

Energy Harvesting and Application of a Tubular Triboelectric Nanogenerator Driven by Water Flow

Pin-Hsu Liao*, Yen-Hao Chiu, Wu-Yang Sean and Yao-Chuan Tsai

Dept of Bio-Industrial Mechatronics Engineering, National Chung Hsing University, Taiwan.

*Corresponding Author: m11354bill@gmail.com

Abstract

In recent years, growing awareness of sustainable and environmentally friendly practices has driven the development of innovative renewable energy technologies. To mitigate the environmental impact of energy production, this study proposed a tubular Triboelectric Nanogenerator (TENG) capable of continuously and stably harvesting energy from flowing water. The designed tubular TENG consisted of two structural components: the inner part served as the primary power generation unit, comprising a friction layer made of polytetrafluoroethylene (PTFE) and copper foil as the electrode material; the outer part functioned as a supporting frame, enhancing mechanical stability and protecting the device from external damage. The tubular TENG was installed inside a water pipe and activated by water flow. The generation mechanism relies on the triboelectric effect, due to the differing electron affinities between PTFE and water, they acquire opposite polarities of charge. Subsequently, electrostatic induction induces charge transfer on the copper electrodes, thereby generating an alternating current voltage. This research investigated the output voltage of a tubular TENG by varying its pipe diameter, electrode length, and water flow rate, along with testing its ability to power LED lights. Our findings indicated that a tubular TENG with an electrode length of 15 cm, a pipe diameter of 15 mm, and a water flow rate of 3 Liters Per Minute (LPM) achieved a maximum peak-to-peak voltage of 13.4 V_{pp}. In the future, it's hoped that small-scale energy from everyday life can be widely harvested, with the collected energy used to power small electronic devices and microsensors, thereby contributing to the development of sustainable energy.

Keywords:

triboelectric nanogenerator, energy harvesting, water flow, sustainable energy.

Introduction

Conventional fossil-fuel-based power generation emits large amounts of greenhouse gases during combustion, contributing to air pollution and global warming. With the growing awareness of environmental protection, various natural energy harvesting technologies—such as solar, wind, hydropower, and biomass—have been developed. Among them, traditional hydropower utilizes the natural water cycle, achieving an energy conversion efficiency of over 90%, long service life, and low operating costs, making it one of the most widely used renewable energies worldwide. However, conventional hydropower is unsuitable for pipeline systems, leaving the green energy present in flowing water within pipes largely untapped [1]. Therefore, developing a sustainable, low-cost, and eco-friendly technology to harvest energy from flowing water is essential to alleviate the energy crisis. This study aims to design a device capable of continuously and stably harvesting energy from water flowing through a tubular structure, providing power for low-power electronic devices [2] and microsensors. Such a system could form a self-powered solution, reducing reliance on batteries or external power sources and extending device lifespan.

Materials and Methods

2.1 Composition and Design of the Generator

In this experiment, a water-flow-driven PCP-TENG tube was fabricated using copper foil, polytetrafluoroethylene (PTFE), and an external support frame. The effects of varying the copper electrode length, TENG tube diameter, and water flow rate on the open-circuit voltage were investigated. The fabrication process is shown in Fig. 1.

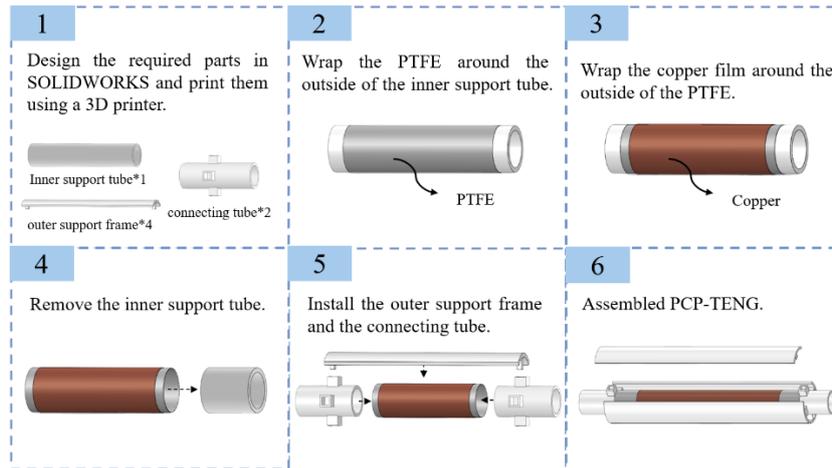


Fig. 1. Fabrication process of the PCP-TENG

2.2 Power Generation Principle and Measurement Setup

As shown in Fig. 2, the power generation mechanism involves triboelectric charging and electrostatic induction. Frictional contact between the PTFE and flowing water generates charges of opposite polarity. The charged PTFE induces electrostatic charges on the copper foil electrode, and the subsequent electron exchange between the copper foil and the ground produces an alternating output voltage.

As shown in Fig. 3, the measurement instruments include a flowmeter and an oscilloscope, connected to the PCP-TENG via water pipes to measure the open-circuit voltage.

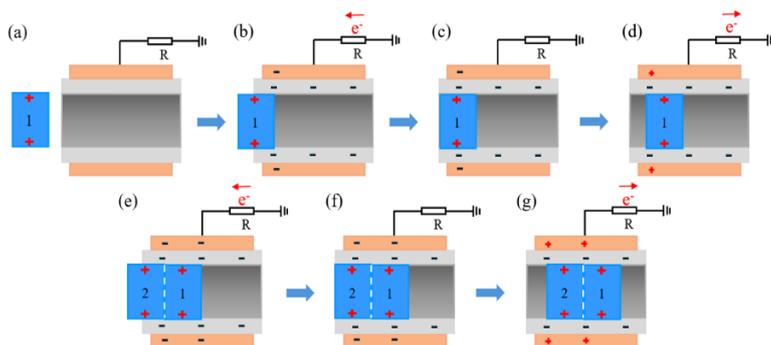


Fig. 2. Power generation principle of the PCP-TENG



Fig. 3. Measurement setup

Results and Discussion

First, regarding the effect of electrode length (Fig. 4), a longer electrode increases the contact area with the water flow, thereby generating more triboelectric charges and enhancing the output voltage. Experimental results show that when the electrode length increased from 5 cm to 20 cm, the output voltage rose from 9.2 V_{PP} to 15.2 V_{PP} . Next, for the effect of pipe diameter (Fig. 5), when the diameter increased from 12.5 mm to 20 mm, the output voltage decreased from 14.8 V_{PP} to 11.2 V_{PP} . This result is consistent with the formula proposed in previous studies [2]. Finally, regarding the effect of water flow rate (Fig. 6), the output voltage is related to the amount of triboelectric charges generated. Increasing the flow rate raises the contact frequency between the water and the PCP-TENG tube, resulting in more triboelectric charge generation and higher output voltage. The power supply performance of the PCP-TENG for LED lighting was also tested (Fig. 7). The generated AC voltage was converted to DC voltage through a bridge full-wave rectifier, enabling the simultaneous illumination of 15 white LEDs.

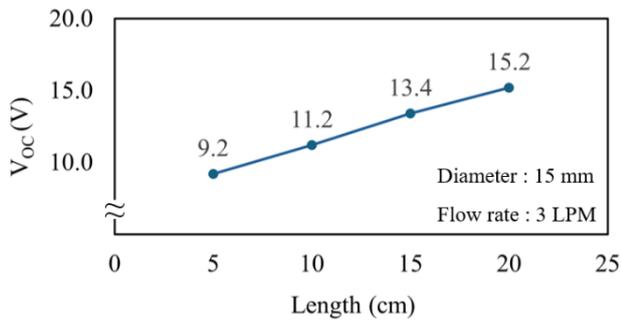


Fig. 4. Output voltage vs. electrode length

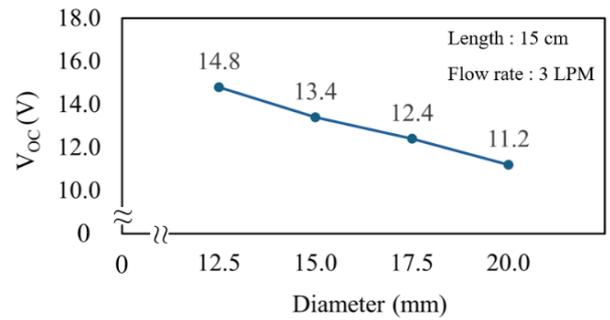


Fig. 5. Output voltage vs. pipe diameter

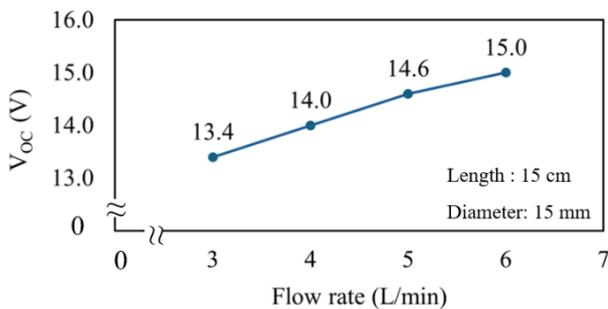


Fig. 6. Output voltage vs. water flow rate

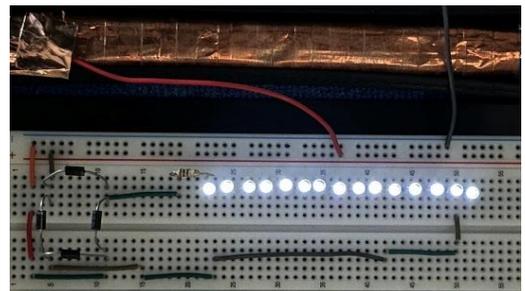


Fig. 7. LEDs power supply test

Conclusion

This study developed a single-electrode-mode PCP-TENG based on the triboelectric effect between flowing water and PTFE, combined with electrostatic induction from a copper electrode. Experimental results showed that output voltage is positively correlated with electrode length and water flow rate and negatively correlated with pipe diameter. When the electrode length and pipe diameter of the PCP-TENG are set to 15 cm and 15 mm, respectively, and the flow rate is 3 LPM, it can generate a maximum peak-to-peak voltage of 13.4 V_{PP} and successfully powered fifteen white LEDs. These results demonstrate the potential of the PCP-TENG for supplying energy to small electronic devices and microsensors in practical applications.

References

- [1] K. Munirathinam, D.-S. Kim, A. Shanmugasundaram, J. Park, Y.-J. Jeong, and D.-W. Lee, "Flowing water-based tubular triboelectric nanogenerators for sustainable green energy harvesting," *Nano Energy*, vol. 102, pp. 107675, 2022.
- [2] X. Tan, Z. Na, R. Zhuo, F. Zhou, D. Wang, L. Zhu, and H. Wu, "Micro water energy harvesting system based on tubular triboelectric nanogenerator," *Engineering Research Express, Advanced Functional Materials*, vol.6, pp. 045348, 2024.