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Triboelectric effect to harness fluid flow energy

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Triboelectric effect to harness fluid flow energy

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Abstract. We are reporting energy scavenging from fluid flows inside tubular structures using triboelectric effects. Two separate designs of triboelectric generators are proposed. A tubular design that uses liquid-solid interaction mechanism for water, and freestanding flapping films design utilizing contact-separation mechanism for wind flow energies conversions. The developed generators exhibit capabilities to produces power from fluid motions through the tube. Osmotic water having conductivity of 2.05±0.05 µS/cm provides higher triboelectric responses in comparison to tap water (conductivity of 322.0±2.0 µS/cm) flow. An average power of 37.4 µW for an osmotic water flow of82.5±0.5 cm^3/s was generated for two pairs of triboelectric generators. Under a wind flow of 8.2±0.1 m/s and using three pairs of generators an average power of 144.8 µW was obtained across an optimum load resistance *(R_L)* of 7.6 MΩ.

1. Introduction

With the growing demand of internet of things (IoT) and the limited lifespan of batteries prompts the demand for energy harvesting from renewable and sustainable energy sources and of developing self-powered electronics systems. Mechanical/ kinetic energies, that is generally wasted in everyday life, including water and wind flow energies can be harnessed to power low-power electronics.

Different principles, such as, electromagnetic [1] and piezoelectric [2], can be implemented to convert fluid flow energies to electrical signal. In recent time, triboelectric nanogenerator (TENG), that uses contact electrification and electrostatic induction mechanisms [3], has attracted extensive attention to harvest energy from kinetic motions/ vibrations implementing various designs because of simple fabrication process, possibilities of using wide varieties of materials and high energy conversion efficiency [4]. To date, several TENGs have been reported to harness mechanical energies from water flow [5–8], and wind flow [9–11]. However, fluid flow energy conversion through supply pipes infrastructure using triboelectric effect remains little explored.

Herein, we are reporting simple effective approaches to harvest, fluid flow energy scavenging, such as, water and wind flow energies through the tube/ pipe structures using soft triboelectric generators. In this regard, two separate mechanisms, namely, water-solid interaction and vertical-contact separation principle was implemented for water and wind energy scavenging, respectively.

2. Experimental procedure

2.1. Materials and designs

During this work, water-solid interaction design was used to harness water flow energy (Figure 1(a)), that consists of polytetrafluoroethylene (PTFE) tube with diameter of 16 mm and two metallic electrodes separated by fixed spacing attached to the outer wall. Freestanding flapping film design based on contact and separation principle was used for wind energy harvesting, which composed of PTFE and polyurethane (PU) active layers (Figure 1(b)). The geometric parameters of tubular and freestanding flapping triboelectric generators are listed in Table 1.

Commercial PTFE foil was purchased from 'Angst+Pfiste' and PU (MM4520) was supplied by SMP Technology Inc. As electrodes, XYZ-axis conductive scotch (9719, 3M) and conductive PU based elastomeric composite (CPU) prepared by dispersing electrically conductive carbon black pellets (Ketjenblack EC-600JD, Akzo-Nobel) were used.

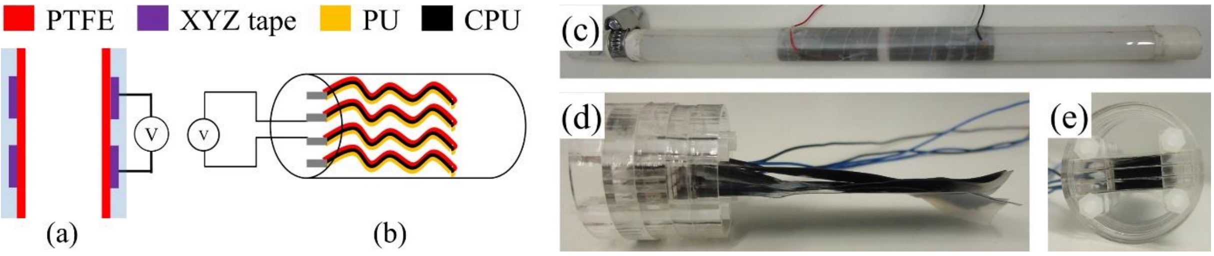

Figure 1. (a) Schematic of tubular generator design, (b) freestanding flapping film design, (c) photograph of tubular generator for water and (d, e) flapping film generator for wind flow energy harvesting.

Table 1. Dimensions of triboelectric water and wind energy harvesters.

Water energy harvester		
Tube diameter [mm]	:	16
Electrode length [mm]	:	25, 50
Gap between layers [mm]	:	5, 10, 20
Thickness of PTFE layer [μm]	:	30
Thickness of XYZ- axis tape [μm]	:	100

Wind energy harvester		
Film area [cm^2]	:	9.75
Gap between layers [mm]	:	1
Thickness of PTFE layer [μm]	:	30
Thickness of CPU layer [μm]	:	20
Thickness of PU layer [μm]		60

2.2. *Experimental process*

The thin foil of PTFE was applied as active triboelectric layer to prepare water-solid interaction-based tubular-shaped triboelectric generator to scavenging water flow energy inside the pipe structure. The XYZ-axis conductive tape was implemented as electrodes. Initially, XYZ tape was patterned, laminated on one surface of PTFE layer and wired. Thereafter, polyethylene terephthalate (PET) foil having thickness of 125 μm was laminated on PTFE structure with electrode in a way that electrodes are sandwich between PTFE and PET layer. Finally, the laminated layer was shaped in the form of tube/pipe, having diameter of 16 mm, with PTFE as active internal layer of the tube that will come in contact with water while operation (Figure 1(c)). The triboelectric generator having freestanding flapping film design for wind energy harnessing was prepared using PTFE and PU as active triboelectric layers. In this case, PTFE foil was utilized as substrate. Film casting technique was implemented to deposit conductive CPU composite layer as electrode followed by the deposition of PU to prepare PTFE-CPU-PU structure. Prior to the casting process, plasma treatment was conducted to enhance the adhesion between layers. Finally, triboelectric generator was assembled, by placing PTFE and

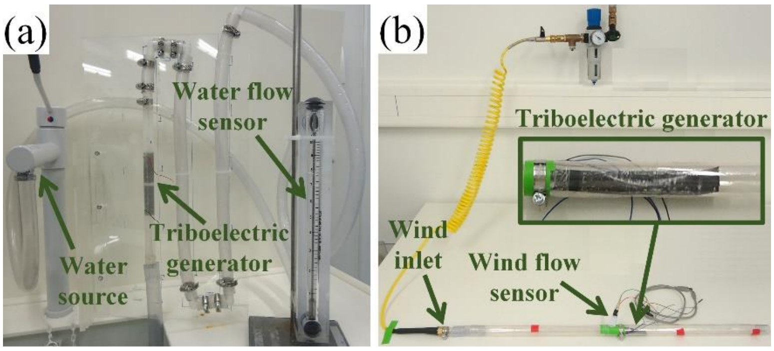

Figure 2. Image of experimental setup for (a) water flow and (b) wind flow.

PU layers facing one another (Figure 1(d, e)). The developed generator was then mounted inside the tube having diameter of 25 mm.

Figure 2 shows experimental setup for water and wind flow energy harvesting. During this work, to increase the frictional motion of water, loop was created to generate vertical fall of disturbed water flow inside active section. However, due to fixed tube diameter of 16 mm (used in this work), above the water flow rate of 82.5±0.5 cm^3/s, water column form inside the pipe that blocked the frictional flow of water over PTFE layer. Therefore, during the tests, maximum flow rate of 82.5±0.5 cm^3/s was used for the particular experimental setup as presented. The tests for water energy harvesting were performed using laboratory water supply installations for osmotic water (conductivity: 2.05±0.05 µS/cm) and normal tap water (conductivity: 322.0±2.0 µS/cm). For the wind flow energy scavenging, the holder of the films allows the wind to flow through the spacing only to maximize the film vibration. The output responses of the generators were measured across load resistances for certain flow using oscilloscope and power outputs was calculated. Finally, the root-mean-square (rms) values of voltage and current responses, and average of the output power was calculated over 10 second measurement duration.

3. Results and discussions

The tubular triboelectric generator having a diameter of 16 mm with two electrodes that was used to harvest water flow energy has two electrodes. PTFE was used as functional triboelectric layer and water acted as second functional material. When water came in contact with PTFE layer, exchange of charges took place due to contact electrification. The disturbed flow of water, causes unbalance in contact areas of water and PTFE layer in two zones that leads to charge flow between electrodes through the outer circuit. Therefore, using water-solid interaction principle, triboelectric output can only be generated until water is in frictional motion over active area of the functional PTFE layer, as soon as the frictional motion of the water halt triboelectric voltage generation stops instantly.

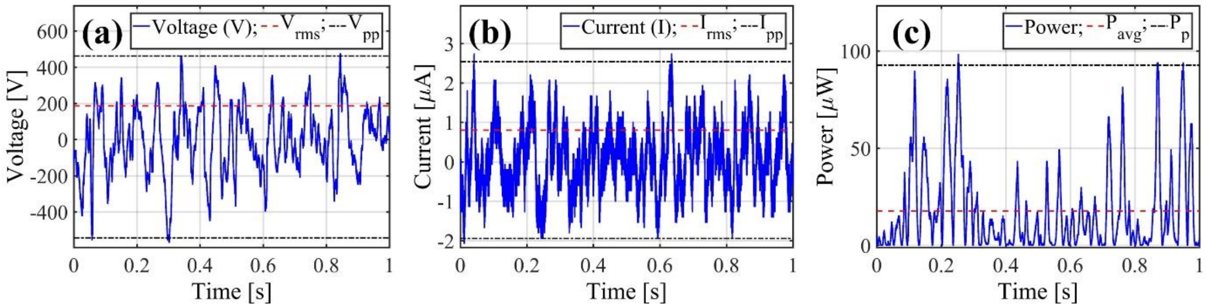

Figure 3. Triboelectric responses of tubular generator (having electrodes having lengths of 5 cm each and spacing of 5 mm between them) for osmotic water flow at rate of 82.5±0.5 cm^3/s, (a) open-circuit voltage, (b) short-circuit current and (c) power output across load resistance of 69.8 MΩ.

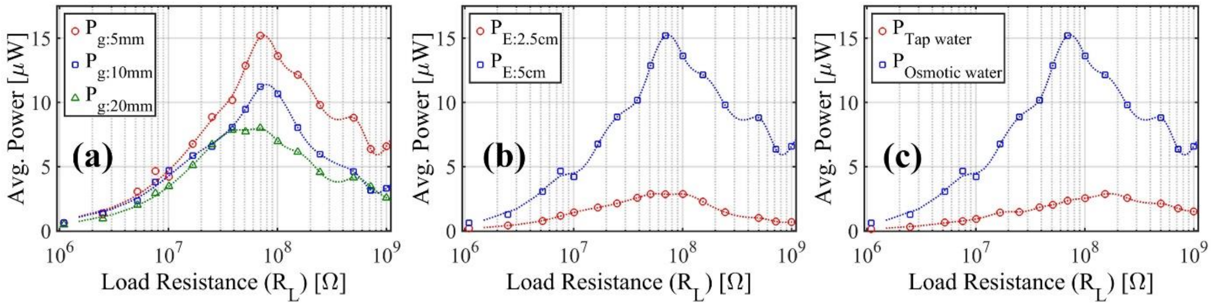

Figure 4. Average power output across load resistances (R_L) of tubular generator while water energy harnessing for water flow rate of 82.5±0.5 cm^3/s, (a) influence of spacing between two electrodes having lengths of 5 cm each for osmotic flow, (b) influence of electrodes length for fixed spacing of 5 mm between them for osmotic flow, and (c) influence of type of water flow (for electrodes having lengths of 5 cm each with spacing of 5 mm).

Electrode size of 2.5 cm and 5 cm (for fixed circumference for the tube diameter) and spacing of 5 mm, 10 mm and 20 mm between electrodes were tested. Figure 3 presents the open-circuit voltage (V_{OC}), short-circuit current (I_{SC}) and output power response over across load resistance (R_L) of 69.8 MΩ of tubular generator with electrodes having lengths of 5 cm each and spacing of 5 mm between them for osmotic water flow at rate of 82.5±0.5 cm^3/s.

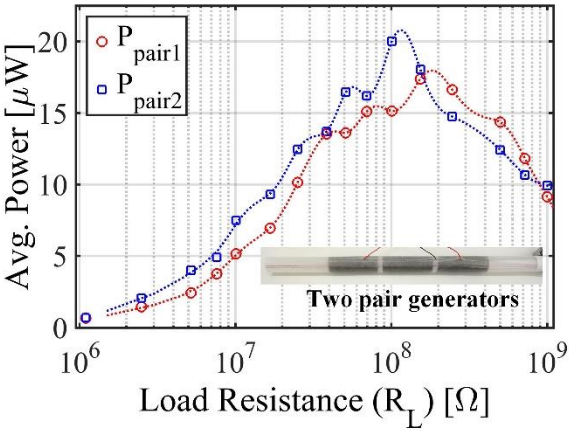

Figure 5. Average power output of tubular-generator having two generators for water energy harvesting under osmotic water flow rate of 82.5±0.5 cm^3/s across load resistances.

For the constant electrode size of 5 cm, the effect of varying spacing between electrode were examined (Figure 4(a)). Experiment shows that the for the fixed electrode size, the output triboelectric power response increases with the decreasing spacing between electrodes. Similarly, for the constant spacing of 5 mm between electrodes (Figure 4(b)), the higher triboelectric responses were observed for larger electrode size. The maximum power output was obtained for the electrode size of 5 cm with 5 mm spacing between electrodes. For the osmotic water flow at flowrate of 82.5±0.5 cm^3/s through the tubular generator, with two electrodes size of 5 cm each and spacing of 5 mm between them, generated average output power response of 15.2 μW across optimum R_L of 69.8 MΩ.

Triboelectric responses of the water-solid interaction principle based tubular generator is influenced by the type of water for constant flow rate (Figure 4(c)). The normal tap water, having conductivity of 322.0±2.0 μS/cm, reduced the optimum output average power output by ~5 times, when compared to the optimum average power output for osmotic water (conductivity of 322.0±2.0 μS/cm) for the constant water flow rate of 82.5±0.5 cm^3/s. Therefore, the dielectric property of the water is one of the important factor for water flow energy harvesting using water-solid interaction mechanism-based generator. Higher dielectric property of the water facilitated higher contact electrification and thus higher output responses. Finally, multiple pairs of triboelectric generator were implemented within the same tubular-generator shape to enhance the generated output power, as presented in Figure 5. For the osmotic water flow rate at 82.5±0.5 cm^3/s using two pairs of generators fabricated by mounting three electrodes having size of 5 cm each separated by 5 mm spacing in between, the total optimum average power output of 37.4 μW was harnessed.

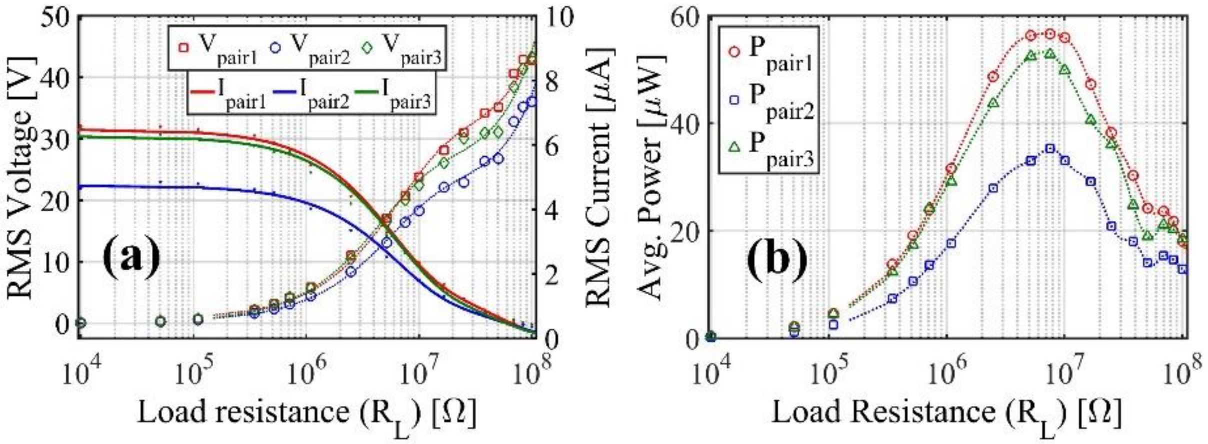

Figure 6. Triboelectric responses of freestanding film design generator for wind energy harvesting for wind speed of 8.2±0.1 m/s, (a) rms voltage and current, and (b) average power output across load resistances (R_L).

Similarly, the triboelectric principle can be used to harness wind flow energy. In this regard, freestanding flapping film-based generator was designed that consists of active PTFE and PU layers. The wind flow through the generator leads to the contact and separation between active triboelectric layers, which triggers charges transfer and drives electron flow between their corresponding electrodes. The triboelectric responses of generator for wind energy harvesting is illustrated in Figure 6. For single pair triboelectric generator average power (P_{avg}) of 56.6 μW for the optimum R_L of 7.6 MΩ and wind speed of 8.2±0.1 m/s. The output power response under the wind flow can be enhanced by stacking multiple pairs of generator within same frame. For three pairs of triboelectric generators under the wind flow at 8.2±0.1 m/s, total optimum average power output of 144.8 μW across 7.6 MΩ was obtained.

4. Conclusions

In summary, we have demonstrated the implementation of triboelectric effect for fluid flow, namely, water and wind flow, energy harvesting within enclosed pipe system. For water energy harvesting, triboelectric water-solid interacting mechanism was used with the tubular pipe being made of triboelectric material covered with electrodes. Whereas, freestanding triboelectric film-flapping generator was designed for wind flow energy conversion. Under optimum operational conditions, by stacking multiple pairs of generators, both tubular and freestanding film based triboelectric devices generated average output powers of tens to hundred of microwatts from water and wind flow. Future work will be focused on the optimization of the materials and designs of the generators for fluid flow energy scavenging with improved output responses.

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