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Calculation of transferred charges from a water droplet with a contact angle θ in a triboelectric nanogenerator

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***Abstract**: We have analytically calculated the induced charges on the bottom of asubstrate that has aphobic or philic surface on whicha water droplet is positioned with a contact angle θ on its top surface. Thiswill be helpful forestimatingthequantity of transferred charges according to the contact surface between the charged droplet and the substrate in a triboelectric nanogenerator system.*

***Key words:**transferred charges, water droplet, TENG, contact angle.*

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I. Introduction

Contact electrification between a liquid, such as water, and a solid insulating material has been applied to harvest energy from water [1-6]. A water droplet, which forms on a hydrophilic or hydrophobic dielectric surface with a contact angle,θ, can be described by Young's equation as shown below[7].

$$\cos\theta = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}}, \quad \ldots\ldots. (1)$$

where $\gamma_{SV}, \gamma_{SL}, and\ \gamma_{LV}$represent theinterfacial free energies per unit area for solid-vapor, solid-liquid, and liquid-vapor interfaces, respectively.The contact area between the water droplet and the dielectric surface is associatedwith the induced transferred charges on the bottom of the dielectric flowing from the ground, as well as with the currents in a triboelectric nanogenerator. If the dielectric surface is philic, then it goes into the wetting state, the contact area between the droplet and the dielectric surface will become large. On the contrary, if the surface is phobic, the contact area between them willreduceandthe contact angle would increase. Based on these configurations, the transferred charges are determined via electrostatic induction through the dielectric material. In this work, we analytically derived the equations of the induced transferred charges on the bottom electrode according to the various contact angles that a water droplet forms on the dielectric surface.

II. Analytic derivation of transferred charges induced from a water droplet with a contact angle

Based on the volume calculation method[7], the volume of awater droplet resting on a 2D plane (i.e., horizontal surface) adoptingasphericalcap shape with a circular basal contour and the constant contact angle around the base can be stated as follows:

$$\mathrm{V} = \frac{\pi d^3}{24}\left[\frac{2-3\cos\theta + \cos^3\theta}{\sin^3\theta}\right], \quad \ldots\ldots\ldots (2\text{-}1)$$

where d is the diameter of the water droplet and θ is the contact angle. Then, d can be calculated as

$$d = \left[\frac{24\cdot V\cdot \sin^3\theta}{\pi[2-3\cos\theta + \cos^3\theta]}\right]^{1/3} \ldots\ldots(2\text{-}2)$$

Then, the surface area of the water droplet on the basal contour is

$$\mathrm{S} = \pi\left(\frac{d}{2}\right)^2 \ldots\ldots(3)$$

$$= \frac{\pi}{4}\left[\frac{24\cdot V\cdot \sin^3\theta}{\pi[2-3\cos\theta + \cos^3\theta]}\right]^{2/3} \ldots\ldots(4)$$

If the charge density of the droplet,σ, is known, then the basal surface charge of the droplet will beasfollows:

$$\mathrm{Q} = \mathrm{S}\cdot\sigma = \frac{\pi\sigma}{4}\left[\frac{24\cdot V\cdot \sin^3\theta}{\pi[2-3\cos\theta + \cos^3\theta]}\right]^{2/3} \ldots\ldots(5)$$

Due to charge conservation, the collected charges on the bottom metal are

$$Q_{trans} = -\mathrm{Q} = -\frac{\pi\sigma}{4}\left[\frac{24\cdot V\cdot \sin^3\theta}{\pi[2-3\cos\theta + \cos^3\theta]}\right]^{2/3} \ldots\ldots(6)$$

Then, the transferred charge density on the bottom metal will be asfollows:

$$\acute{\sigma} = \frac{-\mathrm{Q}}{A} = -\frac{\pi\sigma}{4A}\left[\frac{24\cdot V\cdot \sin^3\theta}{\pi[2-3\cos\theta + \cos^3\theta]}\right]^{2/3} \ldots\ldots(7)$$

Figure 1 shows the absolute magnitude of the transferred charges on the bottom metal as a function of contact angle, θ. Insert shows the configuration of the charged water droplet and the substrate.Transferred charges flowing from the ground are induced on the bottom electrode attached onto the substrate due to the electrostatic induction mechanism through the dielectric material. As seen in the plot, when the contact angle is zero, the maximum point of the transferred charge is obtained.As θ increases, the amount of Q_{trans} decreases with the change in surface property from superhydrophilic to superhydrophobic. In other words, the contact area associated with the contact angle reduces as θ increases.

III. Conclusion

An analytical equation for transferred charges of awater droplet on adielectric surface with a contact angle was derived in this work. Based on the equation, the relationship between the contact angle and transferred charges was derived. The equation can serve as guidance for the design of the water-TENG structure in energy harvesting application.

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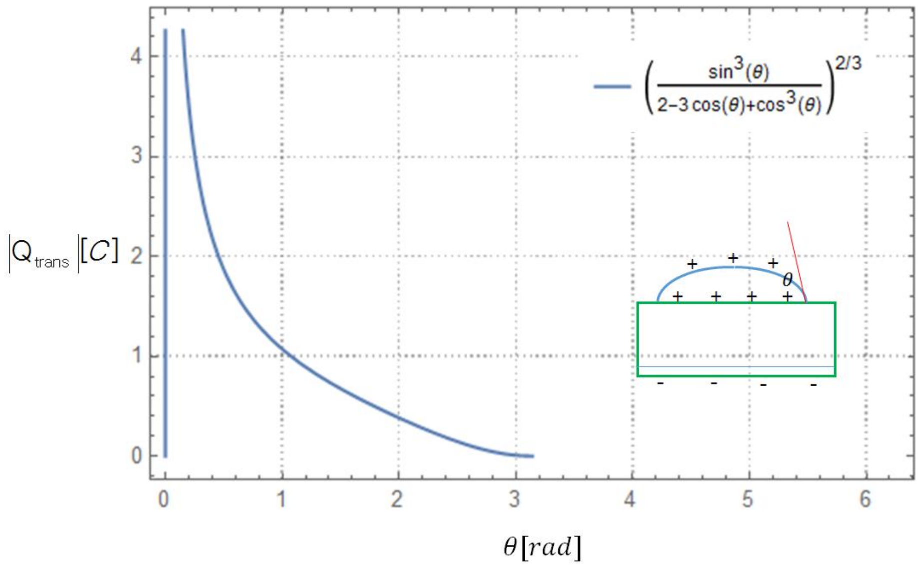
Figure caption

Figure 1: Plot of the absolute value of transferred charges collected on the bottom metal as a function of θ (contact angle). Insert shows the configuration of the water droplet on the substrate with a contact angle,θ. The water droplet is positivelycharged, which can then lead to the negative transferred charges induced on the bottom electrode.



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