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Effect of Flowing Mist Relative Humidity on the Electric Characteristics of Helium Dielectric Barrier Discharge

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ABSTRACT: To examine the effect of humidity on the operation of dielectric barrier discharge (DBD), we tested electric characteristics of an atmospheric DBD in flowing helium between two parallel plates covered by dielectric in water mist. With increasing relative humidity (RH) levels, the signal current indicated different behaviors of the discharge. The discharge began as a multipeak Townsend discharge at low humidity levels. After increasing RH of the injected mist, the width and amplitude of current microdischarges decreased until they reached a diffuse discharge free from microdischarges. With discharge current gradually decreasing with increasing humidity, discharge power began to decrease but then increased continually after reaching a specific humidity value. Our results show that introducing humid mist in the DBD gave this type of discharge efficacious properties that could be applied to the destruction of bacteria found in serum plasma.

KEY WORDS: DBD, humidity, mist, electrical characterization, mode transition, multipeaks, Lissajous figure

I. INTRODUCTION

Atmospheric pressure dielectric barrier discharge (DBD) is widely used to produce homogeneous plasma for sterilization purposes.[1,2] To increase the efficacy of plasma in destroying microorganisms, many researchers have proposed the use of humidity carried by gas introduced to maintain discharge. By adding water vapor to working gas or by simply controlling ambient humidity, plasma discharge occurring in a humid environment may result in the enhancement of its ability to destroy microorganisms. Many researchers have examined the effect of varying humidity level on plasma electric characteristics and the corresponding influence on the effectiveness of the application considered. Messaoudi et al.[3] analyzed the influence of humidity on the DBD-current waveform. These investigators found that the introduction of water molecules affected surface features that control discharge behaviors such as dielectric conductivity. Nersisyan and Graham[4] characterized a DBD operating in an open reactor with flowing helium. They found that the adjustment of flow rate allowed the creation of uniform DBDs with optimized input power. Attempts to identify the role of humidity in plasma sterilization was investigated by Eto et al.,[5] who identified the role of humid air in the treatment of spores in DBD. Dobrynin et al.[6] also indicated the importance of water amount and direct plasma treatment for achieving quicker inactivation of bacteria. Kikuchi et al.[7] investigated the capability of DBD plasma in atmospheric humid air to sterilize bacteria. These researchers found that the water content in air could determine the generation of reactive species such as hydroxyl radicals, which are effective in the inactivation of some spores. Using a DBD reactor with a ceramic filler, Ya-hong et al.[8] examined discharge current behavior in the presence of humidity. They found that in certain conditions of operation, discharge current decreased with increasing relative humidity (RH). Van Deynse et al.[9] found that water vapor–based plasma in DBD can be an excellent tool for the surface activation of polyethylene and changing the water contact angle. Massines et al.[10] pointed out that DBD discharge modes are widely influenced by ambient conditions between the plates in a parallel plate configuration with the injection of helium as the carrier gas. Here, we investigate the effect of varying RH levels of water mist introduced between two parallel plates in a reactor configuration operating under flowing helium gas.

II. MATERIALS AND METHODS

A. Experimental Setup

The experimental arrangement used two circular stainless-steel-plane parallel electrodes 9.5 cm in diameter covered by 1-mm glass layers as the dielectric. The interelectrode gap was adjusted to 3 mm. For initiating and maintaining the discharge, helium gas was introduced from an opening in one of the two electrodes, and water mist was introduced in the space between the two electrodes. Voltage was generated by a high-speed high-voltage amplifier (Trek, Inc., USA; model 10/40A-HS) driven by a function generator (B&K Precision Corp., Yorba Linda, CA; model 4011A). Applied high voltage was measured with a 1000:1 high-voltage probe (Tektronix, Inc., Beaverton, OR; model P6015A, 75 MHz) and the current by a Rogowski coil (Pearson Electronics, Palo Alto, CA; Model 4100, 1 volt/1 amp). The voltage drop across a 100-nF capacitor was measured using a 10:1 oscilloscope probe. Measured signals were displayed on a four-channel digital oscilloscope (Tektronix; model TDS2024C, 200 MHz). Flowing helium gas was introduced by a mass flow controller (MFC) (Omega Engineering, Inc., Stamford, CT; model FMA-A2409). Water mist was generated by a commercial ultrasound nebulizer (Folee Medical Equipment Company, Ltd., Jiangsu Province, China; model W001) that produced water droplets 30 μm in diameter. After passing in the plasma region between the electrodes, water mist went to the treatment chamber. RH as a percentage was measured inside the treatment chamber using a programmable humidity controller with sensor (FOX-1H from CONOTEC Co., LTD, Korea, with range 20–99% RH.). The setup of the experiment can be seen in Fig. 1.

III. RESULTS

Voltage-current characteristics were measured at different RH levels under flowing He

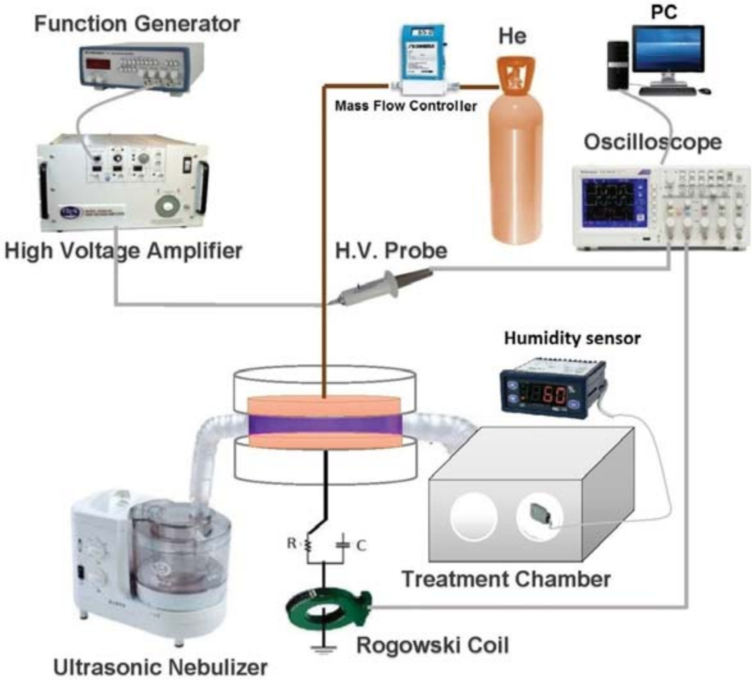

FIG. 1: Experimental arrangement of DBD under flowing helium with the injection of water mist.

gas of 7.3 L/min. The high alternating current (AC) voltage was kept at 6 kV peak–peak, at a frequency of 12 kHz. Figure 2 shows the measured voltage-current characteristics at different humidity levels. The electric charge Q versus voltage V (Q-V) characteristics in the form of Lissajous figures at different humidity levels are shown in Fig. 3.

IV. DISCUSSION

Measurements of current versus voltage (I–V) and and charge versus voltage (Q-V) characteristics of a DBD plasma at different humidity levels of water mist showed pronounced effects of injected mist flow in the interelectrode region of the produced plasma. Figure 2a shows a case with no injected humidity, for which the humidity sensor indicated an ambient humidity of 43% in the treatment chamber. In this case, for almost two excitation cycles, the current signal presented pulses of increased amplitudes during only negative cycles . Those current pulses corresponded to microdischarges, indicating a homogeneous mode regime at a multipeak Townsend discharge mode. As the humidity level increased, the current peaks narrowed, showing decreases in amplitude. This was accompanied by an increase in peaks per half-cycle. Figures 2a to 2d show current waveforms having dissymmetry in peak shape and amplitude during positive and

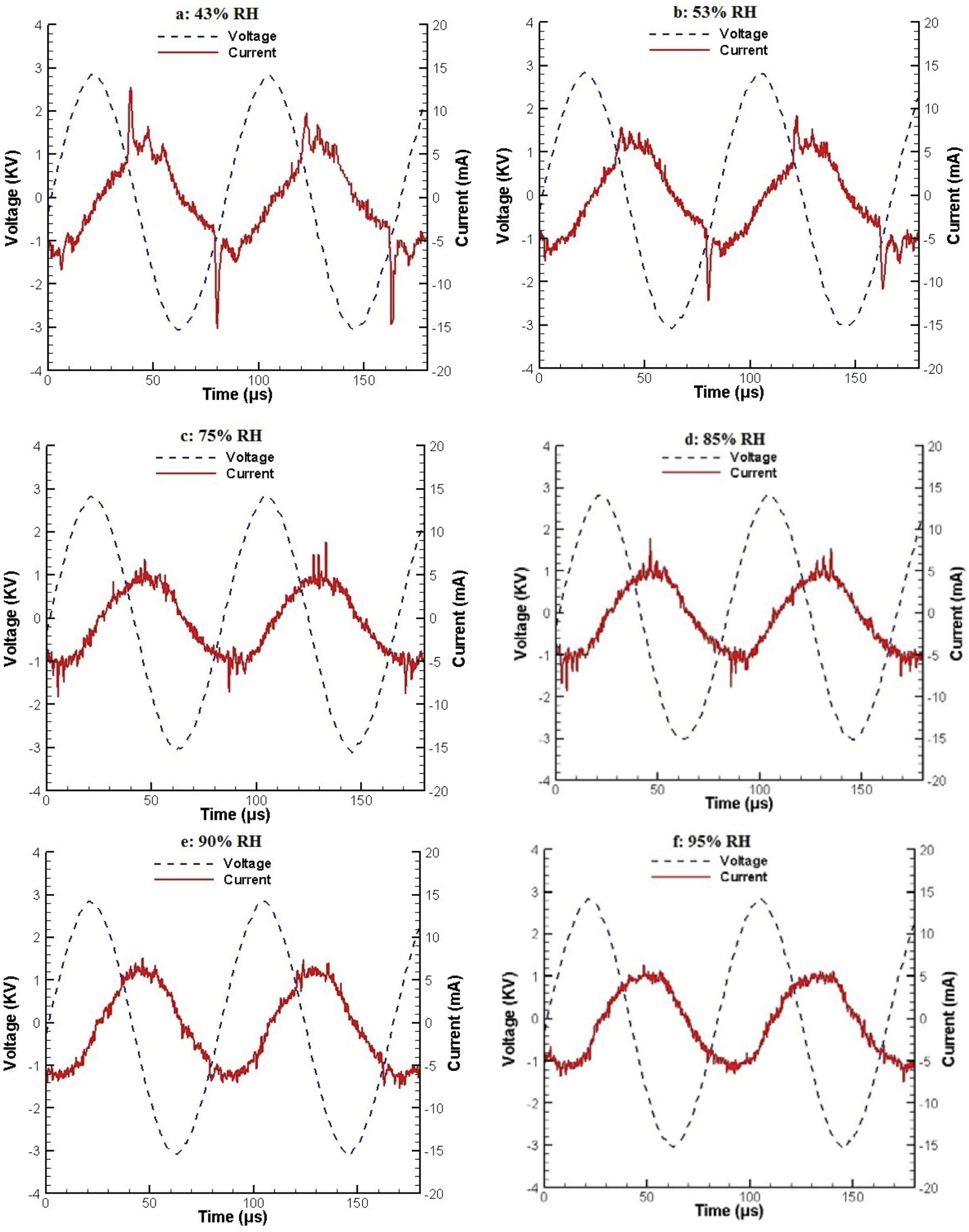

FIG. 2: Voltage and current traces versus time at different humidity levels.

negative half-cycles. Negative half-cycle peaks seemed to be higher than those occurring during positive half-cycles. As shown in Figs. 2e and 2f, as humidity increased to

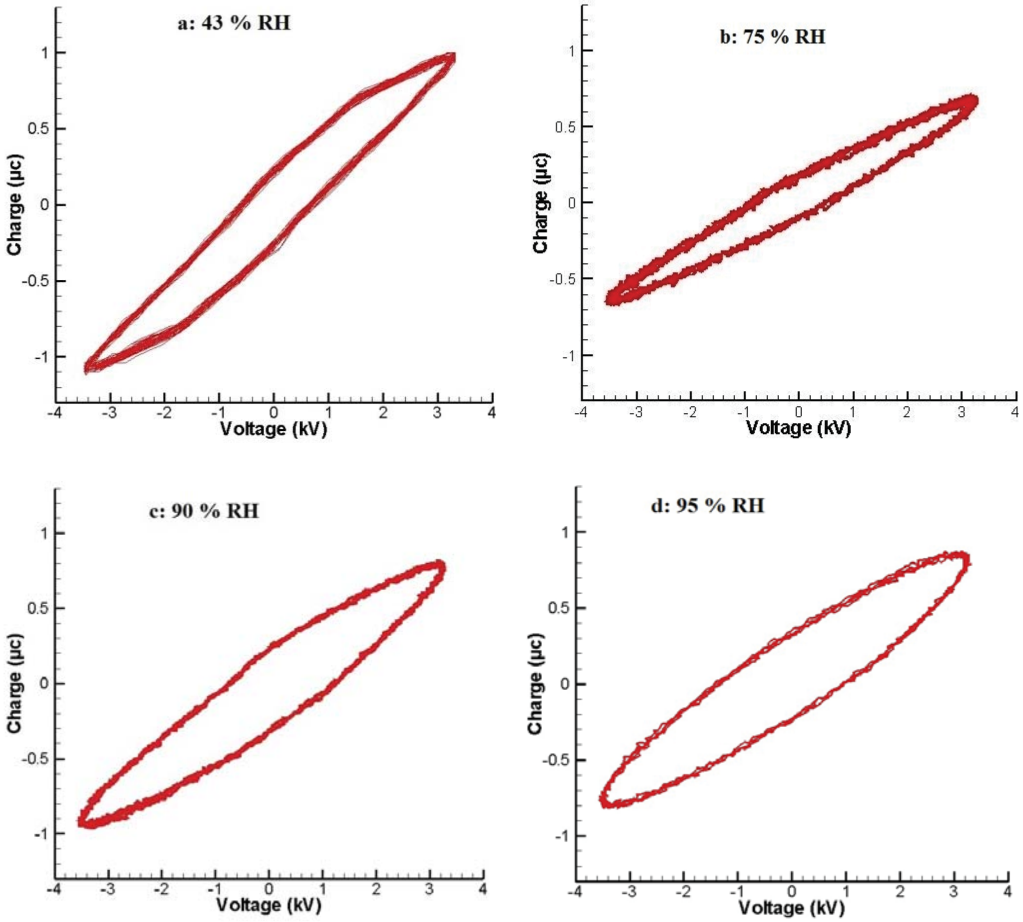

FIG. 3: Q-V characteristics in the form of Lissajous figures at different humidity levels.

90% and above, peak width and amplitude were drastically reduced. The current signal broadened to adopt a sinusoidal shape, indicating an increasingly pronounced diffuse mode. Figure 4 shows the variation of discharge current with RH. Here, the plotted current values take into account the amplitude of current peaks and an average was made between values in positive and corresponding negative half-cycles.

In Fig. 4, the discharge current gradually decreased as RH increased. This result is in agreement with that given by Ya-hong et al.,[8] who attributed the reduction in discharge current with humidity to the electronegative nature of the water vapor molecules adsorbed by high-energy electrons forming negative ions and consuming an effective number of electrons, contributing to DBD current.

Discharge power is calculated from the surface of Lissajous figures of Q-V plots in Fig. 3. The result is displayed in Fig. 5, where the calculated power is plotted versus RH values. The values of power begin to decrease with increasing humidity until they reach

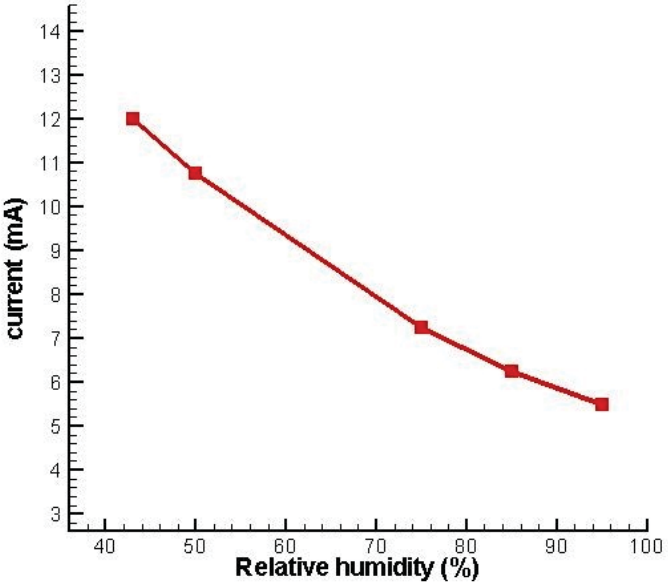

FIG. 4: Discharge current at different RH values.

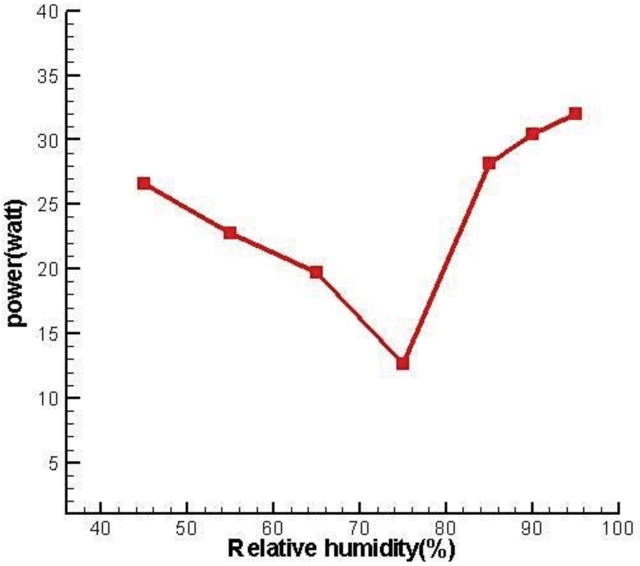

FIG. 5: Discharge power versus RH values.

a value of 75% RH. Power increases gradually with RH. Similar behavior occurring in the curve of discharge power versus ambient humidity was reported by Benard et al.[11]

Because discharge power reflects the efficacy of the discharge,[12,13] increasing the humidity level beyond a certain value will lead to an increase in the power. This is favorable to many applications, especially those in the medical field.

V. CONCLUSION

RH has a significant impact on atmospheric DBD under flowing helium. Introducing humidity through water mist in the interelectrode region under flowing He can cause properties of discharge to change. Under certain RH levels, discharge can operate in a complete diffuse mode without any microdischarges. Above certain RH levels, discharge power can be maximized under flowing helium gas. Increasing humidity may also change surface properties of the dielectric material, which can influence the plasma properties. This effect must be studied more extensively.

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