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Letter to the Editor

Response to Comment on “Modeling and Validation of Nanoparticle Charging Efficiency of a Single-Wire Corona Unipolar Charger”

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Fernández-Díaz and Domat’s preceding Letter to the Editor argued that the geometry of the discharge electrode of the charger of our previous article entitled “Modeling and Validation of Nanoparticle Charging Efficiency of a Single-Wire Corona Unipolar Charger” was a needle but not a wire. Therefore, the boundary condition for the ionic charge density at the discharge wire surface used in the simulation was suspected to be not completely correct. In the present work, the exact shape of the tip of the discharge electrode was examined and found as a hyperbolic point. The experimental onset voltage was further compared with the theoretical onset values calculated by either wire-in-tube or point-to-plane assumption. Results show that the theory of needle-type discharge electrode is also not appropriate either for the boundary condition at the tip because of higher calculated onset voltages than the experimental data.

In Chien et al. (2011), a detailed two-dimensional (2D) numerical model was developed to predict the flow, electric potential, ion concentration, charged particle concentration fields, charged particle loss, and charging efficiency in a single-wire corona unipolar charger. The numerical model is able to predict the experimental nanoparticle charging efficiency very well for particles smaller than 20 nm in diameter. However, Fernández-Díaz and Domat (2014) argued in their Comment that the geometry of the discharge electrode of the charger was a needle but not a wire, and hence the boundary condition for the ionic charge density at the discharge wire surface used in the simulation was not completely correct. They proposed a methodology to replace Equation (9) in Chien et al. (2011) for improving the simulated results.

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The exact shape of the tip of the discharge electrode was examined by an electron microscope (ESPA SYSTEMS Co., Ltd., Hsin Chu, Taiwan) and is shown in Figure 1. The shape of the tip is seen as a hyperbolic point corresponding to the case A in Figure 1 in the Comment by Fernández-Díaz and Domat (2014). The equivalent radius of curvature of the point is equal to 23.7–24 μm , which is slightly smaller than the radius of wire, 25 μm . The blackish wire surface was caused by oxidation.

For the irregular internal geometry of the charging chamber, no simple mathematical models were available to describe the electrical field between the tip of the discharge and grounding electrodes until the numerical work conducted by Chien et al. (2011). For the breakdown voltage and breakdown electric field in point-to-plane corona discharge, the breakdown voltage, V_0 (V), is expressed as (Adamiak et al. 2005; Le et al. 2013)

$$V_0 = \frac{E_b \times a \times \ln\left(\frac{4d}{a}\right)}{2}, \quad [1]$$

where a is the tip radius of discharge electrode (m), d is the point-to-plane spacing (m), and E_b is the breakdown electric field (V/m) which can be calculated as

$$E_b = 3.1 \times 10^6 \delta \left(1 + \frac{0.308}{\sqrt{0.5a\delta}}\right), \quad [2]$$

where a is in cm, and δ is the relative density of the air. The ion current of a single electrode can be calculated as follows (Adamiak and Atten 2004; Le et al. 2013):

$$I = \alpha_i \varepsilon_0 Z_i V_a (V_a - V_0) / d, \quad [3]$$

where I is the corona current (A), α_i is the empirical coefficient, which is 1.58 suggested by Adamiak and Atten (2004),

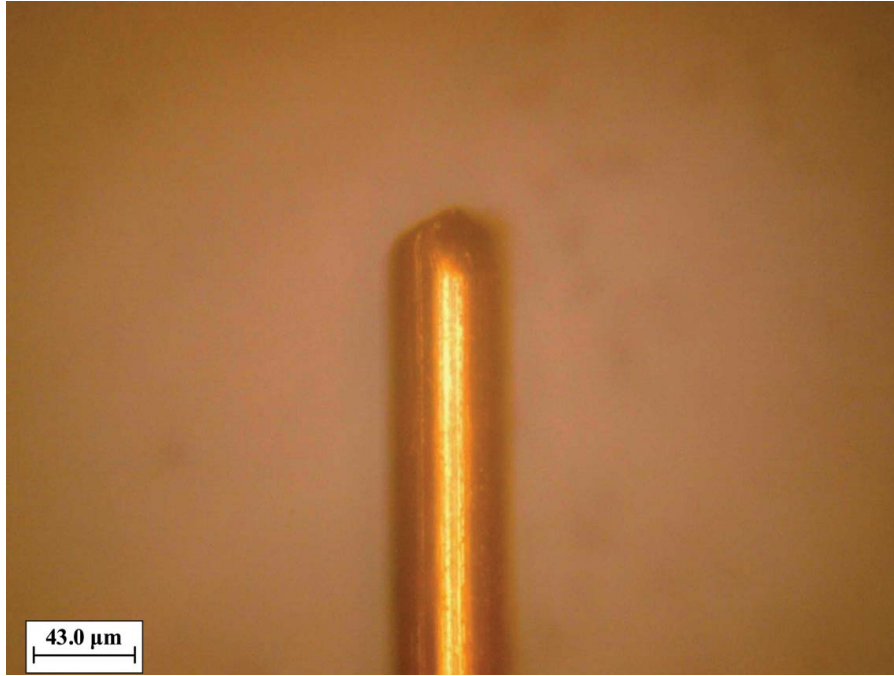


FIG. 1. Micrograph of the tip of discharge electrode of the charge of Chien et al. (2011).

ϵ_0 is the permittivity of air ($C^2/N\cdot m^2$), Z_i is the ion mobility ($m^2/s\cdot V$), and V_a is the applied voltage (V).

The breakdown voltage for the wire-in-tube precipitator (ESP) can be calculated as (Tsai et al. 2008)

$$V_0 = E_b r_w \ln(r_t/r_w), \quad [4]$$

where r_w is the radius of the discharge wire (m), r_t is the radius of the tube (m), and the breakdown electric field is

$$E_b = 3000 + 127d_w, \quad [5]$$

where d_w is the diameter of the discharge wire (m). The corona voltage is given by

$$V_a = V_0 + E_b r_w \left[\sqrt{1+\theta} - 1 - \ln\left(\frac{1+\sqrt{1+\theta}}{2}\right) \right], \quad [6]$$

where θ is defined as

$$\theta = \frac{I r_t}{2\pi\epsilon_0 Z_i E_b r_w}. \quad [7]$$

In the charging chamber, the distance from the tip to the inlet and wall are 0.02 m and 0.015 m, respectively, as shown in Figure 3 in Chien et al. (2011). For the point-to-plane corona discharge, the breakdown voltage was calculated to be 2.98 kV ($d = 0.02$ m) and 2.87 kV ($d = 0.015$ m) at $a = 24 \mu m$ with the corresponding breakdown electric field

of 3.06×10^7 V/m, which is close to that calculated by Equation (5) in the Comment. For the wire-in-tube case, the breakdown voltage was calculated to be 3.35 kV with the corresponding breakdown electric field of 2.09×10^7 V/m, which is also close to that calculated by Equation (4) in the Comment. As shown in Figure 2, the experimental onset voltage is much lower than the theoretical onset values calculated by either wire-in-tube or point-to-plane assumption.

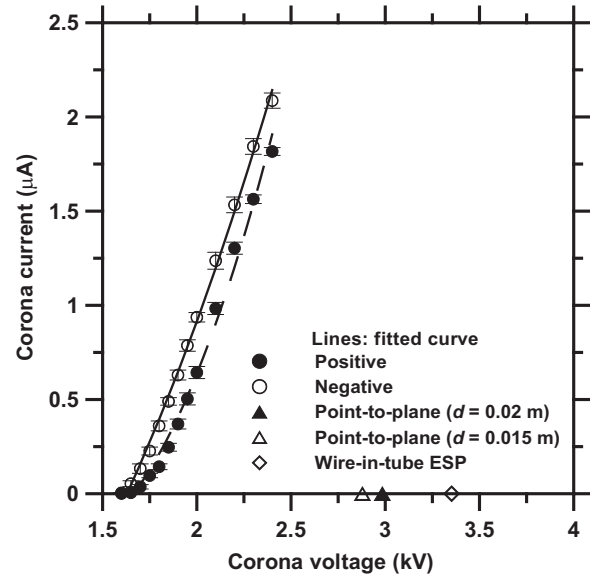


FIG. 2. Comparison of the applied and theoretical onset voltages.

Besides, the applied voltage of +1.6 to + 2.4 kV (corona current: 0.001 to 1.817 μA) and -1.6 to -2.4 kV (corona current: -0.004 to -2.087 μA) in the charging experiment of Chien et al. (2011) for positive corona and negative corona, respectively, is much lower than the above calculated onset voltages. The corona current at the onset voltage is zero, which is not the operating condition of the charger. Instead, the maximum charging efficiency occurs at a certain voltage within the applied voltage range of ± 1.6 to ± 2.4 kV, which is even lower than the calculated onset values.

We agree with Fernández-Díaz and Domat (2014) that Equation (9) in Chien et al. (2011) is only valid for a wire but not for a tip. However, the theory of needle-type discharge electrode is also not appropriate either for the boundary condition at the tip because of higher calculated onset voltages than the experimental data. Besides, particle charging can only occur at a voltage higher than the onset voltage and the numerical study for particle charging was based on the corona current obtained experimentally in Chien et al. (2011). The predicted extrinsic charging efficiencies were shown to be in good agreement with the experimental data with a deviation of

<7%, which cannot be improved further by the method proposed by Fernández-Díaz and Domat (2014).

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