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潤滑環境下における摩擦発電機の出力評価

Output Performance of Triboelectric Nanogenerator Under Oil Lubricating Conditions

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1. Introduction

With the advent of the Internet of Things (IoT) era, the demand for small sensors and electronic devices has increased exponentially, and the number of these is expected to increase further in the future. However, covering the power of sensors and devices with conventional batteries is expected to bring out excessive consumption due to the high cost of battery replacement and environmental problems from the disposal of waste [1]. Triboelectric Nanogenerator (TENG) has been drawing huge attention as an energy harvesting technology to solve the power issue [2]. TENG was newly developed by Wang's group in 2012, and it has various modes such as contact separation mode, lateral sliding mode, contact separation single electrode mode, lateral sliding single electrode, freestanding mode, etc. Its operation principle is based on the combination of the triboelectric effect and electrostatic induction [3]. Therefore, the magnitude of the output depends on the triboelectric properties of the dielectric material used. TENG stands out in various points, such as small-scale, lightweight, low cost, and high power density [4]. Moreover, because contact electrification is common in daily life, TENG has great accessibility and wide applicability to energy harvesting. TENG has shown potential applications such as self-power sensors, wearable sensors that harvest energy from human daily movements, and blue energy harvesting devices [5-7]. However, since contact electrification involves friction, and as a result wear inevitably occurs, which can adversely affect the stability and durability. To compensate for the limitations, various research papers have been reported: TENG deposited with diamond-like carbon (DLC) films, lubricated-TENG, and liquid-liquid interface TENG using ferrofluid [8,2,9]. In this study, lubrication was introduced to overcome the limitation. Fundamental research was conducted to investigate the output performance of TENG under lubricating conditions. In order to identify the effect of applying lubricants, various lubricants are used such as hydrocarbons, alcohols, carboxylic acids, and base oils with different dynamic viscosity and functional groups between the interfaces of a lateral sliding single electrode mode TENG. Also, the change of electrical output concerning normal load and sliding velocity in the TENG with Hexadecane was investigated.

2. Experiments

Figure 1 shows the working principle of lateral sliding single electrode mode TENG. An acrylic plate was installed for insulation on the reciprocating part of the friction tester. A 1-mm-thick aluminum plate was attached to it, and 90-μm-thick PTFE tape was attached to be used as a dielectric material. An acrylic plate was installed on the upper part for insulation also, and an aluminum plate to be used as an electrode was attached below the acrylic insulator. The upper aluminum plate (electrode) was connected to the grounded oscilloscope and multimeter. Various lubricants were dropped between the two sliding interfaces such as hydrocarbons, alcohols, carboxylic acids, and base oils. Most of the experiments were performed with a stroke of 30 mm, a frequency of 1 Hz, and a normal load of 1 N. To investigate the difference in the output according to normal load and sliding velocity, experiments were conducted under the normal loads of 5 N and 10 N and the sliding velocities of 0.5 Hz, 2 Hz and 3.5 Hz with Hexadecane as a lubricant liquid. Open-circuit average pk-pk voltage, which is the average value of the difference between the maximum and minimum voltages obtained in the last 10 cycles out of 100 cycles, is used as a representative value of electrical output.

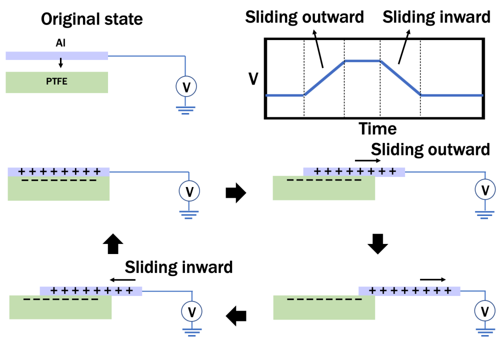

Fig. 1 Working principle of lateral sliding single electrode mode TENG Sample of figure

3. Results and discussion

The results depending on the type of lubricants, normal loads, sliding velocities, and dynamic viscosities are illustrated in Figure 2. The results demonstrated that TENG with hydrocarbons composed only of carbon and hydrogen, showed higher output than other groups. Carboxylic acids produced lower output than dry. Alcohols recorded the lowest output. Also, as the normal load increased, the outputs of both lubricated-TENG with Hexadecane and dry-TENG increased and saturated. This is because the effective contact area increases with a high normal load [3]. In dry-TENG, there was only a little difference in output with increasing sliding velocity, but in lubricated-TENG, the output increased significantly. Since the corresponding range of sliding velocity is considered as a boundary lubrication regime due to the low velocity, it suggests that the output increases with increasing sliding velocity in this regime. This could be the reason why the lubricant with higher viscosity yields a higher output at the same sliding velocity.

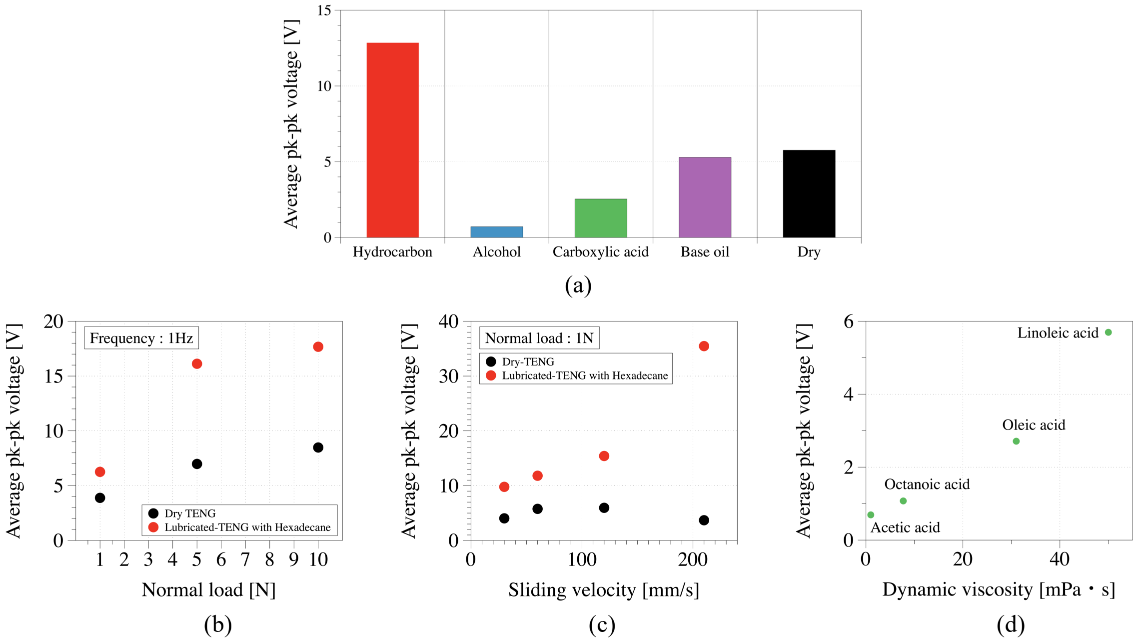

Fig. 2 Electrical output of TENG according to various (a) types of lubricant, (b) normal loads, (c) sliding velocities, and (d) dynamic viscosities

4. Summary

The change of electrical output according to various lubricants, normal loads and sliding velocities was observed using sliding-mode lubricated-TENG. As a result, the electrical output tends to increase with saturation as the normal load increases in both dry-TENG and lubricated-TENG due to the effective contact area. The output in dry-TENG is independent of the sliding velocity, whereas the output of lubricated-TENG in the boundary lubrication regime increases as rising velocity. Finally, between lubricants with functional groups, the higher the viscosity, the higher the output under the same sliding velocity condition. It is believed to be due to the difference in lubricant behavior with viscosity. This fundamental study suggests that for lubricated-TENG based on sliding motion, the lubricant behavior should be considered when predicting output or setting conditions.

Acknowledgment

This work was partially supported by JKA and its promotional funds from KEIRIN RACE.

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