Experimental research on spectral intensity of needle-plate corona discharge

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Abstract. A needle-plate corona discharge is investigated at atmospheric pressure in air. The current-voltage characteristics are measured in three kinds of needle-plate gaps. The corona discharge process is analyzed to obtain the relationship between the needle-plate gap and discharge current. The corona discharge emission spectrum is given through collecting emission light signal from the discharge area of needle-plate corona by emission spectroscopy. The spectral intensity of $N_2 (C^3Π_u → B^3Π_g)$ of 337.1 nm spectrum line is studied with varying the discharging voltage. By measuring the spot size of light emission, the relationship is discussed between the thickness of corona layer and voltage. The spectral intensity dependence on the voltage approximately shows a linear relationship. Spectral intensities in different positions are compared by analyzing the grey value of the discharge image. It shows that spectral intensity turns stronger and the stability of the grey value is greater under the same voltage with decreasing the distance from the needle tip.

1. Introduction
In recent years, the atmospheric pollution caused by energy utilization attracted much concerns. At the same time, particulate matter and gaseous pollutants (Sulfur dioxide and nitrogen oxides) have become the most important atmospheric environment pollution sources in China. The high energy electron and many active particles can be produced by the process of needle-plate corona discharge, which can oxidize the gaseous pollutants molecules and convert them into acid mist or aerosol particles. Then, the atmospheric pollution was controlled by collecting the poisonous gas. The needle-plate corona discharge has attracted considerable attention because of its low dynamic and high removal rate. It is widely used for elimination of the atmospheric pollutants. Although a lot of research has been studied on the needle-plate corona discharge, these works are mainly focused on the mechanism analysis, numerical simulation and influencing factors [1-3]. Up to now, few works has been done on the research of the thickness of corona layer and spectral intensity in different positions. Spectral intensity is related to electronic density. The thickness of corona layer and electronic density produced by corona discharge are the main influence on pollutant removal efficiency. In this paper, a self-made needle-plate discharge device is used to generate corona discharge in the atmosphere. The needle-plate corona discharge process and current-voltage characters curve are analyzed. Through the method of emission spectrum and reading the discharge image grey value data, the study is performed, which

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contains the relations among the voltage, the electron density and thickness of corona in different position of the corona.

2. Experimental set-up
The experimental set-up is shown schematically in figure 1. It is done at atmosphere pressure. A needle with 0.1 mm curvature radius of needle tip is used as the cathode electrode, which connects to the negative high voltage DC power with 0~60 kV continuous adjustable. A rotundity copper plate with 65 mm diameter connecting to ground is used as anode. The microamps current value is measured in different voltages and needle-plate gaps. A camera is used to record the discharge images. Photoshop is used to measure dimension and gray level of spot of light-emitting photos, and get the thickness of corona layer and spectral intensity of corona luminous area. Grating spectrometer is used to get spectrum of the corona.

3. Results and discussions
In the experiment, the current-voltage characters curve is measured at 2cm, 3cm, 4cm needle-plate gap, respectively, as shown in figure 2.

The current-voltage curve of negative corona discharge is analyzed which is under the condition of 3 cm needle-plate gap. When the voltage increases from zero gradually, the silent non-self-sustaining dark discharge will firstly occur. The current is very weak under this voltage, and its intensity depends on the space remaining amount of ionization. As shown in figure 3. The plate current appears at 7 kV firstly. When the voltage is added to 8 kV, the supply current will appear. The plate current is greater than the supply current at the same voltage. Townsend electron avalanche theory can give some explanations. When an electrons run from cathode to the anode, they will ordinal collide with gas...
atomic. Then it leads to electronics grow with avalanche, and much more electrons reach the plate. When the voltage increases to 7.4 kV, corona discharge began. That voltage is called onset voltage, accompany with a sudden increase of current between the electrodes (from $10^{-14}$ to $10^{-6}$A) and in a smaller radius of curvature of the electrode appeared the hazy glow. Adamiak [4] studies current-voltage characteristics of the needle-plate corona discharge, getting a needle-plate corona discharge current-voltage relation for, $I=AK\varepsilon(U-U_0)^{d-1}$, $K$ for ion migration rate, $\varepsilon$ for gas dielectric constant; $U_0$ for onset voltage; $d$ for electrode gap. According to the literature [5], onset voltage can be estimated through the I-U curve-fitting. This paper adopts straight-line fitting onset voltage of needle-plate corona discharge, and get theoretical onset voltage is 5.04 kV. After onset voltage, when the voltage is 8 kV, the supply current greater than the plate current 1.7 $\mu$A, then the two currents approach. When the voltage is 17 kV, the two currents are equal. This is because space charge effect is around the needle electrode, which hindered the electronic transfer to the anode, leading to two current gradually closed. With the increase of voltage, the supply current is greater than the plate current gradually. There are three main reasons. First, with the increase of the voltage, a large number of neutral air molecules to accumulate before the board, high-speed movement of electrons can not directly reach the plate, due to the blocking of the plate electrode. Second, with the increase of electronic near the plate, electronic exclusive each other, so part of the electrons can not reach the plate. Third, the movement of ions caused a strong ion wind in the discharge space [6], so the movement of electrons by the ion wind generated disturbance. When the applied voltage is much higher than the onset voltage, corona discharge will be transformed into spark discharge.

The relations between corona voltage and needle-plate gap is also investigated. The corona onset voltage increases with increasing the gap of the needle-plate. When the needle-plate gap is 2 cm, the onset voltage is 6.2 kV. When the needle-plate gap is 4 cm, the onset voltage is 8.7 kV. It is because the needle-plate gap increases, the electric field between the electrodes become weak, which weaken the positive and negative ions or electrons, positive ions compound and energy level transition caused by electronic collision of air molecules, and electronic avalanche growth. Figure 2 shows that the discharge current increases with the increase of voltage, and the current difference also increased gradually with different needle-plate gap.

Figure 4 shows a spectrum of the needle-plate corona discharge. The spectral analysis proves that there is a strong ionization and inspire in corona luminous layer. Cathode surface exist the positive ion secondary electron emission, optical emission and the secondary emission caused by metastable atoms. Around high-voltage needle electrode, the main spectral intensity is second positive system of $N_2$. According to the literature [7], the second positive system of $N_2(C^1\Pi_u\rightarrow B^3\Pi_g)$ spectral distribution is: $\Delta v=+2,297.7 \text{ nm}$; $\Delta v=+1,315.9 \text{ nm}$; $\Delta v=0,337.1 \text{ nm}$; $\Delta v=-1,357.7 \text{ nm}$; $\Delta v=-2,380.5 \text{ nm}$; $\Delta v=-3,405.9 \text{ nm}$; $\Delta v=-4,343.4 \text{ nm}$. The experiment results are consistent with it.

Microscopically speaking, filamentous streamer is not continuous on the time distribution in DC corona discharge. There is a time interval between two adjacent streamers. Streamer frontier is the enrichment of the high energy electron. However, from the macroscopic viewpoint, DC corona discharge is a continuous discharge. DC corona discharge is a continuous process, formation and demise of $N_2(C^1\Pi_u)$ will reach a balance if the corona is stable. The experiment found that the spectral intensity of 337.1 nm have a certain fluctuation in fixed voltage and needle-plate gap. In this paper, we scanned wavelength with 337.1 nm in the time scale of 20 s. Through calculation the average of data, the spectrum line strength is obtained. The relationship between electronic density and voltage is shown in figure 5. Results show that the spectral intensity increases linearly with the rising of voltage approximately.
Transition of strong electric field in corona layer to weak in periphery is not a mutation, but a gradual change. So space ionization and excitation change from strong to weak is a gradual transition [8]. Figure 6 shows light-emitting photo of needle-plate corona discharge. After onset of the discharge, the images of discharge are recorded by taking photos of the corona discharge in needle electrode. We select luminous images of grey value 5 as the corona area and peripheral area boundaries. The length of needle direction light is the standard of the thickness of corona layer. The experiment measured the thickness of corona layer diagram at different needle-plate gaps and voltages. Figure 7 shows the relationship between thickness of corona layer and voltage.

When the voltage between the poles gradually increasing from zero, electronic move slowly and direction relatively scattered, which caused it can not inspire air particles and produce radiative transition in the process of electron moving to the grounding plate. So we don’t observe corona light around the needle electrode. After onset voltage, light of corona discharge appears around the needle electrode, with the rapid thickness of corona layer growth. The spontaneous radiation transition of stimulate particles is the cause of corona layer light-emitting. If continue to increase the voltage, the current and electric field strength will increase, with increase of the charged particle velocity. It enhances collision particle energy, the impact ionization rapid development. At the same time, the process of electronic and positive ions, positive ions and anion composition reinforced. And more non-steady-state particle transit to the ground state or lower energy state, so that radiation photon number
was increase significantly, with the increase of the thickness and brightness of corona layer. It is shown that in a stable of corona discharge. When thicknesses of corona layer attain and maintain the flat part with little change. With the increase of needle-plate gap, the stable area is obviously, the corresponding to external voltage range get big. In stable area, the thickness of corona layer is close to each other in different needle-plate gap. With the voltage rising continuously, the thickness of corona discharge development from flat rise, which is shown that corona discharge transit to the pre-breakdown streamer. From figure we can observe that, along with the increase of voltage and reduce of needle-plate gap, the thickness of corona layer is increased obviously.

![Figure 7](image7.png)  
**Figure 7.** The relationship between thickness of corona layer and voltage at different needle-plate gap.

![Figure 8](image8.png)  
**Figure 8.** The relationship between gray level and voltage in different positions.

The change of space ionization and excitation from strong to weak is a gradual transition. So we can get the spectral intensity in different positions by reading the corona luminous gray value of the photos in different locations at 3 cm needle-plate gap. Figure 8 shows the relationship between gray level and voltage in different position. The light-emitting photo data is consistent with measurement of spectral intensity. So reading light-emitting photo data instead of spectral intensity in different corona area position is feasible. The figure shows that in the same voltage, the closer from the needle tip, the bigger of spectral intensity and the greater stability of the value. The farther away from the tip, the smaller of spectral intensity, and the higher of fluctuating value. Results show that spectral intensity with the growth of the voltage is close to a relation with linear strengthen.

4. Conclusion

a) The corona onset voltage increases with increasing the gap of the needle-plate. With the increase of voltage, discharge current increases, and with different needle-plate gap the current difference also increased gradually.

b) Around High-voltage needle electrode, the main spectral intensity is second positive system of \(N_2\). The thickness of corona layer grows rapidly after onset voltage. And then there will be a stable region. When the voltage continues to increase, the thickness of corona layer rises rapidly. At the same voltage, the thickness of corona layer is bigger with decreasing of the needle-plate gap.

c) In the same voltage the closer from the needle tip, the bigger of spectral intensity and the greater stability of the value. The farther away from the tip, the smaller of spectral intensity, and the higher of fluctuating value. Results shown that spectral intensity with the growth of the voltage is close to a relation with linear strengthen.
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