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Design and optimization of rotating triboelectric nanogenerator by water electrification and inertia

Taehun Kim, Jihoon Chung, Dae Yun Kim, Joo Hyun Moon, Sukyung Lee, Minhaeng Cho, Seong Hyuk Lee*, Sangmin Lee*

School of Mechanical Engineering, Chung-Ang University, 84, Heukseuk-ro, Dongjack-gu, Seoul 156-756, Korea

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ABSTRACT

The recent energy crisis has resulted in numerous energy-harvesting methods receiving significant attention in the past decades. To overcome this crisis, we successfully develop a first-ever rotating water triboelectric nanogenerator (TENG) based on water-electrification and rotating fluid inertia. The proposed TENG is a fully packaged design composed of partially filled cylinder and gear systems. To the best of our knowledge, the correlation of inner fluid motion and electrical voltage output performance using fluid dynamics analysis is demonstrated for the first time. In addition, we propose guidelines for optimum design and operation of a TENG using a non-dimensional factor *G*, which is based on the angular velocity of the cylinder and the volume ratio of the water and cylinder. In addition, a multiphase fluid flow simulation is introduced to demonstrate fluid dynamic motion and the electrical potential based on instantaneous water motion. Furthermore, a portable hand-driven device combined with a gear train that can light 30 LEDs instantaneously is introduced to demonstrate the wide applicability of the proposed TENG. Thus, our study supports a simple model where a rotating cylinder is filled with water and can be used effectively to expand new types of energy-harvesting methods.

1. Introduction

Generating electricity from water is one of the largest renewable energy production methods globally. In the past decades, there have been significant developments in using electromagnetic water turbines to generate electricity from hydroelectric plants such as dams and pumped storage. Because hydroelectric generators generate electricity from the kinetic energy of water, they can produce massive energy with low cost and reduced CO_2 emissions. However, these generators have various downsides including high construction costs, complicated fabrication processes, and damage to local ecosystems due to construction of reservoirs. Alternatively, with the rapid development of nanogenerators, numerous studies have utilized nanogenerators as water energy harvesters [1–6]. Among these energy-harvesting methods, the use of a triboelectric nanogenerator (TENG) is a notable energy-generating mechanism that has high efficiency, low cost, and simple fabrication. TENGs generate electricity from mechanical input through a combination of triboelectrification between two dielectrics and electrostatic induction [7–9]. Many studies have shown TENGs harvesting hydrokinetic energy through watermills [10] or waterproof enclosed designs [11–13], and the possibility of using water itself as the contact electrification material has shown the liquid surface to be a direct contact for solid surface TENGs [14–16]. A liquid–solid contact TENG is much less likely to be affected by humidity and be damaged by friction between dielectrics, which is the biggest obstacle to be solved for sustainable TENG operation. In addition, packaged TENGs have been reported to generate energy under harsh environmental conditions [17–19]; hence, there were a few studies that demonstrated liquid–solid contact TENGs as a packaged design [20,21]. However, all previous packaged designs are based on reciprocation, causing the electrical output of the TENG to be generated only once each time water contacts the device. Therefore, utilizing rotation, which is a continuous and ambient motion in nature, is necessary for TENG designs. Furthermore, as the water behavior in a packaged system is the principle factor for liquid–solid contact TENGs, understanding the behavior of water, along with the optimization of TENG operational conditions, is required. Thus, an all-in-one approach for compact and packaged water TENGs is necessary.

In this study, we introduce the first rotational portable water TENG that generates electrical power through water electrification and inertial force. This rotational water TENG is based on the water flow of a partially filled rotating cylinder. For the first time, we

* Corresponding authors.
E-mail addresses: shlee89@cau.ac.kr (S.H. Lee), slee98@cau.ac.kr (S. Lee).
URLS: http://cau.ac.kr/~mtel/ (S.H. Lee), http://slee.cau.ac.kr (S. Lee).

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demonstrate a new mechanism of using contact-separation between the water surface and two distant electrodes inside a rotating cylinder. As the device rotates, water repeatedly contacts and separates with the patterned electrodes on the inner surface of the rotating TENG creating an alternating current. To demonstrate the water behavior inside a rotating device, we show the dynamic behavior of water depending on a non-dimensional factor *G*, which is based on the angular velocity of the cylinder and the volume ratio between the water and cylinder. Moreover, because water behavior is an essential factor for rotating water TENG, the electrical voltage and current output are investigated based on experimental and numerical methods. By considering the non-dimensional factor, a rotating water TENG can be designed and operated with optimized dimensions and angular velocity. A single

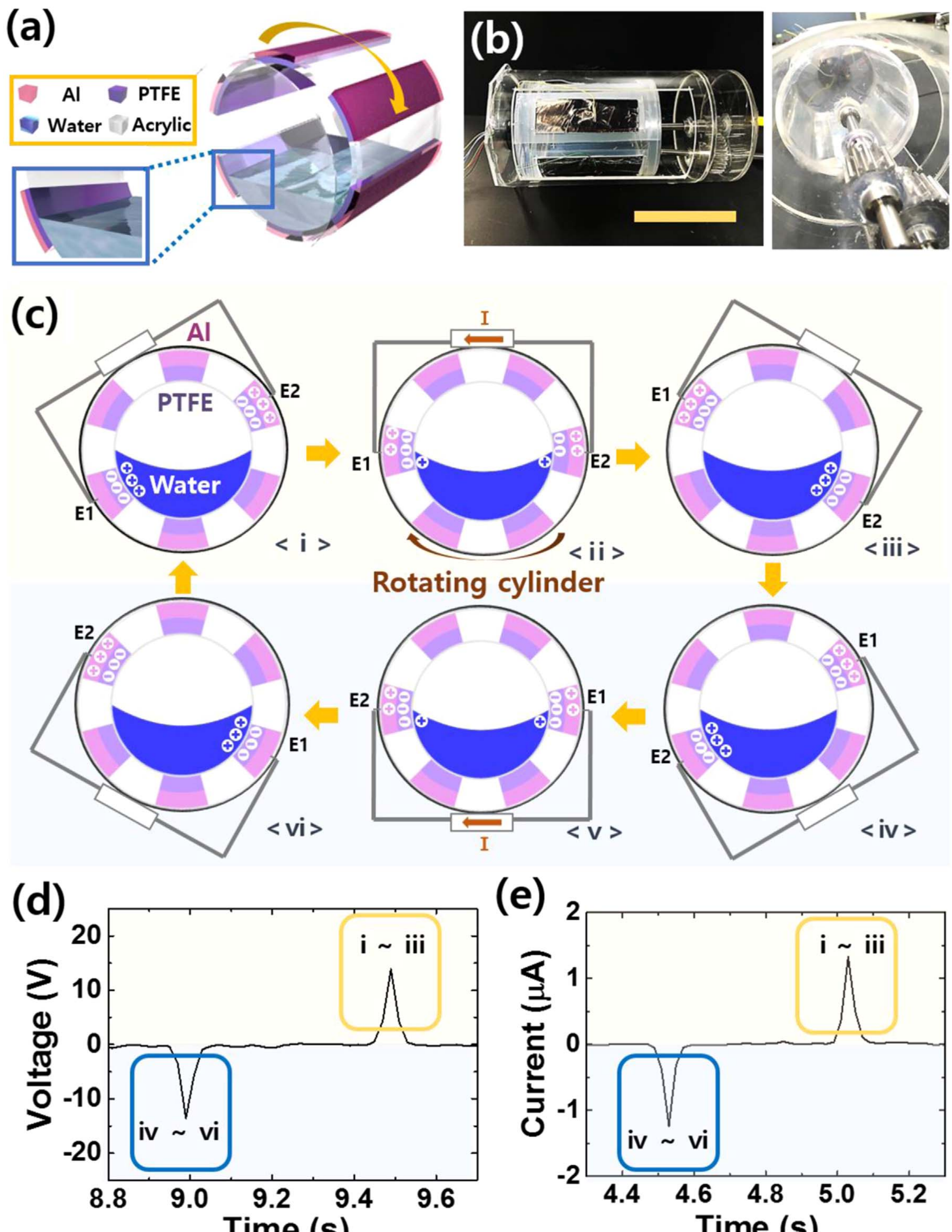

Fig. 1. Schematic and working principle of a rotating water TENG. (a) Schematic structure of a rotating water TENG. (b) Photograph of fabricated device including gear trains and TENG (scale 10 cm). (c) Step-by-step mechanism of rotating water TENG. (d) Plot of open-circuit voltage (V_{OC}). (e) Plot of closed-circuit current (I_{CC}) of rotating water TENG.