Dehumidification using Negative corona Discharge from a Water Droplet

Yoshio Higashiyama, Masafumi Kamada
Dept. of Electrical Engineering
Yamagata University, Japan

phone: (81) 238-26-3261
e-mail: higashi@yz.yamagata-u.ac.jp

***Abstract*—Negative corona discharge from a water droplet formed at the tip of a capillary electrode involves with repetitive formation and disruption of Taylor cone. At disruption of the cone, nanometer-size fine droplets are ejected. The effect of nanometer droplets released by negative corona discharge from water droplets on dehumidification of ambient air was investigated with focusing on the influence of a diameter of capillary electrode. The higher peak value of the first pulse due to cone disruption as well as the higher frequency of disruption, the more moisture was absorbed. Using four capillary electrodes system, relative humidity can be reduced about 5% for air with a relative humidity of 90%.**

I. INTRODUCTION

Negative corona discharge from a water droplet involves with formation of a Taylor cone and its disruption into fine sprays [1-4]. Even under DC field, a droplet deforms periodically and the periodic vibration of the water droplet yields governed by resonant frequency of the droplet [5, 6]. The regular vibration due to formation and disruption of the cone manifests a series of corona pulse group in the current waveform [4, 6]. The first pulse group corresponds to the cone disruption or ejection of a nanometer size charged fine droplets [7]. The magnitude of the first pulse at breakup was controllable by the conductivity of the sample water and would be effective to produce nanometer-sized charged droplets [7]. Negative corona discharge from a water droplet is affected by relative humidity in air in combination of ejected fine droplets [8].

Corona discharge from a water droplet or water surface has been investigated, focusing on gas treatment, inactivation of air born microorganism, removal of odor [9, 10]. To dehumidify air by corona discharge or micrometer-size charged droplets produced by electrospray have been investigated [11, 12]. For indoor application of nanometer-size charged droplets, the smaller amount and finer droplets would be appropriate. Since the charged droplets produced has relatively heavier mass than ions, they enable to fly the longer distance. The purpose of this paper is to confirm the effect of negatively charged droplets with nanometer size produced by disruption of the droplet on dehumidification in a room air.

II. EXPERIMENTAL SETUP

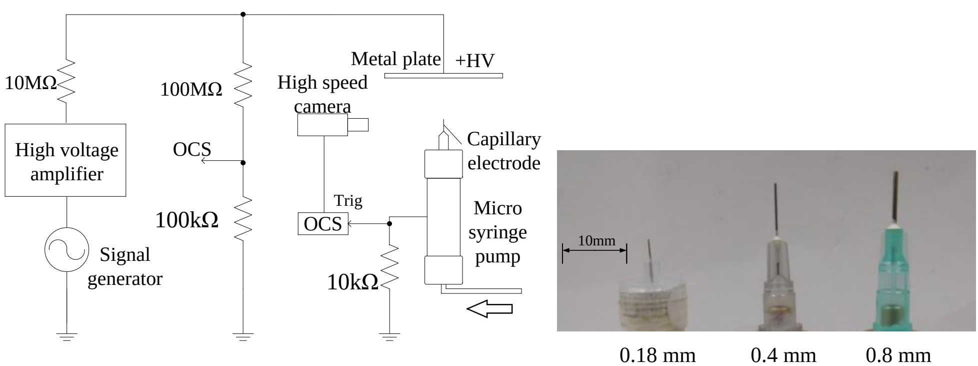
To cause corona discharge from a water droplet, a capillary and a brass plate electrode was used. Fig.1(a) shows schematic diagram for measuring corona discharge current and for observing behavior of the droplet by a high speed camera. By applying the positive voltage to the plate electrode, negative corona discharge occurs from the droplet.

Three kinds of capillary electrode with the outer diameter of 0.18, 0.4 and 0.8 mm were used to compare the performance of dehumidification as shown in Fig. 1(b). The tip of the electrode was cut with flat shape. The counter brass electrode with a 50mm wide and 200mm length was located at the distance of 50 mm. Sample water was fed into the capillary electrode by a micro syringe pump with aflow rate of 0.3 to 0.5mL/h.

Humid air with a given relative humidity, RH, was supplied into the discharge chamber from a 120 L air bag where RH was adjusted at 70 to 90 % by a ultrasonic humidifier. Air inside the bag was stirred to reach a uniform RH for 30 minutes.

The waveform of corona current flowing through a capillary electrode and a register of 10 kΩ was measured with a digital oscilloscope (Tektronix, TDS5104B, 1 GHz, 5 GS/s). The motion of a water droplet was taken with a high-speed video camera (Photoron, Mini AZ) at a speed of 40,500 frames/s synchronized with the oscilloscope.

To enhance the dehumidification effect, four cappillary electrodes were set in a discharge chamber with a size of 70 mm height, 200 mm length, 55 mm width as shown in Fig. 2. To evaluate the moisture contents collected, moisure absorbing polymer sheet, MAPS, was set at the brass electrode.



(a) Schematic diagram of the circuit (b) Capillary electrodes used

Fig. 1. Experimental circuit for observing corona discharge from a water droplet

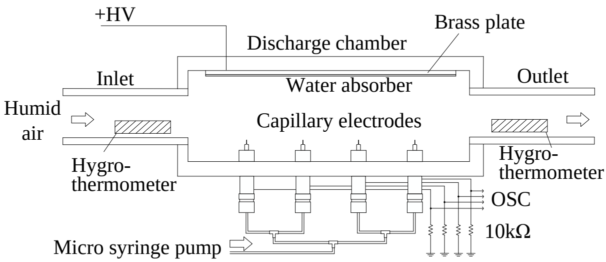
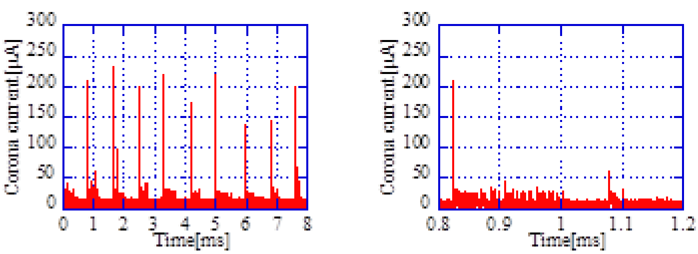


Fig. 2. Dehumidifier by charge droplet produced from corona discharge from four capillary electrodes.

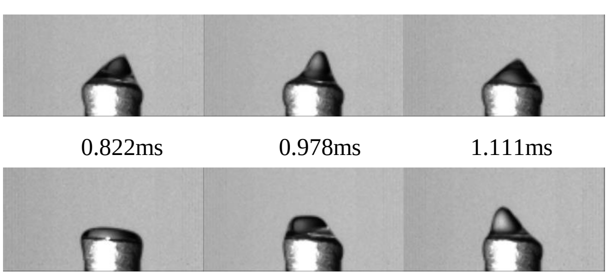
III. RESULTS

A. Change in humidity during corona discharge

Fig. 3 shows the current waveform of corona discharge from a water droplet and the motion of the droplet during discharges. Corona discharge occurs periodically. This indicates the droplet repeats formation of a sharpened cone and the returning to a round droplet at almost regular period. A series of pulse trains consists of the largest first pulse corresponds to the disruption of a Taylor cone and the successive corona discharges occurring during the returning process. Breakup of the tip of a Taylor cone produces a number of fine charged droplets and they would capture water vapor in air.



(a) Corona pulse groups (b) Enlarged waveform



0.822ms 0.978ms 1.111ms

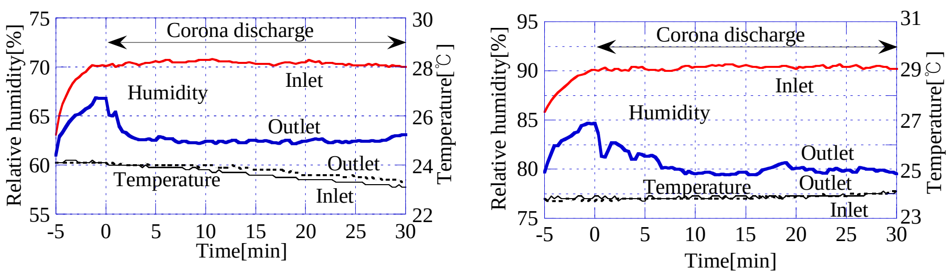
1.355ms 1.600ms 1.689ms

(c) Cone formation

Fig. 3. Cone formation and disruption during corona discharge from a water droplet formed at 0.4 mm diameter capillary tube.

An enlarged corona pulse trains in the pulse groups is shown in Fig. 3(b) where the time axis of abscissa corresponds to that shown in Fig. 3(a). The time variation in shape of the droplet in Fig. 3(c) is consistent with Fig. 3(b). When humid air with 70 and 90 % RH was supplied to the discharge chamber, the time variation of RH and air temperature at the inlet and outlet of the chamber was shown in Fig. 4 for the applied voltage of 9kV and corona discharge of 30 minutes. Since the MAPS absorbs water vapor to some extent, the absorbed moisture amounts could be evaluated by the difference in RH measured at inlet and outlet at t=0, that is, before onset of corona discharge in Fig. 4. RH in the air passing through the chamber decreased without corona discharge. The RH in air at outlet was 3, 4, and 6 % lower than that in the inlet for 70, 80 and 90 %, respectively.

From onset of corona discharge, RH decreased around 5 % of RH in air regardless of humidity fed into the chamber. The moisture contents in air was collected by charged fine droplets and/or ions produced by corona discharge from a water droplet. The difference in RH of the inlet and outlet air increased by 8 and 11 % for 70 and 90 % RH. This means the net amount of the 5% decrease of RH due to charged droplets play a role to decrease of 5 %, regardless of RH in fed air. Fig. 5 shows the comparison of net moisture contents collected by the MAP for 30 minutes. The net amount of the moisture was obtained by total weight of the collected moisture subtracted water content to the capillary electrode during 30 minutes. The amount of collected moisture reached 140mg and 220mg from the humid air with 70 and 90% RH, respectively.



(a) RH 70% (b) RH 90%

Fig. 4. Time variation of relative humidity of humid air into the discharge chamber.

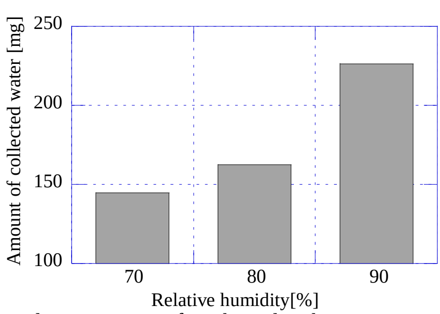
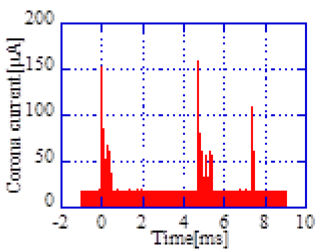


Fig. 5. Collected water contents from humid air by negative corona discharge from water droplets.

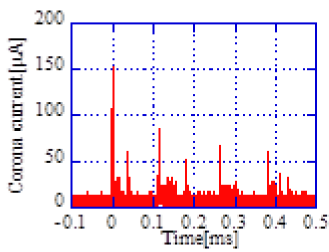
B. Effect of droplet diameter

The current waveform and droplet motion were shown in Fig. 6 where a capillary electrode with a diameter of 0.8 mm was used. Although the waveform in Fig. 6(a) resemble to that in the Fig. 3(a) except the number of pulses , the enlarged waveform revealed that first pulse group consisted of several small pulse groups, that is, the relatively lower first pulse occurred and successive corona pulse followed. The pictures of the droplet shows this situation. Only the cone tip repeated up-and-down motion and whole droplet returned from the cone occurred at 0.4 ms later. The droplet from the 0.8 mm diameter capillary electrode involves with the vibrating motion of the whole droplet and the tip of the cone. Both motions would eject the fine charged droplets by disruption of the cone respectively.

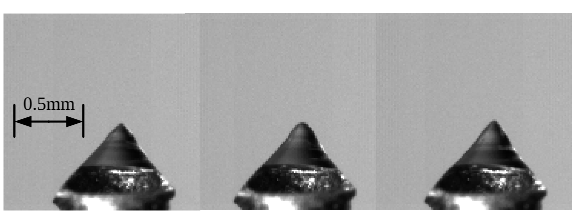
Fig. 7 shows the moisture content collected by the corona discharge from a droplet formed at three kinds of capillary electrode. Corona discharge from a water droplet at a 0.4 mm electrode able to collect moisture at the most. Fig. 8 shows the first pulse and frequency of obtained from each current waveform. The content of collected moisture was explained by the magnitude of the first pulse and occurrence frequency of the breakup of a cone. The number of the charge droplet corresponds the magnitude of the first pulse and the disruption frequency.



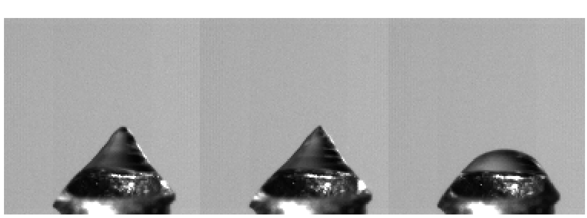
(a) Corona pulse group



(b) Enlarged waveform

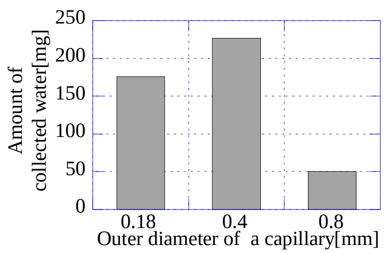


0.000 ms　　0.089ms　　0.155 ms

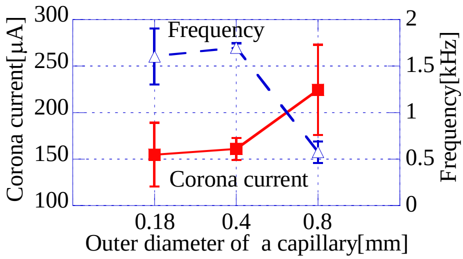


0.222 ms　　0.267 ms　　0.400 ms

Fig. 6. Cone formation and disruption during corona discharge from a water droplet formed at 0.8 mm diameter capillary electrode.



(a) Moisture content collected for 30 minutes



(b) Characteristics of corona waveform

Fig. 7. Effect of the size of capillary electrode on collected water contents and the magnitude and occurrence frequency of disruption from a water droplet.

The waveform of the corona discharge from a water droplet consists of the first pulse current due to ejection of the fine droplets and corona discharge current occurred at the vicinity of the cone tip. Fig. 8 shows comparison of amounts of collected moisture in the period of 30 minutes by corona discharges from a water droplet and a needle electrode. The peak value of the pulse height was set at 40 µA for both case. Although negative ions produced by corona discharge from the needle electrode was surely effective to collect the moisture, the amount of the moisture contents was one quarter of that from water droplets. This collection effect would be due to the longer flight of the nanometer-size charged droplets owing to its inertia and probably longer life time than negative ions in the space. Therefore, negative water droplets would have a more chance to encounter moisture in air.

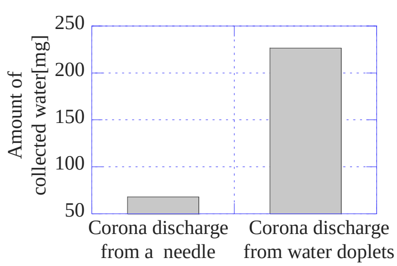


Fig. 8. Effect of the corona discharge on the amount of collected water.

The size of the moisture in air by nanometer-size charged droplets was measured by the particle sizer (TSI, SMPS 3910). Fig. 9 shows the time variation of the number of particles measured at the outlet of the discharge chamber by every one minute. Before onset of corona discharge, the particles with 100 to 420 nm was dominant and the number of them were around 2000 particles/cm^3, which contained in air fed into the dehumidification chamber from the air bag. After the beginning of corona discharge, particles in air were hardly detected. This indicates water vapor or moisture was collected to the high voltage electrode by coalescence with charged water droplets at least in the diameter range. The particles or water molecules below 10 nm might pass through the chamber.

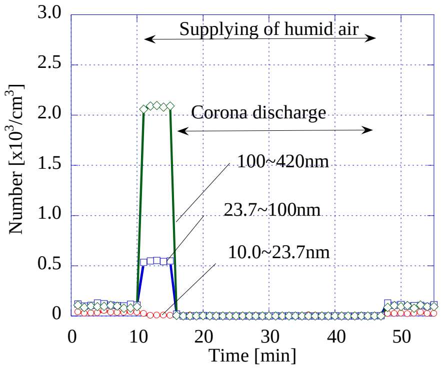


Fig.9. The time variation of the number of vapor particle in air with or without corona discharge.

Acknowledgement: This work was supported by JSPS KAKENHI Grant 15H03957.

REFERENCES

[1] J. Zeleny, " Instability of electrified liquid surfaces ", *Phys. Rev.*, vol. 10, no. 1, pp. 1-6, 1917

[2] G. Taylor, "Disintegration of water drops in an electric field", *Proc. R. Soc. London*, A280, pp.383-397, 1964

[3] L.B. Loeb, " Electrical Coronas, "University of California Press Berkeley, 1965, p. 249,

[4] T. Sugimoto K. Asano, and Y. Higashiyama, "Negative Corona Discharge at a tip of a water cone deformed under dc field", *J. Electrostatics*, vol. 53, pp. 25-38, 2001

[5] T. Yamada, T. Sugimoto, Y. Higashiyama, M. Takeishi, and T. Aoki, "Resonance phenomena of a single water droplet located on a hydrophobic sheet under ac electric field", *IEEE Trans. Industry appl*., vol. 39, no. 1, pp. 59-65, 2003

[6] Y. Higashiyama, T. Shiori: Negative Corona Discharge from a Water Droplet with or without Resonant Vibration, Int. Symp. on Electrohydrodynamics, ISEHD 2012, Gdańsk, Poland, 2012

[7] Y. Higashiyama, T. Nakajima, T. Sugimoto, Influence of conductivity on corona discharge current from a water droplet and on ejection of nano-sized droplets, *J. Electrostatics*, vol.88, pp. 65-70, 2017

[8] Y. Higashiyama, S. Sugimoto, T, Sugimoto: Influence of Relative Humidity on Corona Discharge from a Fine Droplet Formed at a Tip of Capillary Electrode, ISEHD 2014, Okinawa, Japan (2014)

[9] H. Suda, N. Iwamoto, Y. Matsui, T. Yamauchi, K. Okuyama, "The study of application using electrostatic atomization", Proc. Annual Meeting of Inst. of Electrostatics Japan, 12pB-5 (2003) pp.237-238

[10] N. Shirai, S, Uchida, F. Tochikubo: Atmospheric negative corona discharge using Taylor cone as a liquid cathode, *Jpn. J. Appl. Phys*. **53** 026001, 2014

[11] M. Reznikov: Dielectrophoretic Dehumidification of Gas Steam in Low and Moderate Electrical Fields, *ESA, ESJ, IEEE Joint Meeting* , 2003

[12] M. Reznikov M. Salazar: Electrically Enhanced Condensation I: Effects of Corona Discharge, *IEEE Trans. Industry Appl.*, vol.51, no.2, pp.1137-1145, 2015