Characterization of electrical property and ion mobility in positive corona and dielectric barrier discharge with point to plane configuration

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Abstract. Atmospheric non-thermal plasma has been widely used. The aims of this research are to characterize electrical properties and charge carrier mobility of corona discharge and dielectric barrier discharge (DBD) plasma reactor with multiple points to plane configuration. Plasma was generated by DC high voltage and a 2 mm glass plate used as dielectric barrier covers passive electrode surface. Plasma current and voltage were measured using an analog multimeter and oscilloscope. Charge carrier mobility was calculated using Sigmond’s unipolar saturation current modified with multiple points to plane approach. Experiment result showed that electric current is proportional to squared voltage, in accordance to unipolar saturation current. Charge carrier mobilities obtained for corona and DBD were in range of 1.66 – 7.18 cm²/V.s and 0.331 – 0.848 cm²/V.s, respectively. Charge carrier mobility in DBD reactor increases with increasing distance between electrodes. Maximum charge carrier mobility in corona discharge was obtained at a distance of 1 cm, while in DBD at 4 cm.

1. Introduction
Atmospheric pressure nonthermal plasma have been widely used in practice, e.g., in biomedical [1], sterilization [2], and surface modification [3]. It is usually generated using corona discharge and dielectric barrier discharge (DBD). Low initial voltage DBD can be obtained by modification electrode geometry. Generally, we used asymmetric electrodes such as plane-parallel or coaxial geometries. Compared with plane-parallel or coaxial geometries, the use of multipoint-to-plane geometry has several advantages, such as low operating voltage and low dielectric loss [4]. Study of electrical properties of plasma using a DBD reactor with multipoint-to-plane geometry had been done [5]. This study examines the effect on the presence of a dielectric barrier on the current characteristics against the applied voltage in the positive multi-point plasma corona reactor configuration and the value of its charge carrier mobility.

2. Methods
In this experiment, we used multipoint to plane electrode configuration reactor. The multipoint electrode consists of 64 stainless steel-pointy needles with 2 cm interneedle distance. The plane electrode was 25 cm diameter-stainless steel plate. The multipoint electrode was given positive
polarity (anode), while the plane electrode was given negative polarity (cathode) of the power supply. The interelectrode gap was varied within range \( d = 1-4 \) cm. We used 30x30x0.2 cm soda-lime glass with dielectric constant 4.1 \( \varepsilon_r \) as a dielectric barrier.

Plasma was generated using a high-voltage DC source (0-10) kV with observed current values of each increase of 0.2 kV. The electric current in the circuit was measured using a multimeter (Sanwa Japan YX360TRF), while the voltage generated from a high DC voltage source (HV) is measured using an oscilloscope (INSTEK oscilloscope GOS-620) connected to a high voltage probe (HV Probe, DC max Voltage DC 40 kV, AC 28kV code number EC 1010, EnG1010, Made in Taiwan) to convert the voltage from the kilo order to the volts so that the output voltage can be read by the oscilloscope. This study was conducted at atmospheric pressure with room temperature (28–31) °C. The schematic of the apparatus used in this study is shown in Figure 1.

The characteristics of electric current (I) to voltage (V) are observed without (corona) and with the addition of glass (DBD). In this experiment, current measurements begin from a voltage of 0 kV until before the corona incandescent discharges occur. The value of mobility can be calculated using equations (1).

\[
I_S = \frac{2\mu eN}{d} V^2
\]

with

\[
\varepsilon = \varepsilon_0 \varepsilon_r
\]

Where \( I_S \) is unipolar ion saturation current (A), \( V \) is corona voltage (V), \( \mu \) is unipolar ion mobility \( (m^2/V.s) \), \( \varepsilon_0 \) is permittivity of the vacuum \( (8.85\times10^{-12} F/m) \), \( d \) is the interelectrode distance (m), and the values of \( \sqrt{I/V} \) are obtained from the slope value of the \( \sqrt{I} - V \) graph. Positive ion currents in the corona are positively charged ions.

The dielectric materials of relative permittivity are \( \varepsilon_{r1} \) for the first material and \( \varepsilon_{r2} \) for the second material, then the total dielectric permittivity for two materials follows equation (3).

\[
\frac{1}{\varepsilon_{rt}} = \frac{1}{\varepsilon_{r1}} + \frac{1}{\varepsilon_{r2}}
\]

\[ \text{Figure 1. A schematic of the experimental apparatus.} \]
3. Results and Discussion

3.1. Current-Voltage Characteristics

The presence of plasma can be characterized by noise, typical ozone odor and photon emission around the active electrode. However, in this study, there is no visible photon emission from the air because it is still located in the Townsend area which is a dark discharge. The rise in applied voltage causes a non-linear current-voltage relationship. The electrical properties of the positive corona discharge plasma can be presented through the I-V graph of Figure 2 and DBD in Figure 3 shows the magnitude of the corona current proportional to the square of the voltage \((I-V^2)\) corresponding to the unipolar saturation current equation (equation 1). The above graphical shape is similar to the typical current-voltage characteristic for corona discharge. At the same voltage, the greater the distance between the electrodes, the smaller the resulting current. This is influenced by the distance between the electrodes and the relative permittivity of the dielectric material. The wide gap space creates a weaker electric field, so the resulting corona flow is smaller.

![Figure 2](image2.png)

**Figure 2.** I-V Characteristics of corona discharge with multipoint-to-plane configuration.

![Figure 3](image3.png)

**Figure 3.** I-V Characteristics of DBD with multipoint-to-plane configuration.
3.2. The Mobility of Charge Carriers

The mobility of charge carriers in plasma is the rate of flow of charged particles under the influence of electric fields and is written in cm$^2 / \text{V.s}$. The air component consists of 80% Nitrogen and 16% Oxygen. The N$_2^+$ ion is formed during the normal (positive) polarity corona, the low energy electron is then captured by O$_2$ in the form of O$_2^-$ during the negative polarity corona and creates a charge in the ionization region. In normal polarity corona processes under atmospheric pressure, N$_2^+$ ions collide with gas molecules and give rise to a series of ionization reactions [7].

![Figure 4](image_url)

**Figure 4.** Correlation of current-to-square root of voltage for corona discharge and DBD at d = 1cm.

Figure 4. shows the correlation of the root square of electric current of the corona as a function of the voltage at 1 cm gap. The linear fitting is resulting in a slope value of 9.02×10$^{-6}$ A$^{1/2}$/V for corona discharge and 1.74×10$^{-6}$ A$^{1/2}$/V for DBD. The value of tan $\alpha_1$ will always be greater than tan $\alpha_2$ for each voltage variation because the current produced by the corona is greater than the DBD. From the graph above, the corona and DBD mobility values were 7.18 cm$^2$/V.s and 0.331 cm$^2$/V.s. Then the graph of charge carrier mobility as a function of the distance between electrodes for corona discharge in Figure 5. and DBD in Figure 6.
Figure 5. Charge carrier mobility on corona discharge of each variation of the interelectrode distance.

The results of charge carrier mobility in corona discharges by Utami’s research [5] in 2016 using the same electrode configuration where the greater the inter-electrode distance, the smaller the plasma charge carrier mobility.

Figure 6. Charge carrier mobility on DBD of each variation of the interelectrode distance.

The average mobility value of air-load carriers in the air for corona is (1.66 - 7.18) cm²/V.s, whereas for DBD (0.331 – 0.848) cm²/V.s. Decreased mobility can be affected by electric field
strength between electrodes. The weak electric field makes the least charge resulting from the collision reaction between atoms or ions with charged particles or atoms or ions with atoms or ions. But an anomaly occurs in DBD here, where the carrier mobility increases with the increase of the distance between electrodes. This anomaly can be caused by the incidence of electric dipoles on the glass and the presence of defects in the glass after being bombarded with ions.

4. Conclusion
The voltage-current characterization of the multi-point reactor for the corona and DBD is proportional to the unipolar saturation current (I_s-V^2) equation. The electric current generated in corona discharge is greater than DBD, and it depends on the distance between electrodes. The farther the distance between the electrodes, the smaller the resulting current. The average value of mobility in the air for corona discharge is 1.66 - 7.18 cm^2/V.s, whereas for DBD is 0.331 – 0.848 cm^2/V.s. The highest mobility value of corona is 7.18 cm^2/V.s at d = 1 cm, while for DBD is 0.848 cm^2/V.s at d = 4 cm.

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