

# Breakdown of DC diaphragm discharge in solutions of alkaline metals

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**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 ( $50\text{-}1400\ \mu\text{S}\cdot\text{cm}^{-1}$ ) independently on the electrolyte kind, the recorded breakdown current was 20-50 mA.

**Keywords:** discharge ignition, breakdown voltage and current, alkaline metals.

## 1. Introduction

The 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, 3]. Further the coaxial, diaphragm or capillary configurations have been already studied [4-7]. This contribution is focused on the generation of the diaphragm discharge by the application of the DC non-pulsed high voltage.

Diaphragm discharge is created in the vicinity of 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 [7].

## 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 discharge was created in the pin-hole of the diaphragm using the DC high voltage source which gave the non-pulsed voltage up to 5 kV [8, 9]. Due to

the dual character of the diaphragm discharge, two kinds of plasma streamers were propagated on each side of the diaphragm – longer „positive“ streamers on the side with the cathode and shorter „negative“ ones on the opposite side with the anode [5].

The electric circuit with the discharge reactor and HV source is given according to the scheme in Fig. 1.

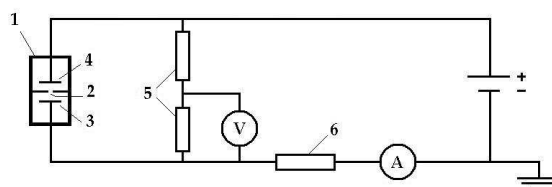


Fig. 1: Simplified scheme of experimental set-up: 1 – discharge reactor, 2 – dielectric diaphragm with pin-hole, 3 – grounded cathode, 4 – anode, 5 – resistances (ratio of division 1:33), 6 – source ballast resistance ( $5.5\ \text{k}\Omega$ ).

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,  $\text{Na}_3\text{PO}_4$ ,  $\text{Na}_2\text{HPO}_4\cdot 12\text{H}_2\text{O}$ ,  $\text{KH}_2\text{PO}_4$  and  $\text{NaNO}_3$ . Solutions of alkaline metals were selected because their advantage was 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  $1400\ \mu\text{S}\cdot\text{cm}^{-1}$ .

## 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  $50\ \mu\text{S}\cdot\text{cm}^{-1}$ ) 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  $1500 \mu\text{S}\cdot\text{cm}^{-1}$ ) 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 [10].

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

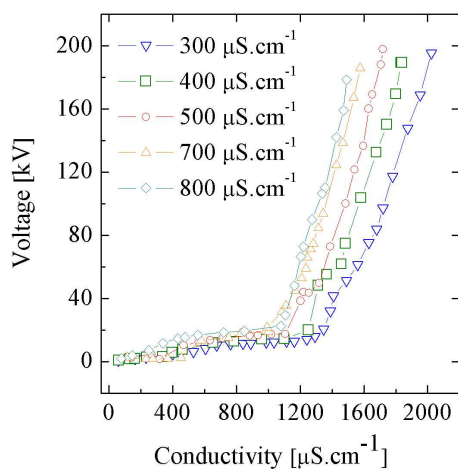


Fig. 2: Selected V-A characteristics of DC diaphragm discharge breakdown as a function of NaCl solution conductivity.

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 Figs. 3 and 4 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 (among chlorides – Fig. 3 – and phosphates – Fig. 4).

Study of 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.

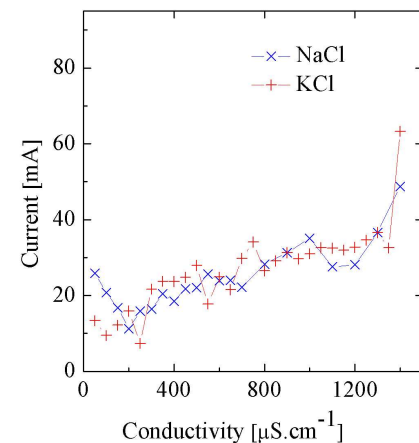
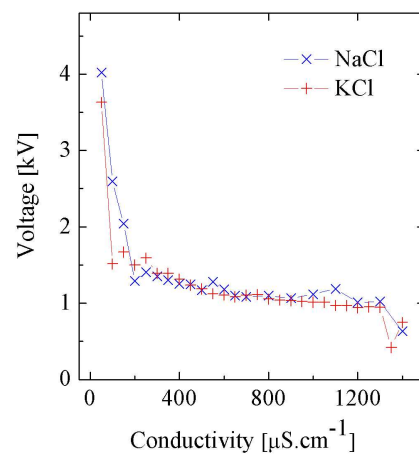


Fig. 3: Dependence of breakdown voltage (up) and current (down) on conductivity of the NaCl and KCl solutions.

Dependence of breakdown current on conductivity of phosphate solutions (Fig. 4 down) revealed some abnormal behaviour at lower conductivity, especially in the  $\text{Na}_3\text{PO}_4$  solutions. We do not have any sufficient explanation for this effect yet.

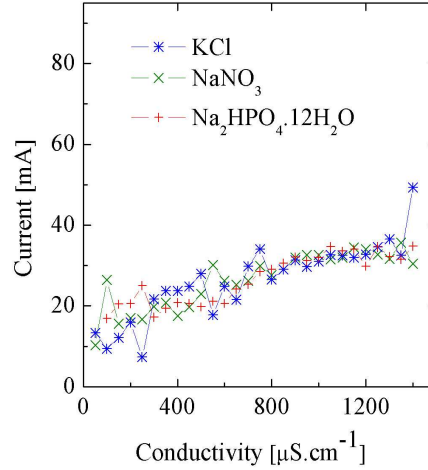
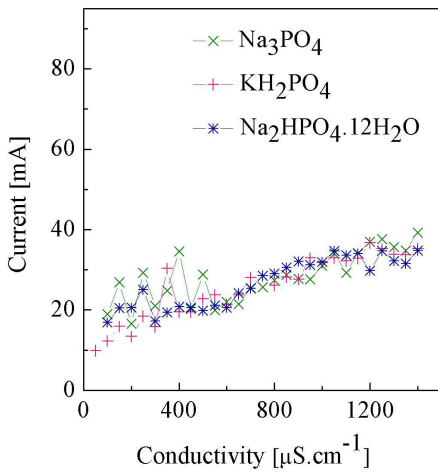
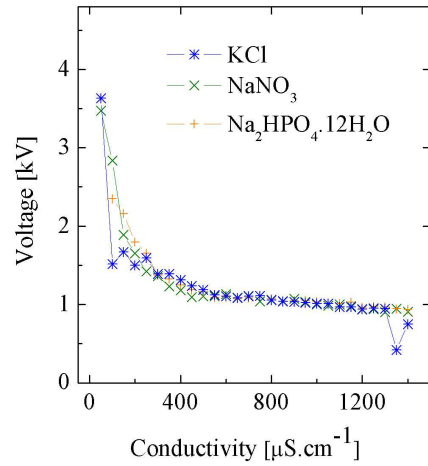
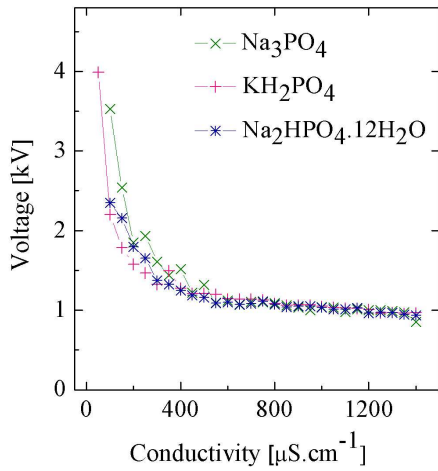


Fig. 4: Dependence of breakdown voltage (up) and current (down) on conductivity  $\text{Na}_3\text{PO}_4$ ,  $\text{KH}_2\text{PO}_4$  and  $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$  solutions.

Fig. 5: Dependence of breakdown voltage (up) and current (down) on conductivity of the  $\text{KCl}$ ,  $\text{NaNO}_3$  and  $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$  solutions.

Comparison of the discharge ignition in electrolytes with different anion group (between nitrate, chloride and phosphates) shows also different breaking conditions. In chloride solutions (Fig. 3 up), the region of slow voltage decrease started already at about  $100 \mu\text{S}\cdot\text{cm}^{-1}$ , however, in phosphate solutions until about  $400 \mu\text{S}\cdot\text{cm}^{-1}$  (Fig. 4 up).

Next figures (Figs. 5, 6) compare dependences of breakdown current, voltage and discharge power on solution conductivity of selected electrolytes with different anion group ( $\text{KCl}$ ,  $\text{NaNO}_3$  and  $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ ). In the case of breakdown voltage, we can see that all characteristics have a similar character: voltage is decreasing with the increasing solution conductivity. But it differs in the point where the fast voltage drop transcended to the slow voltage decrease with the increasing conductivity.

No significantly differences were observed in current characteristics. The breakdown current was increasing with the increasing conductivity.

The important parameter of observed breaking point is 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. 6) 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 instability of the discharge operation.

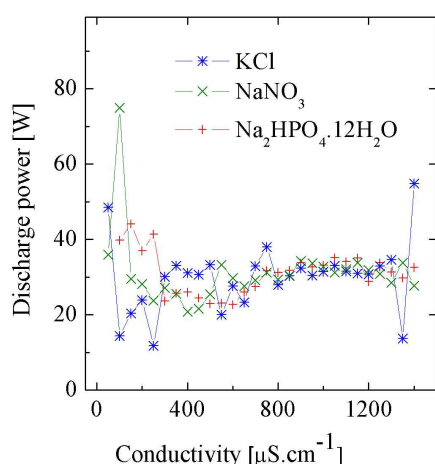


Fig. 6: Dependence of discharge power at breakdown point on conductivity of the KCl,  $\text{NaNO}_3$  and  $\text{Na}_2\text{HPO}_4\cdot 12\text{H}_2\text{O}$  solutions.

Obtained results demonstrate a slight difference between the discharge power enhancements caused by the increasing conductivity of electrolytes consisting of ions with different size (Fig. 6). When smaller ions ( $\text{Cl}^-$ ) are contained in the solution, discharge power increases more intensively with the increasing conductivity, probably due to the higher mobility of these anions (higher mobility stimulates discharge current). On the other hand, presence of bigger anions ( $\text{PO}_4^{3-}$ ) does not cause so significant power enhancement as a function of the increasing conductivity because such anions are much slower. However, this fact will be an object of our further studies.

#### 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 dependent 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 corresponding to the breakdown point increased

with the increasing solution conductivity. This increase was influenced by the used electrolyte kind, especially according to the anion size. The breaking power values varied from approximately 20 to 60 W.

#### Acknowledgements

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#### 5. References

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