

Comparison of discharge power in dielectric barrier discharge (DBD) with stainless steel and KCl liquid electrode

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Abstract. A Dielectric Barrier Discharge (DBD) device is developed to generate cold atmospheric plasma. Two different materials used as a top electrode: stainless steel and KCl liquid are considered. The bottom electrode is stainless steel for both cases. The gap of this DBD can be varied up to 3 mm. The DBD is powered by an AC high voltage in the range of ± 10 kV with frequency in a range of 2-7 kHz. It is found that the discharge with KCl liquid electrode yield higher power than that with stainless steel electrode.

1. Introduction

Dielectric barrier discharge (DBD) device is a typical non-equilibrium plasma device that can be operated at atmospheric pressure [1]. A typical DBD consists of two electrodes and, at least one dielectric barrier in between. The dielectric barrier limits charge transported in the discharge. To generate plasma, an AC high voltage is applied such that the applied voltage is greater than breakdown voltage of the medium gas. There have been many studies about effects involved parameters such as electrode structure, frequency, applied voltage, gas gap, gas types etc. These parameters can affect electrical characterization of DBD. Okazaki et al. [2] worked with different gases including helium, neon, argon, nitrogen, oxygen and air at atmospheric pressure, in which different performances were observed. Fang et al. [3] studied DBD using metal wire mesh electrodes in nitrogen, Ar, air in which similar results were obtained. Rahel et al. [4] studied DBD using two water electrodes separated by two 1 mm thick Pyrex sheets of glass in air. Wang et al. [5] various studied the different electrode of DBD in atmospheric pressure. Titov et al. [6] studied physical characteristics of atmospheric pressure dc discharge with liquid electrode by using distilled water and aqueous solution (KCl, CuCl₂, FeSO₄). Fuangfung et al. [7] studied different types of electrode by using KCl liquid electrode in atmospheric pressure for waste water treatment. The DBD have applications for the industry. Xu [8] studied applications of DBD such as excimer radiation sources, UV/VUV lamps, ozone generators and their applications in pollution control.

In this paper, the comparison of discharge characteristics of DBD in atmospheric pressure air with two different structure electrodes: stainless steel electrode and KCl liquid electrodes is reported. The electrical measurements are used to characterize the discharges.

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2. Experimental setup

A schematic diagram of the experimental setup in this work is shown in figure 1. This DBD system can be used for generating plasma in atmospheric pressure. The discharges are created between two parallel electrodes. Two different materials are used as the top electrode: stainless steel 304 electrodes and liquid electrodes in a Petri dish. The bottom electrode, used-for both cases, is stainless steel with a dimension of 110 mm diameter and 3 mm thickness. The liquid electrode in this work is potassium chloride (KCl) solution with a concentration of 0.2g/150ml. In other case, the top electrode is made of stainless steel 304 with the same dimension as the bottom electrode. All the electrodes are covered by glass plates with a thickness of 3 mm. The discharge gas gap can be adjusted in the range of 1-3 mm. The AC high voltage was applied in a range of ± 10 kV with frequency in a range of 2-7 kHz. Note that, for a fixed gap, when the frequency changes, the applied voltage will change too. A capacitor of 470 nF, connected between bottom electrode and ground, are used for measuring the accumulated charge on the dielectric plate. The measured signals are recorded by an oscilloscope RIGAL DS1052E. Figure 2 shows typical plasma occurred during the discharge. Figure 2(a) shows the side view of the plasma and figure 2(b) shows the top view of the plasma.

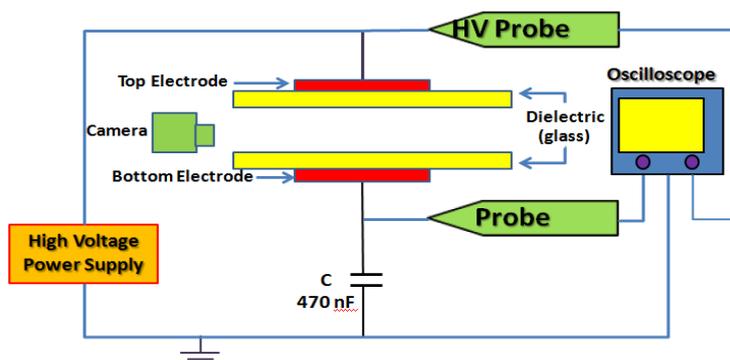


Figure 1. Schematic diagram of DBD.

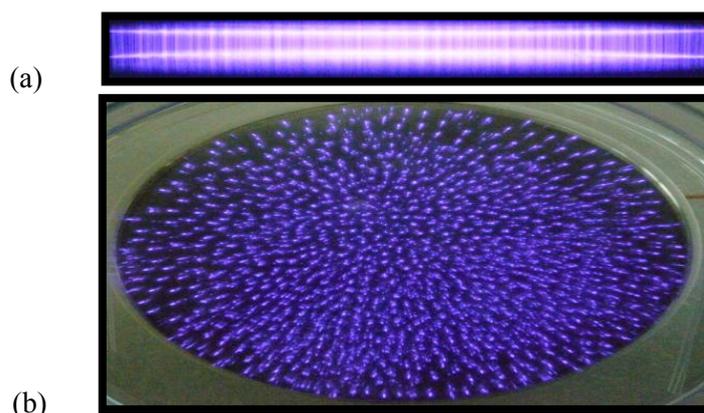


Figure 2. Plasma discharge (a) side view
(b) top view when using KCL electrode.

3. Results and discussions

The discharge power of the DBD can be determined by using a high voltage probe measuring voltage across the top and bottom electrodes and the charge transferred (Q) across them. The charge transferred can be calculated from the voltage across the 470 nF capacitor and its capacitance. The plots of Q - V diagram, called the Lissajous diagram, as shown in figure 3 can be used for determining the discharge

power (P) of the DBD, which is the enclosed area in Q - V Lissajous diagram. However, in this experiment, there are streamers, micro filaments or micro arc discharges occurred in each of the discharges, resulting in a distortion of data. Streamers discharge is a type of electrical discharges which can form when there is a voltage difference. A computational method is used to process the experimental data by using sinusoidal wave function $y = A\sin(\omega t + \phi)$ to fit the experimental data. The fit curves are shown as the solid lines in figure 3.

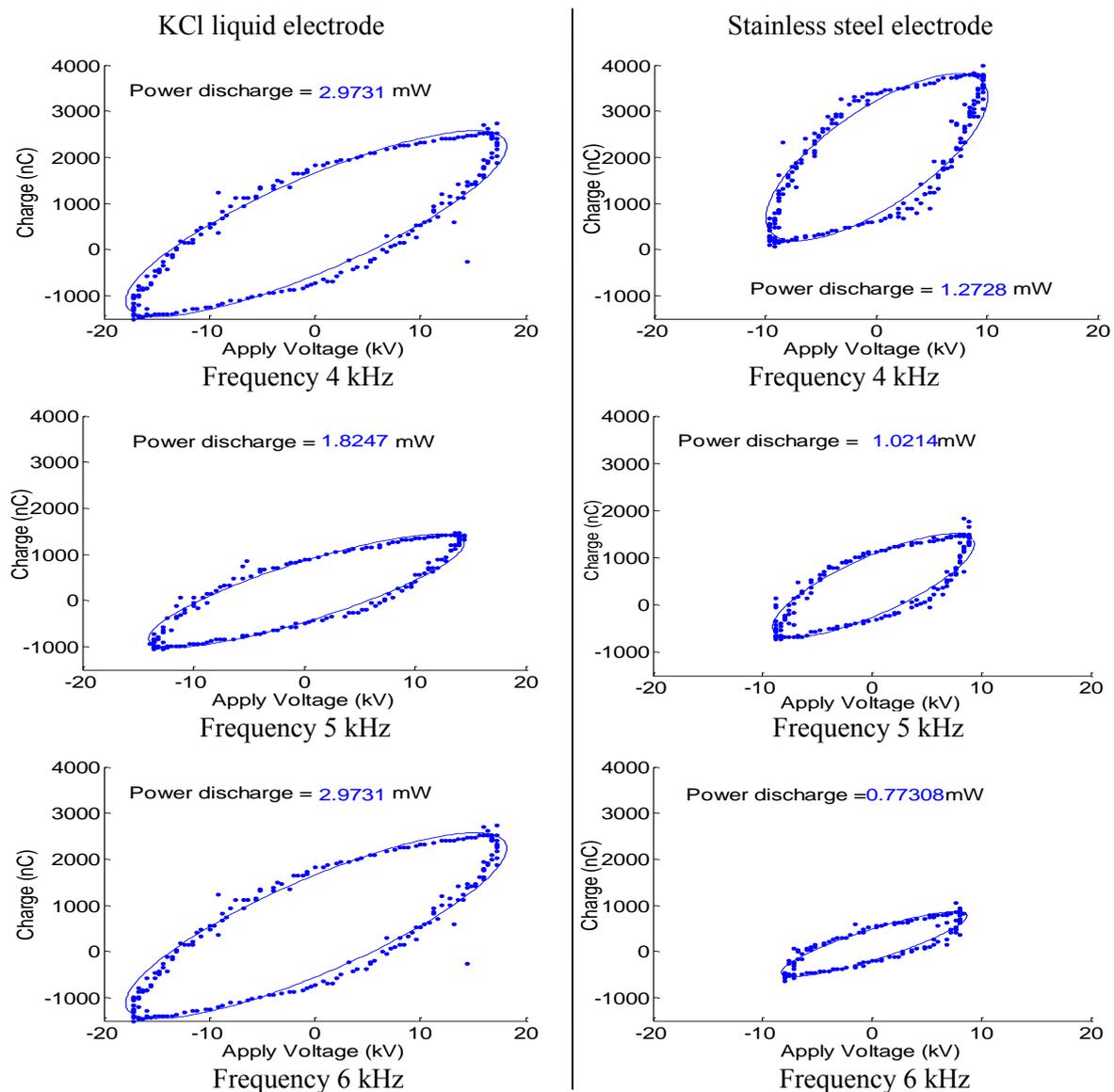


Figure 3. Q - V Lissajous of the DBD with a liquid electrode (left) and a stainless electrode (right) at the frequency of 4-6 kHz.

The discharge power in the DBD plasma can be calculated by dividing the energy discharge with the period. The energy discharge can be calculated from the Q - V area plot, which is the power from the discharge of one cycle. Discharge power can be calculated from equation (1).

$$P = \frac{W}{T}, \quad (1)$$

where P is the discharge power, W is the energy from the discharge, and T is the period of one cycle of discharge energy.

The energy from the discharge can be calculated from

$$W = \int_{t_0 - T/2}^{t_0 + T/2} v(t) \cdot i(t) dt, \quad (2)$$

where T is the period, $i(t)$ is the current caused by the discharge, and $v(t)$ is the voltage applied.

The current can be calculated from the voltage drop across the capacitor (v_c) and the current time changes as shown in equation (3).

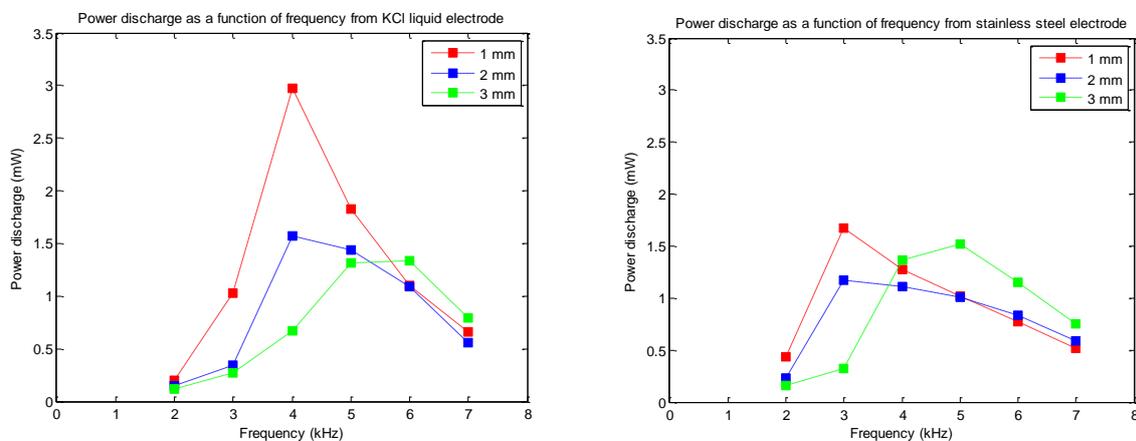
$$i(t) = \frac{dq}{dt} = C \frac{dv_c}{dt}, \quad (3)$$

when q is the amount of charge generated by the discharge, C is the capacitance of the connected capacitor.

Hence, the energy from the discharge of one cycle can be calculated from equation (4).

$$W = \int_{t_0 - T/2}^{t_0 + T/2} v(t) \cdot C dv_c = \int_{t_0 - T/2}^{t_0 + T/2} v(t) \cdot dq(t) \quad (4)$$

Moreover, in this work, the discharge power is measured at various gap distances, in the range of 1-3 mm. The AC high voltage is applied by varying the frequency in the range of 2-7 kHz to operate the plasma discharge. Note that, when the frequency changes, the applied voltage will change. In the case of KCl liquid electrode, the discharge power peaks at frequency 4 kHz for 1 mm and 2 mm gap and at 5-6 kHz for 3 mm gap. In the case of stainless steel electrode, the discharge power peaks at 3 kHz for 1 mm and 2 mm gap, and at 5 kHz for 3 mm gap. These findings could be due to different resonance frequency of each material. In addition, it is found that when expanding the gap, the discharge power is decreasing. However, the stainless steel electrode yields higher discharge power than the KCl liquid electrode in the frequency range of 2-3 kHz. In the frequency range of 4-7 kHz the discharge power from the KCl electrode are higher than those from the stainless steel electrode. The results are shown in figure 4.



(a) KCl liquid electrode (b) Stainless steel electrode
Figure 4. Discharge power as a function of frequency for two types of electrodes.

4. Summary

A cold plasma generated by DBD at atmospheric pressure using high voltage in the range ± 10 kV and frequency 2-7 kHz from two different electrode structures, stainless steel electrode and liquid electrode, is achieved. The discharge power of these two different electrodes are obtained and compared with each other. In most cases, it is found that the discharge power using a KCl liquid electrode with a stainless steel electrode are higher than those using stainless steel electrode.

Acknowledgments

This project is supported by the annual government research budget through Thammasat University. The authors would like to thank Assoc. Prof. Manu Fuangfung of Thammasat University and Mr. Arlee Tamman of Walailuk University for useful comments and helpful suggestions.

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