The Effect of Relative Humidity on Corona Discharge

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Abstract

The stability of corona discharge is significant in electrophotography and the other applications. It has been very known that corona discharge is affected by many factors such as silicone gases and humidity and so on. We had discussed the influence of siloxane gas in previously [1]. In this study, we discussed the influences of temperature and relative humidity to corona discharge. The voltage for maintaining a constant corona discharge current in an atmosphere is monitored as a function of time. The applied voltage changes when the relative humidity changes in the positive corona discharge case. In the negative case, the applied voltage is changed by the temperature variation.

[1] S. Jiang, T. Nakanishi and Y. Hoshino, "Corona discharge Characteristics in Several Relative Humidity Conditions and in Airflow Containing Siloxane Vapor", NIP22, pg422-425, (2006).

Introduction

Corona discharge supplies electrostatic charges in ion generators or electrophotography and so on. Corona discharging devices which have wire-to-plane electrode systems [1] are used for the photoconductor charging and transfer process in electrophotography [2, 3]. A non-uniform electric field is induced between the wire and plane electrodes to generate the corona discharge. In order to maintain a good image printing quality, the uniform and stability of corona discharging distribution are significant. Corona discharge initially gives a uniform charge distribution on a photoconductor. However, the wire electrodes are degraded by corona discharge and other significant factors. This degradation causes a non-uniform charge distribution on a photoconductor and causes a deterioration of copy quality, such as non-uniformity of image density. It has been reported that siloxane vapor which is often used as silicone oil and/or silicone-related material in an eletrophotographic printing generates the growth of needles and films of amorphous silicon oxide on the wire electrode induced by corona discharge [4-10]. And it also has been reported that the accumulation of hydrocarbon on wire surface in negative case when atmosphere containing hydrocarbon vapor which is often used as a liquid developer [11, 12]. However, these are all the influence of mixing gases factors to the corona discharge, the influence of the surroundings factors such as the temperature and relative humidity to the corona discharge have not been clarified.

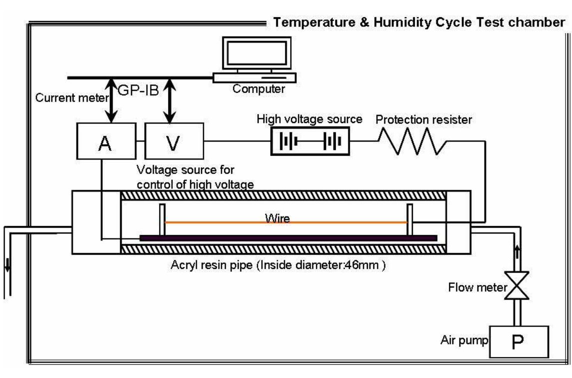


***Figure 1**. Schematic diagram of the experimental system.*

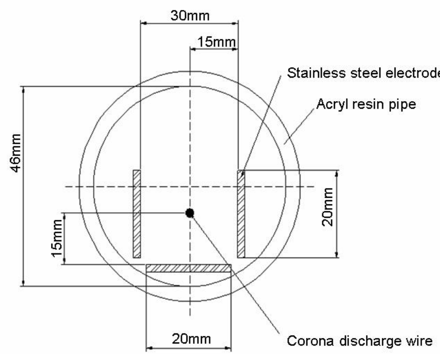


***Figure 2**. A cross section of equipment of corona discharge.*

The corona discharge takes place in air, so that to determine the influences of the temperature and relative humidity are significant for understanding corona basic mechanisms. In the present study, we compared with the applied voltage variation in different temperature or relative humidity. The applied voltage is controlled with time in order to maintain a constant corona current. After the corona discharge occurred, the morphology of the wire surfaces were analyzed by scanning electron microscopy (SEM), and the chemical compositions of the wire surfaces were analyzed by energy dispersive X-ray spectrometry (DES).

Experiment

A schematic diagram of the experimental system is shown in Figure 1. Corona discharges are generated by a non-uniform strong electric field that is induced near the wire in a wire-to-plane system at atmospheric pressure. A cross section of equipment of corona discharge is shown in Figure 2. A gold-plated tungsten wire was used as the wire electrode. It had a plating thickness of 2 um, and was 60 um in diameter and 320 mm in length. The wire electrode is surrounded by three plate electrodes that are made of stainless steel and parallel to the wire electrode at a distance of 15 mm. The dimensions of the plate electrodes are 20 mm x350 mm. For both safety and sending airflow into the corona discharging area, the corona discharging device is assembled in a 46-mm-diameter acryl resin pipe. With the application of high voltage, a plasma sheath of corona discharge takes place just around the wire electrode due to the intense non-uniform electric field. The applied voltage is controlled by a computer program to maintain a constant current. The voltage, which is applied every 2 seconds, is saved to the memory of the computer. The discharging current is

Table 1 Temperature and relative humidity conditions in temperature variation case.

	Step 1	Step 2	Step 3
Temperature (℃)	20 degrees	30 degrees	20 degrees
Relative Humidity	90%	56%	90%

Table 2 Relative humidity conditions at 20 degrees case.

	Step 1	Step 2	Step 3
Relative Humidity	50%	90%	50%

maintained constant at 0.5 or -0.5 mA that is bigger than the currents usually used in electrophotographic printing. Atmospheric airflow is introduced at a 2.0 l/min flow rate by an air pump during the corona discharges. When an airflow is applied to the discharge area, the voltage for maintaining a constant discharge current decreases due to the blowing off of discharge suppression gas such as ozone [13-16]. It was shown experimentally that the voltage decrease is nearly constant at an airflow rate of 2.0 l/min. So the airflow was introduced at 2.0 l/min.

The corona discharging device is placed inside a test chamber (DS-I DW made in Kato co.,Ltd.) which can control temperature and relative humidity to stabilize. The temperature can be set to a value between -10 degrees to 80 degrees. The temperature distribution inside the simulator is ±1.0 degree (no loading inside). And the relative humidity also can be set to a value between 30 to 95%. The distribution of relative humidity is ±3.0% (no loading inside). Using this test chamber, the corona discharges were occurred in several different temperature or relative humidity cases.

Corona discharge in temperature variation case

Maintaining the stability of the corona discharge, to understand the influences of surroundings factors such as temperature and humidity is significant. In this measurement, the influence of corona discharge will be discussed in temperature variation case. The temperature and relative humidity conditions are shown in Table 1. According to Table 1, the density of the atmospheric H_2O in the test chamber was maintained to a value for 15.5 g/m^3 in every step. In order to get more stable state in the test chamber, the measurement suspended and waited for 10 hours when temperature and relative humidity conditions changed to the next step. Initially, the temperature was set to 20 degrees in the test chamber. At Step 2, the temperature increased up to 30 degrees. Final, at step 3 the temperature returned 20 degrees again. Corona discharge occurred for 2 hours in every step.

Corona discharge in different relative humidity case

It is known that H_2O is a familiar factor to affect the corona discharge. We discussed the relative humidity influence in both corona polarity cases. The temperature was set at 20 degrees centigrade and the relative humidity conditions are shown in Table 2 in the test chamber. We compared with the applied voltage variation in different relative humidity. Also, it is as same as previous, the measurement stopped and waited for 10 hours when temperature and relative humidity conditions changed to the next step and corona discharge occurred for 2 hours in every step.

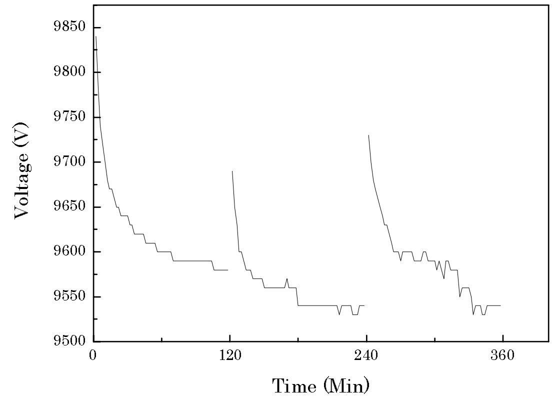


***Figure 3**. Dependence for voltage to maintain a constant discharge current (+0.5mA) over time for the temperature and relative humidity conditions listed in Table 1 for the positive discharge.*

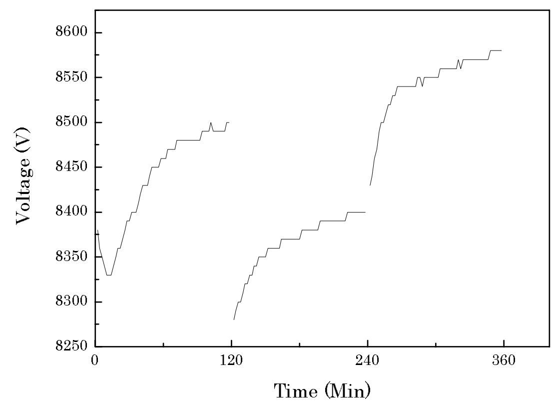
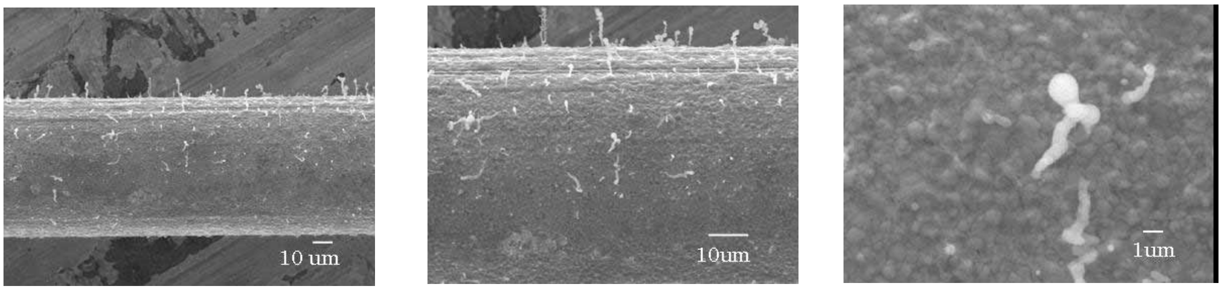


***Figure 4**. Dependence for voltage to maintain a constant discharge current (-0.5mA) over time for the temperature and relative humidity conditions listed in Table 1 for the negative discharge.*

Following the Table 2, at the first step, the relative humidity was kept to 50% in the test chamber, at the step 2, the relative humidity was increased up to 90%, and at the step 3, the relative humidity returned to 50% again.

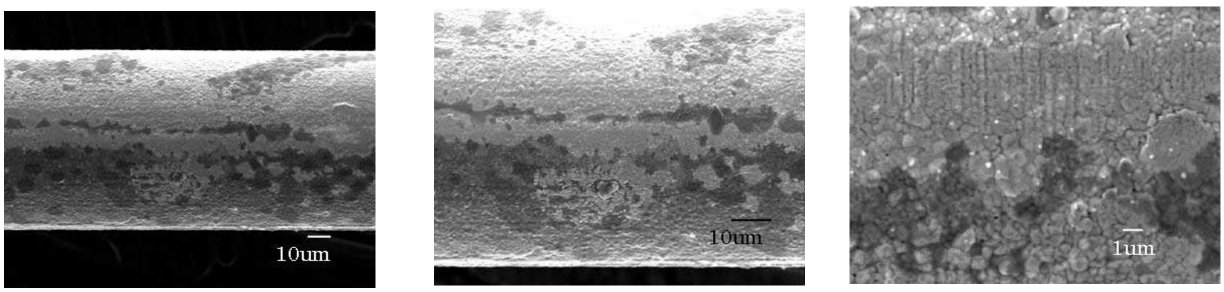
Results and discussion

Figure 3 shows the variations for the applied voltage to maintain the discharge current at a constant 0.5mA over time for the temperature and relative humidity conditions listed to Table 1 in the positive corona discharge case. According to temperature variation, there are not found that the manifest difference of applied voltage among each step listed to Table 1. However, according to temperature variation, we found a manifest difference of applied voltage compared with each step listed to Table 1 in negative corona discharge case. The variations for the applied voltage to maintain the discharge current at a constant -0.5mA over time for the temperature variation conditions listed to Table 1 in the negative corona discharge case are shown in Figure 4. The applied voltage decreased 100v when the temperature rose from 20 degrees to 30degrees. In other words, the negative corona discharge is promoted by the temperature rise. When the temperature returned from 30 degrees to 20 degrees, the applied



(a) *(b)* *(c)*

Figure 5. *SEM micrographs of the wire anode for temperature and relative humidity conditions listed to Table 1, (a)×750, (b) ×1500, (c) ×7500. The discharge time was 360minutes.*



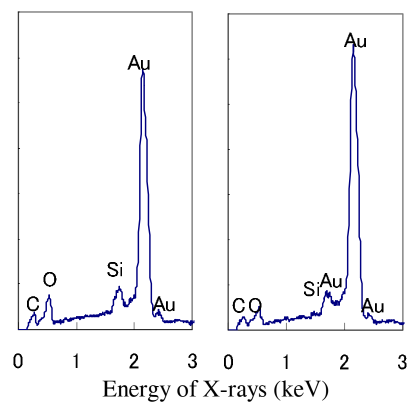
(a) *(b)* *(c)*

Figure 6. *SEM micrographs of the wire cathode for temperature and relative humidity conditions listed to Table 1, (a)×750, (b) ×1500, (c) × 7500. The discharge time was 360minutes.*

voltage increased and was over the applied voltage of step 1. That is, the negative corona discharge is restrained by the temperature drop. In negative corona discharge case, as the positive ions bombard the cathode, more trigger electrons are created and the negative corona discharge is become self-sustained. In the higher temperature, the discharge is promoted. This may be due to small differences in the secondary ionization coefficient along the wire. The coefficient depends on the cathode material, its surface properties, and the microgeometry of the surface [3]. In the higher temperature case, we can assume that the wire cathode and near by the wire cathode also have a higher temperature. So that, more trigger electrons are created by the ions bombard.

Figure 5 and Figure 6 show the micrographs of wire electrodes for the temperature and relative humidity conditions listed to Table 1, respectively. As shown in Figure 5, a small amount of needles grew on the anode. The needles grown on the wire anode are perpendicular to the axis of the wire anode toward the plate electrodes. As shown in Figure 6, some marks of a deep color appeared on the wire cathode. The marks were considered caused by the light element collisions to impact the wire cathode.

Figure 7 shows the results of qualitative analysis by EDS. Silicon and oxygen were manifest detected as components by EDS analysis in the positive discharge case. Whereas, silicon appeared on cathode surface was not very decided. In order to further investigate the needles grown on the wire anode, the result of mapping analysis of wire anode was shown in Figure 8. According the mapping analysis, it is known that the needles were consisted by silicon and oxygen. It is considered that the needles maybe were silicon oxide such as SiO_2.



(a) *(b)*

Figure7. *Results of qualitative analysis by EDS for temperature and relative humidity conditions listed to Table 1, (a) in positive corona discharge case, (b) in negative corona discharge case.*

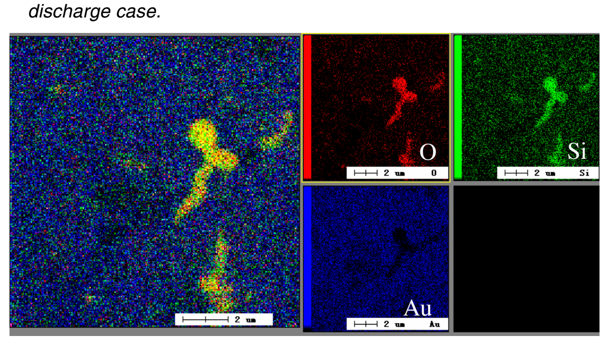


Figure 8. *Result of mapping analysis for temperature and relative humidity conditions listed to Table 1 for positive case.*

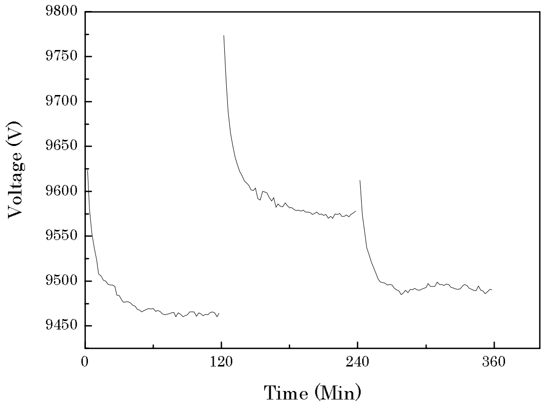


Figure 9. Dependence for voltage to maintain a constant discharge current (+0.5mA) over time for the temperature and relative humidity conditions listed in Table 1 for the positive discharge at 20 degrees.

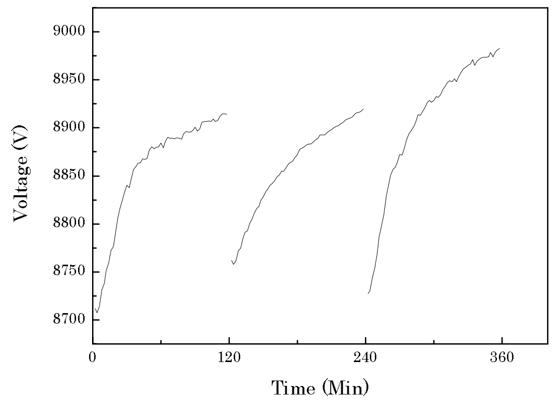
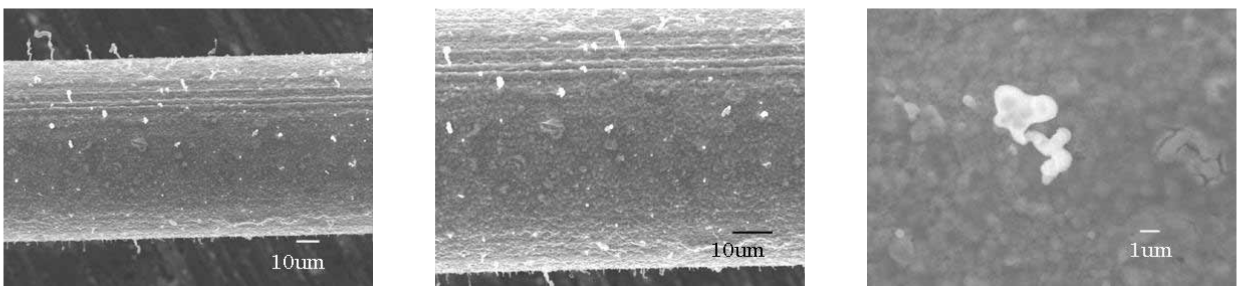
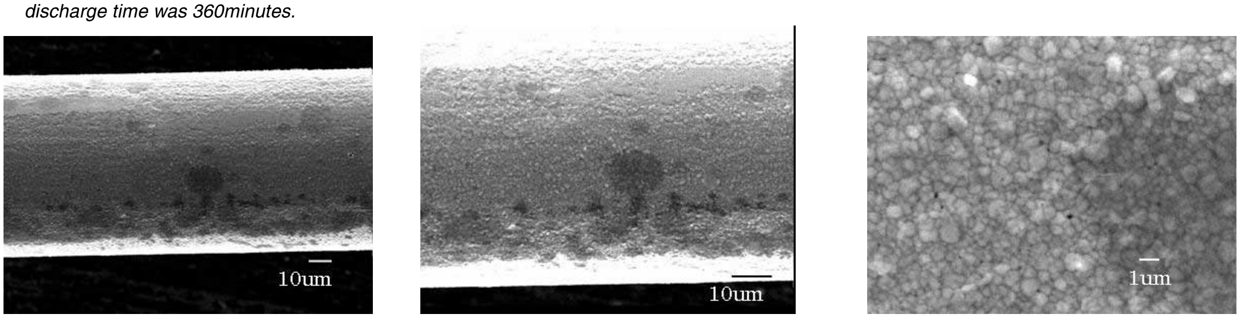


Figure 10. Dependence for voltage to maintain a constant discharge current (-0.5mA) over time for the relative humidity conditions listed in Table 2 for the negative discharge at 20 degrees.



(a) (b) (c)

Figure 11. SEM micrographs of the wire anode for the relative humidity conditions listed to Table 1, (a)×750, (b) ×1500, (c) ×7500. The discharge time was 360minutes.



(a) (b) (c)

Figure 12. SEM micrographs of the wire cathode for the relative humidity conditions listed to Table 2, (a)×750, (b) ×1500, (c) ×7500. The discharge time was 360minutes.

The variations for the applied voltage to maintain the discharge current at a constant 0.5mA or - 0.5mA over time for the relative humidity conditions listed to Table 2 are show in Figure 9 and Figure 10, respectively. As shown in Figure 9, the applied voltage increased approximately 250v when the relative humidity rose from 50% to 90% at 20 degrees. And the applied voltage decreased approximately 200v when the relative humidity dropped from 90% returned to 50% at 20 degrees. However, there are not found that the manifest difference of applied voltage among each step listed to Table 2 in the negative corona discharge case. Shahin (1966) studied the ion species for N_2, O_2 and air, with controls placed on the water content of these gases. He found the $(H_2O)_nH^+$ ion clusters dominated the positive corona discharge. As the relative humidity rises, n becomes bigger, and ion mobility is restrained.

The SEM micrographs of the wire for the relative humidity conditions listed to Table 2 in the positive and negative corona discharge cases are shown as Figure 11 and Figure 12, respectively. It is similar to Figure 5, a small amount of needles also grew on the wire anode surface for the relative humidity conditions listed to Table 2 in positive corona discharge case. Some marks also were found in the wire cathode surface for the relative humidity conditions.

Figure 13 shows the results of qualitative analysis by EDS. Figure 14 shows the result of mapping analysis by EDS in positive corona discharge case for the relative humidity conditions listed to

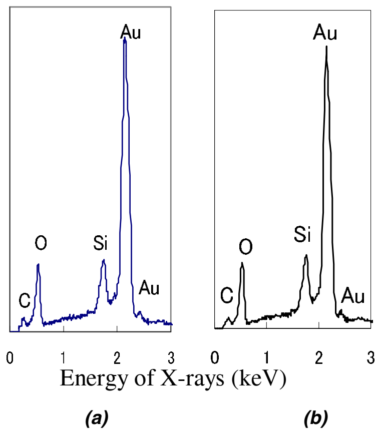


***Figure 13**. Results of qualitative analysis by EDS for the relative humidity conditions listed to Table 2, (a) in positive corona discharge case, (b) in negative corona discharge case.*

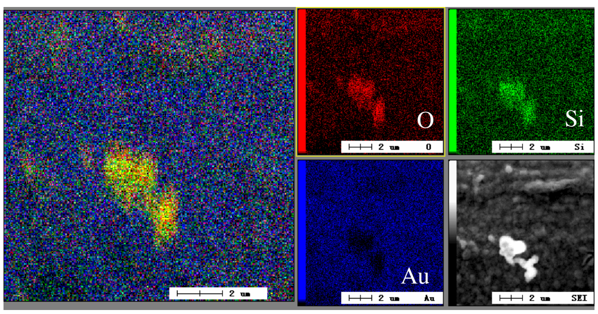


***Figure 14**. Result of mapping analysis for the relative humidity conditions listed to Table 2 for positive case.*

Table 2. The components of needles were detected by silicon and oxygen. Thus, it is considered that the needles may be were silicon oxide such as SiO_2.

Conclusion

In this study, the influences of temperature and relative humidity on corona discharges were discussed. In positive corona discharge case, the applied voltage increases when the relative humidity rises, and the applied voltage decreases when the relative humidity drops. It is considered that ion mobility is dominated by a value of n of $(H_2O)_nH^+$ ion. When the relative humidity rises, n becomes bigger, and the ion mobility is restrained, the applied voltage increases. Meanwhile, there are not found that the manifest difference of applied voltage for the temperature variation case.

In the negative case, the applied voltage decreases when the temperature rises, and the applied voltage increases when the temperature drops. It is considered that may be the secondary ionization coefficient along the wire is changed by the temperature variation. In other hand, the negative corona discharge is affected insignificantly in relative humidity change case.

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