Proceedings of the 18th UK Heat Transfer Conference
9-11 September 2024, Birmingham
UKHTC2024-19

# IMPROVED PERFORMANCE OF DROPLET-BASED ELECTRICITY GENERATORS USING SPECIALLY SHAPED SUBSTRATES

Huachen Su, Yuying Yan
Faculty of Engineering, University of Nottingham, UK

## 1. ABSTRACT

As an emerging technology, droplet-based electricity generators (DEGs) have been continuously developed in recent years and has been investigated in areas such as increasing the voltage generated by a single droplet, integration with different systems, etc [1]. The aim of this study is to investigate the potential of DEG for generating frequency. In this work, conical DEGs are investigated to explore their effect on the performance of DEGs. The experiments used three different angles of conical copper plate as substrates, in addition to a group of flat substrates as a control group. The use of conical DEGs requires little in the way of droplet size and height compared to schemes that use superhydrophobic surfaces to increase frequency.

## 2. INTRODUCTION

A droplet-based electricity generator (DEG) is an innovative device that transforms the kinetic energy of falling water droplets into electrical energy using the contact electrification. This effect occurs when two different materials come into contact, and in DEGs, this interaction is between water droplets and a hydrophobic triboelectric layer.

The structure of a DEG is precisely engineered to optimize this energy conversion process. It primarily consists of 4 elements. 1. Hydrophobic Triboelectric Layer (electret): This layer is crafted from materials that not only have high triboelectric properties but also repel water. The hydrophobicity ensures that the water droplets can easily roll off or bounce, enhancing the triboelectric effect by increasing the contact and separation speed, which is crucial for generating a higher electrical charge [2]. 2. Bottom Electrode: Positioned beneath the triboelectric layer, the electrode's role is to collect the electrical charges generated during the droplet's contact and separation from the triboelectric surface. This collected charge is then channelled into an external circuit, producing electricity. 3. Top Electrode: An electrode immediately above the upper surface of the hydrophobic triboelectric layer, which should be positioned to contact the droplet as it spreads to its maximum [3]. 4. Housing and Water Guiding System: The entire assembly is often encased in a protective housing that also serves to guide the water droplets to the triboelectric layer effectively. This design ensures that the droplets impact the surface at optimal angles and speeds, maximizing energy conversion efficiency. The resulting DEG is designed so that its generating voltage can be regarded as the ratio between the transferred charges and its capacitor, as demonstrated in Equation 1:

$$V = \frac{Q}{C_{HTL}} = \frac{Qd}{\varepsilon_p A_{max}} \tag{1}$$

where $V$, $d$, $C_{PTFE}$, $Q$, $\varepsilon_p$ ,and $A_{max}$ are the voltage generated, the thickness of electret layer, the capacitance of electret layer, the transferred charges, the dielectric constant of hydrophobic triboelectric film and the maximum spreading area of a water drop.

Most research now focuses on the amount of energy that can be converted from a single droplet impact, but the frequency of power generation is also an issue that needs to be addressed in order for the system to be applied. On a normal hydrophobic surface, if a droplet falls at a frequency of 50 Hz, the frequency of daily alternating current (AC), the droplet will form a water column, making the change in solid-liquid contact area, a key requirement for power generation, impossible to achieve. The hydrophobicity and shape of the electret surface are key factors in reducing contact time. These factors can have a significant impact on droplet dynamics,

*Corresponding Author: yuying.yan@nottingham.ac.uk

meaning that a hydrophobic surface with a high contact angle reduces adhesion and energy dissipation, thus promoting droplet bounce. The reduced interaction and adhesion allow the droplet to retain more of its kinetic energy, leading to a higher bouncing off the surface rather than spreading or sticking. At the same time, this experiment uses conical electret and bottom electrodes to increase the reduced droplet spreading due to the increased hydrophobicity. The aim of this experiment is to investigate whether conical DEG is a solution by studying the self-cleaning time and its output.

## 3. METHDOLOGY

The main objective of the experiments in this project is to investigate the effect of different solid surface structures on the self-cleaning time as well as the maximum diffusion area of the droplets. The experiment will be set up with three experimental groups. Experimental group will test the performance of the DEG at different numbers of cone top angles, 60°, 90° and 120°, and the schematic can be seen in figure 1. A high-speed video camera was used to observe the behaviour of the droplets on the cone surface, i.e. the spreading range and the separation time from the electret surface. All surfaces in contact with the droplets are superhydrophobic Polytetrafluoroethylene (PTFE).

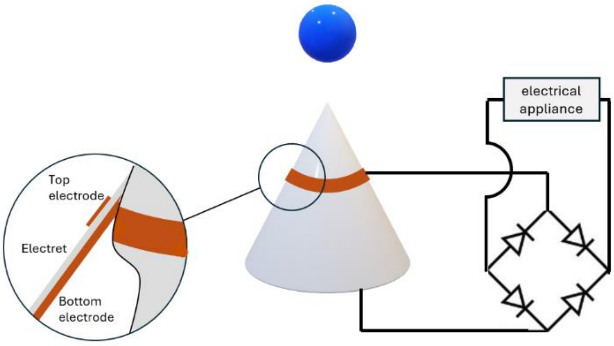


Figure 1. Schematic of conical DEG system

The parameters related to the droplets in this experiment are fixed. The physical parameters of the droplet are usually limited by the Weber number, which is calculated as follows:

$$We = \frac{Drag\ Force}{Cohesion\ Force} = \frac{\rho v^2 l}{\sigma} \quad (2)$$

where $\rho$ is the density of the fluid, $v$ is the velocity, $l$ is the characteristic length, and $\sigma$ is the surface tension. The weber number for each droplet in this case is 81. By controlling the height at which the drop falls and the thickness of the dropper, the Weber number can be controlled in the right range.

## 4. RESULTS

It is found that for a normal conical DEG, the smaller the cone angle, the smaller the maximum solid-liquid interface area and the smaller the output voltage. However, the self-cleaning cycle of conical surface of DEG is very short, when the cone angle is of 90° and the Weber number of the droplet is of 81, the droplet completes the whole process from the initial contact to separation within 5.1ms, which makes the frequency of the system to be as high as 196 Hz. The self-cleaning times for specific conical DEGs can be seen in Table 1 and Figure 1. The droplet bouncing induced by the superhydrophobic surface determines whether the droplets can leave the electret and electrode surfaces quickly, and the angle of the cone top angle determines whether the droplets can fly away quickly instead of falling back to the DEG surface. Moreover, Fig. 1 shows that the voltage generated by the DEG is only about one-third of that of the other two groups when the cone top angle is equal to 60°. The variation of the generated voltage is much sharper than the variation of the diffusion area of the droplets on different DEG surfaces. The mechanism behind this phenomenon remains unknown.

Table 1. Self-cleaning time and the peak voltage of conical DEGs with different angles.

| Apex angle of DEGs (°) | Self-cleaning time (ms) | $\boldsymbol{U_{peak}}$ (V) |
|---|---|---|
| 60 | 4.6 | 26.5 |
| 90 | 5.1 | 54.7 |
| 120 | 6.9 | 64.8 |

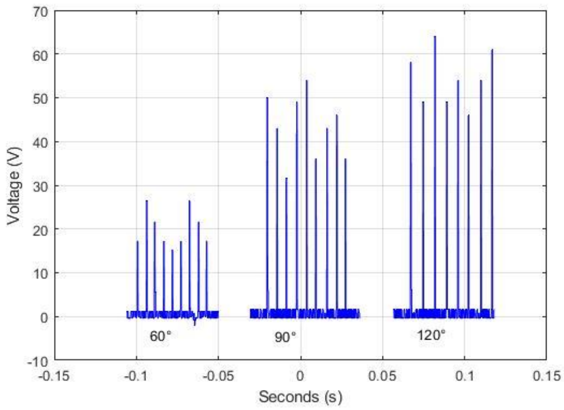

Figure 1. Voltage of conical DEGs with different angles.

To further quantify the outputs of DEG, the average voltage (URMS), known as the root mean square values of voltage in one measurement period and expressed as equation 3, would be a reasonable choice.

$$U_{RMS} = \sqrt{\frac{\int U(t)^2 dt}{T}} \quad (3)$$

where $U(t)^2$ and T denotes the measured voltage over time and the total time of the measurement, respectively. It is calculated that the DEG exhibits the best output when the cone top angle is 90°, i.e., $U_{RMS}$ equals to 8.12V.

## 5. CONCLUSIONS

The conical DEG has a high reference value in terms of the possibility to increase the frequency of DEG generation. Although, like DEGs on superhydrophobic surfaces, the processing is more complex and the power generation per droplet is reduced compared to normal DEGs, conical DEGs perform better in terms of increasing the frequency and require a lower Weber number of droplets. However, there is no good explanation for the sudden drop in single-droplet power generation in heterogeneous DEGs. This may be a part worth exploring.

## ACKNOWLEDGMENT

This work was supported by Royal Society (IEC\NSFC\211210) and H2020-MSCA-RISE-778104–ThermaSMART.

## REFERENCES

[1] Tang, W., Chen, B.D. and Wang, Z.L., Recent progress in power generation from water/liquid droplet interaction with solid surfaces. (2019). Advanced Functional Materials, 29(41), p.1901069.

[2] Lin, Z.H., Cheng, G., Lee, S., Pradel, K.C. and Wang, Z.L., Harvesting water drop energy by a sequential contact-electrification and electrostatic-induction process. (2014). Advanced Materials, 26(27), pp.4690-4696.

[3] Xu, W., Zheng, H., Liu, Y., Zhou, X., Zhang, C., Song, Y., Deng, X., Leung, M., Yang, Z., Xu, R.X. and Wang, Z.L., A droplet-based electricity generator with high instantaneous power density. (2020). Nature, 578(7795), pp.392-396.