VOLTAGE GENERATED FROM TRIBOELECTRIFICATION OF RABBIT FUR AND POLYMERIC MATERIALS

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ABSTRACT
Triboelectric Nanogenerators are emerging technology with huge potential in a variety of fields, from green energy to self-powered sensors. They are the products of triboelectrification which causes a generation of electrostatic charges on any two surfaces that come into contact with one another. This study aims at investigating the behavior of the voltage output of many different triboelectric nanogenerators with load, in both contact and separation as well as sliding.

It was found that, when the applied load on a TENG increases, the generated voltage increases linearly. The generated voltage at sliding was higher than that generated in contact and separation. Besides, rough contact surfaces generated relatively higher voltage especially at contact and separation due to the increase of the contact area subjected to friction.

KEYWORDS
Voltage, triboelectrification, contact and separation, sliding, rabbit fur, polypropylene, polytetrafluoroethylene, Kapton.

INTRODUCTION
It is well known that when two materials come into contact with one another, electric charges of equal but opposite values accumulate on each surface. This phenomenon is known as triboelectrification, [1 - 4]. Since triboelectrification is such a widespread phenomenon, reducing it when necessary is important, as it is hypothesized that electrostatic charges (ESC) can accelerate the growth of cancer cells, [5] and can cause fires, [6, 7], research was done to try to find ways to reduce the electrostatic charge generated by different textiles, like reducing the charge generated by polyester, [8], artificial turf, [9], and floors, [10]. It is not essential that in all circumstances, low ESC is desirable, for example, it is thought that masks and medical equipment can resist viruses like Covid-19 better if they have a negative charge generated on their surfaces, [11 - 14].

In order to predict the amount and type of charge generated on each surface when two surfaces come into contact, the triboelectric series was developed, [15 - 17]. It ranks materials by their likelihood of acquiring a positive charge when they come into contact with another
material. Thus, materials lower in the series are more likely to obtain a negative charge, in the triboelectric series, where polytetrafluoroethylene (PTFE), polypropylene (PP) and Kapton lie close to the bottom of the series, while rabbit fur lies close to the top of the series, [18].

Triboelectrification was recently used as a source of clean energy. If metal electrodes were placed on one surface of two different materials that are on the opposite ends of the triboelectric series, and the two materials were then forced to come into contact with one another, a potential difference will generate between the two electrodes due to the different charges that accumulate on both of them. If the two electrodes were shorted, a small current will pass between them, before an equilibrium state is reached. This device is known as a triboelectric nanogenerator (TENG). The TENG can be used in energy generation, [19 - 22] and self-powered sensors, [23 - 26]. The output voltage of a TENG can be predicted using the V-Q-x equation, [27].

Previous work has been done to obtain a relationship between the applied force on a TENG and its output voltage in contact and separation mode, it was found that in most cases, the voltage rises rapidly at first, then the rate of increase of voltage with force starts to decrease and the relationship becomes more and more linear, [28 - 30].

The present study aims to investigate the voltage generated from contact and separation as well as sliding of rabbit fur and polymeric materials.

EXPERIMENTAL
Eight different TENG terminals were made of aluminum foil adhered to the tested contact surfaces by a thin layer of double-face adhesive. The dielectrics used were rabbit fur, PP, PTFE and Kapton. The rabbit fur was adhered to a wooden cube of 40 × 40 ×40 mm³, while the polymeric materials PP, PTFE and Kapton in the form of tape were adhered to a polymeric base. Both rubber fur and polymeric tapes were fitted by an aluminum sheet of 0.25 mm thickness to be used as terminals to measure the generated voltage resulting from contact and separation as well as sliding.

![Fig. 1 The measuring procedure.](image_url)
The tested different dielectrics were pressed against each other under load varying from 3.3 to 20.5 N and separated. Then the voltage between the two aluminum foil electrodes was measured using a voltmeter. This process was repeated 10 times for every load value for
every pair of dielectrics, and the average voltage values were calculated. The details of the measuring procedure and materials are shown in Figs. 1 – 4. During sliding the rabbit fur was slid along the length of 200 mm of the polymeric tapes and the voltage after separation was measured using a voltmeter.

RESULTS AND DISCUSSION
The results of this experiment are shown in Fig. 5 – 9, where the voltage generated from contact and separation as well as sliding of the tested materials is illustrated. As for rabbit fur and Kapton, Fig. 5, voltage significantly increased with increasing normal load at contact and separation as well as sliding. It can be noticed that the relationship between the normal load and the voltage is linear, however, this seems to contradict the previous results, [30], which describe the relationship between voltage and load as rapid rising at first, and then later plateauing and approaching a linear relationship after crossing a specific threshold. However, considering that those experiments were done at higher loads than the ones at which the threshold mostly exists. The linear relationship can be useful in most applications. Sliding of the tested specimens, the voltage generated was relatively higher than the voltage generated in contact and separation. The values of the voltage at 20.5 N load were 1200 and 300 mV at sliding as well as contact and separation respectively.

The voltage generated from contact and separation as well as sliding of rabbit fur on PP, Fig. 6, significantly increased up to values higher than that observed for rabbit fur/Kapton. This behavior was expected due to the location of PP and rabbit fur in the triboelectric series. Further voltage increase was observed for the pair of rabbit fur/PTFE, Fig. 7, where the highest values were approximately 3000 and 4000 mV at contact and separation as well as sliding respectively. This observation can recommend those materials to be applied in TENG development.
Fig. 6 Voltage generated from contact and separation as well as sliding of rabbit fur on PP.

Fig. 7 Voltage generated from contact and separation as well as sliding of rabbit fur on smooth surface of PTFE.
Further experiments were carried out to investigate the influence of the surface texture on the voltage generated from TENG. PTFE film was adhered by emery paper of 60 and 120 grit.
grit as substrates, Figs. 8 and 9. It was noticed that the roughened PTFE by 120 grit generated relatively higher voltage than that measured for 60 grit. That is clearly shown at contact and separation. It seems that as the number of asperities of the contacting surfaces increases the ESC increases. This can be attributed to the increase of the contact area of PTFE subjected to the friction of the fur fibers.

CONCLUSIONS
1. As the applied load on a TENG increases, the generated voltage increases.
2. At the load range tested in this experiment, voltage increases linearly with load.
3. At sliding, the generated voltage was higher than that generated in contact and separation.
4. Increasing the number of asperities of the contacting surfaces increases the generated voltage.

REFERENCES