object of our further studies.

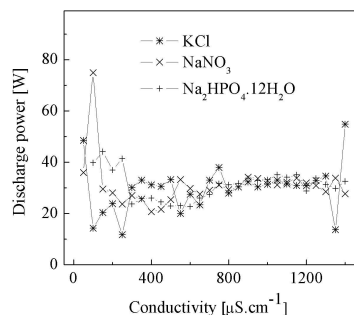


Fig. 4: Dependence of discharge power at breakdown point on conductivity of the KCl, NaNO_3 and $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ solutions.

4 Conclusion

This contribution presented results obtained from the investigation of the breakdown phenomenon during the diaphragm discharge creation in liquids using the DC non-pulsed high voltage. Electrical V-A characteristics were recorded during the measurements in selected electrolyte solutions of various initial conductivity and subsequently, the breakdown magnitudes of voltage and current were estimated for each experimental condition. In general, the breakdown voltage laid in the region of 1100-1300 V and its magnitude slightly decreased with the increasing solution conductivity in the main studied region from 100 to 1400 $\mu\text{S}\cdot\text{cm}^{-1}$. Until 50 $\mu\text{S}\cdot\text{cm}^{-1}$, the observed drop of breakdown voltage was much intensive (from 4 to the average 1 kV). Breakdown voltage was also independent on the kind of used electrolyte in the solution, probably from the viewpoint of its chemical structure, influenced mainly by ion size. Breakdown current was determined about 20-50 mA. Its magnitude slightly increased with the increasing solution conductivity. Also discharge power related to the breakdown point increased very slightly with the increasing solution conductivity. This increase was influenced by the used electrolyte kind, especially according to the anion size.

Acknowledgements

This work was supported by the Czech Science Foundation, contracts No. 202/03/H162 and 202/07/P371.

References

- [1] P. Lukes, Water treatment by pulsed streamer corona discharge, Ph.D. Thesis, Institute of Plasma Physics AS CR, Prague 2001.
- [2] B. Sun, M. Sato, J.S. Clements: *J. Electrostatics* **39** (3), 189 (1997).
- [3] M. Monte, F. De Baerdemaeker, C. Leys, A.I. Maximov, *Czech. J. Phys.* **52**, D724 (2002).
- [4] F. De Baerdemaeker, Capillary discharges in electrically conductive aqueous solutions, Ph.D. Thesis, Ghent 2007.
- [5] Z. Stara, Study of chemical processes in electrical discharges in liquids, Ph.D. Thesis, Brno 2006.
- [6] J. Prochazkova, Z. Stara, F. Krcma, *Proc. 16th Symp. App. Plasma Processes*, 292 (2007).