EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 20, No. 1, January 2023, pp. 41 - 50 ISSN 2090 - 5882
(Received October 19. 2022, Accepted in final form November 18. 2022) jest.journals.ekb.eg

ENHANCING THE EFFICIENCY OF TRIBOELECTRIC NANOGENERATOR BY ELECTROSTATIC INDUCTION

Ali A. S.[1], Youssef M. M.[2] Ali W. Y.[3] and Rashed A.[3]

[1]Mechanical Engineering Dept., Faculty of Engineering, Suez Canal University, EGYPT.
[2]Automotive and Tractors Engineering Dept.,
[3]Production Engineering and Mechanical Design Dept.,
Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
The present work aims to enhance the efficiency of the triboelectric nanogenerator (TENG) by electrostatic induction. The two surfaces of the TENG were made of polytetrafluoroethylene (PTFE) and polyamide (PA) due to their location in the triboelectric series where contact and separation as well sliding of two materials were carried out. Electrostatic induction was proposed to insert a coil of insulated copper wires wrapped on the surface of hollow box, representing the frame of the coil, of different height under the surface of PTFE. The voltage difference between PTFE film coating insulated copper wire coil and PA was measured.

It was found that voltage remarkably increased up to maximum then drastically decreased with increasing the height of the frame containing the copper coil. Based on the experimental observation, it seems that induction of the copper coil is the reason for the voltage increase due the induced electric field. The significant voltage increase depends directly on the electric field that is much influenced by the height of the hollow box containing the coil. Besides, transverse sliding showed the highest voltage, while contact and separation displayed the lowest voltage values. Inserting steel sheet under PA surface, significantly increased the voltage due to the increase of the magnetic field. Using two layers of the coil offered the highest voltage values, then as the number of layers increased, voltage decreased.

KEYWORDS
Triboelectric nanogenerator, polytetrafluoroethylene, polyamide, copper wire coil, electrostatic induction.

INTRODUCTION
Universe climate warming caused by the accelerated consumption of fossil fuels is one of the most serious dangers that the world faces. It is necessary to increase the investment in the field of renewable and clean energy. TENG may be suitable

alternative, [1 - 3]. Several attempts were carried out to increase the efficiency of TENG, [4, 5]. Recently, it was revealed that providing one of the contacting surfaces (PTFE) by insulated copper wires increased the voltage difference between the two surfaces of the TENG, [6]. It was observed that the voltage decreased as the diameter of the wires increased. It seems that copper wires induced an electric field that generated an electric current. In addition to that, the voltage difference depended on the number of copper wires turns as well as the direction of sliding relative to the copper wires. It was proposed that the charged zones on the two surfaces of the TENG generate ESC, [7, 8]. The two surface of the TENGs based on contact–separation mode were assembled by using PA and PTFE on acrylic sheet.

The intensity as well as the sign of ESC generated on the surface of the two contacting materials due to the triboelectric effect is controlled by the triboelectric effect, [9 - 11], related to the triboelectric series that rank materials by acquiring positive or negative charge on the surface of the contacting material. PTFE obtains a negative charge upon contact with the other materials, [12], while PA acquires a positive charge, [13]. When PA and PTFE are put in contact with each other, PTFE gains high negative charge, while PA gains high positive charge. Contact and separation between two dissimilar materials generates ESC.

The TENG is always made of two dielectric materials that are located on the opposite sides of the triboelectric series and then two electrodes are adhered to them. Because contact and separation as well as sliding, the two dielectric materials induce equal and opposite charges on their surfaces. That potential difference provides an electric current applied in energy harvesters, [14 -17], and self-powered sensor, [18 - 21]. TENGs are be classified into contact and separation sliding type TENGs, [22 - 25].

The effect of induction on the intensity of ESC generated on the surfaces of polymers slid against PTFE, polypropylene (PP), and PA was investigated, [26 - 29], where metallic wires and carbon fibers reinforcing PE and sliding against PA showed relatively higher values of ESC due to the generation of an electric field inside the PE matrix.

The aim of the present study is to enhance the efficiency of triboelectric nanogenerator (TENG) by electrostatic induction. It is proposed to insert a coil of insulated copper wires wrapped on the surface of hollow box of different height under the surface of PTFE to increase the ESC generated by induction. The voltage difference between PTFE film coating insulated copper wire coil and PA was measured.

EXPERIMENTAL

Two sets of tests have been performed. It is proposed to introduce insulated copper wire coil around a hollow box of 10, 20, 30 and 40 mm height coated by PTFE film. The other surface is prepared from PA textile adhered to wooden block of 300 mm long and 100 mm wide. The two terminals are made from aluminium (Al) film of 0.25 mm thickness, where the first terminal is adhered under PTFE and the second is

adhered under PA textile, Figs. 1 and 2. In order to investigate the effect of magnetic field on the voltage difference of the proposed TENG, steel sheet of 0.25 mm thickness is placed under PA textile, Fig. 3. The applied load was 10 N. After sliding, the voltage difference between the two sliding surfaces was measured. The sliding distance was 0 (contact and separation) and 200 mm for sliding. The test sliding velocity was nearly controlled to be 2 mm/s. The insulated copper wires were of 0.1 and 0.2 mm and 80, 100 and 160 turns.

The test procedure consists of contact and separation as well as sliding in the direction of the wires (longitudinal sliding) and normal to the wires direction (transverse sliding), Fig. 4. In contact and separation, the load is applied for 5 seconds then the measurement of the voltage is achieved. Sliding is carried by loading the PTFE on PA textile and sliding for 200 mm manually.

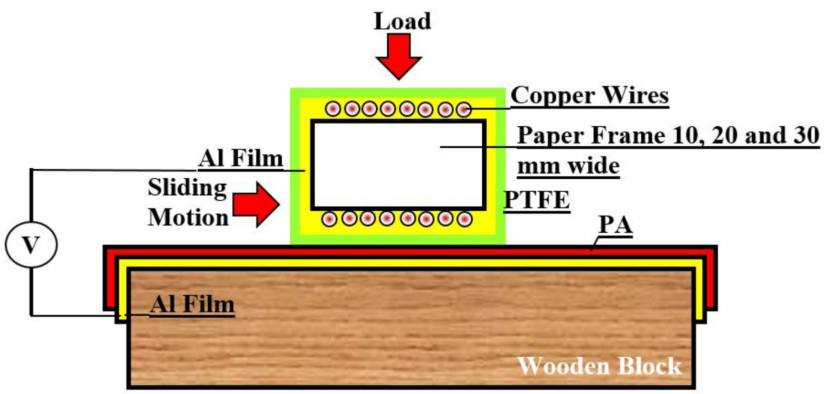

Fig. 1 Schematic drawing of the test procedure.

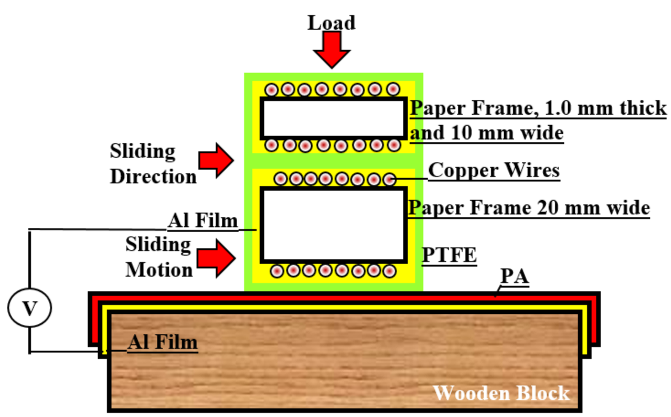

Fig. 2 Details of the tested specimen.

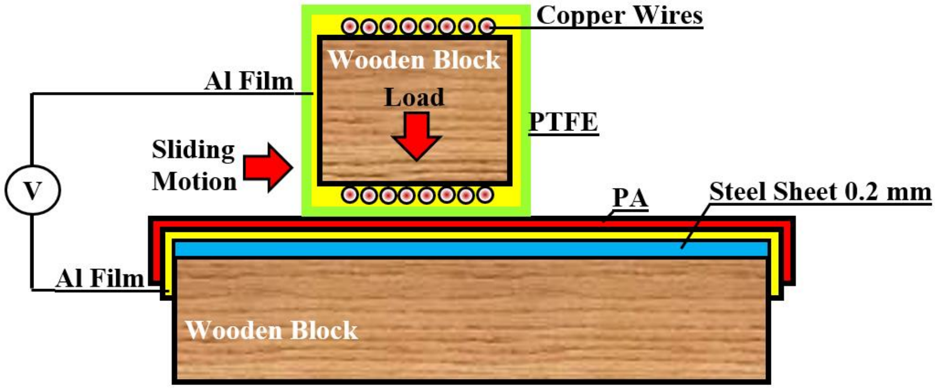

Fig. 3 Arrangement of the test specimens where sheet steel was inserted under PA.

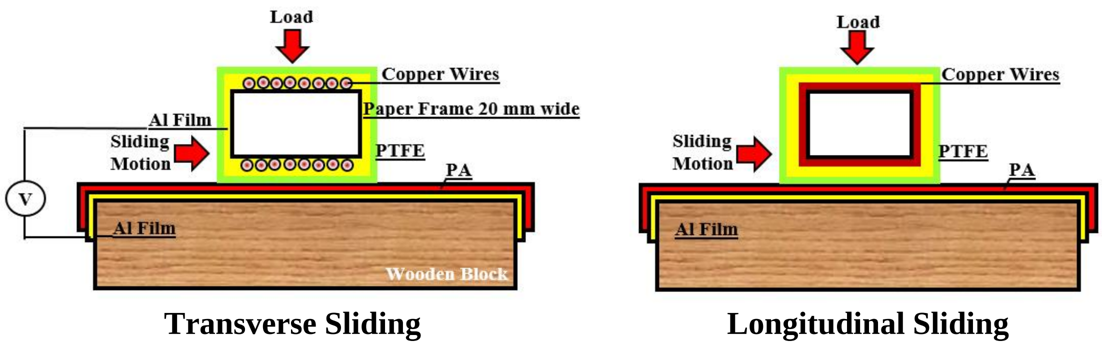

Fig. 4 The direction of sliding relative to the wire direction.

RESULTS AND DISCUSSION

Voltage generated from contact and separation as well as sliding of PTFE coating insulated copper wires coil of 0.2 mm diameter and 100 turns on PA is shown in Fig. 4. It is clearly shown that voltage significantly increased up to maximum then drastically decreased with increasing the height of the coil frame. The highest voltage values were observed at 10 – 20 mm height. Those values were 820, 2500 and 3000 mV for contact and separation, longitudinal and transverse sliding respectively.

It seems that the electric field generated from the induction of the copper coil is responsible for that behavior. The generation of the double charge layers on the two contact surfaces in the presence of the coil generated an extra electric field of value higher than that generated from friction. The distribution of the ESC generated on the contact surfaces is illustrated in Fig. 5.

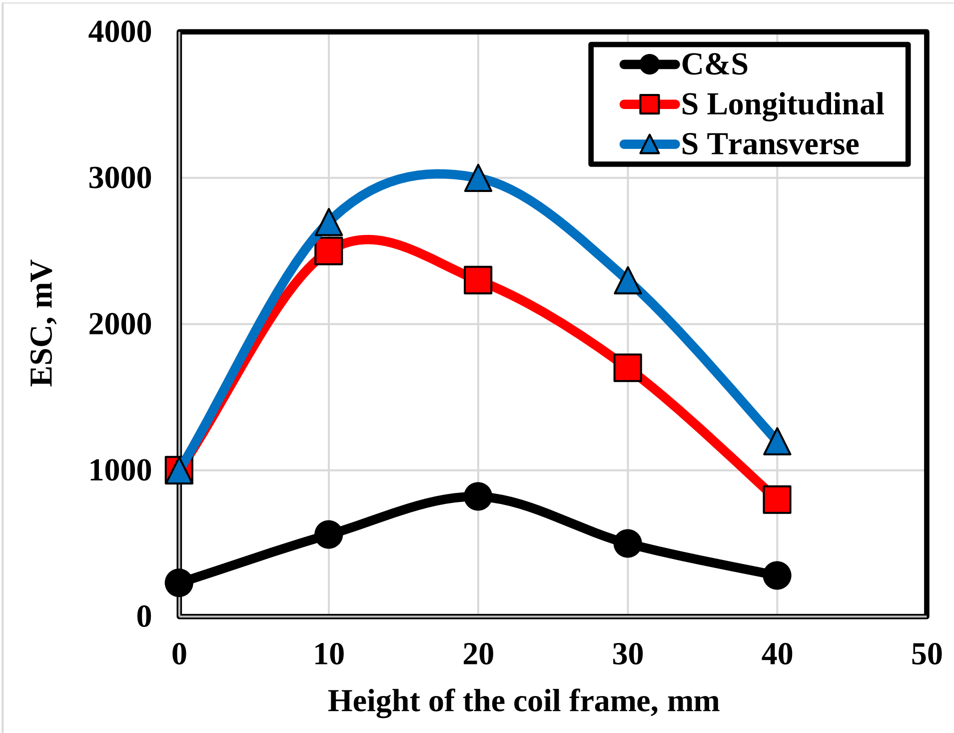

Fig. 4 Voltage generated from contact and separation as well as sliding of PTFE coating insulated copper wires coil of 0.2 mm diameter and 100 turns on PA.

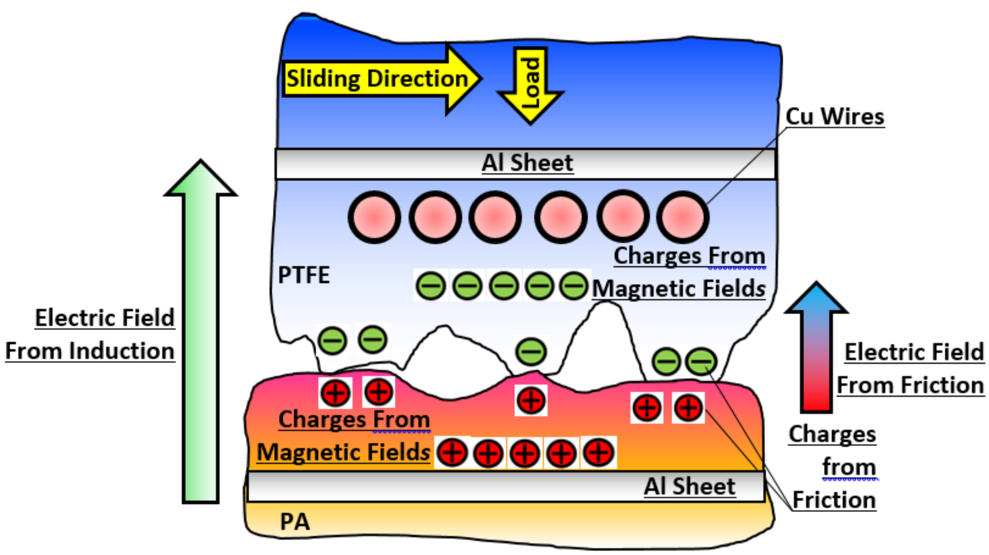

Fig. 5 Illustration of the distribution of the ESC generated on the contact surfaces.

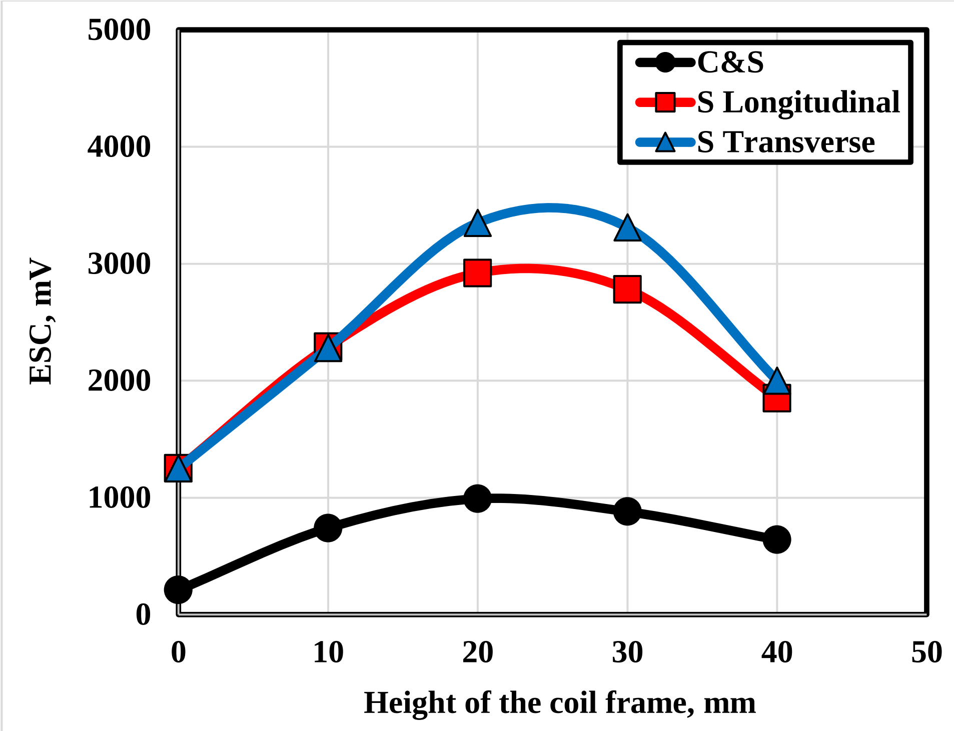

Fig. 6 Voltage generated from contact and separation as well as sliding of PTFE coating insulated copper wires coil of 0.2 mm diameter and 100 turns on PA coating aluminum film and steel substrate.

It is well known that the strength of the electric field crossing the sliding surface is related to the intensity of ESC generated. Faraday indicated that the change of the electric field may induce a current in in the coil and thus create a source of electromotive force (voltage, potential difference). When the coil is moved through electric field, or electric field moves through the coil, electric current will be induced and flow into the coil and consequently voltage difference will increase. The significant voltage increase depends directly on the electric field that is much influenced by the height of the coil frame. The results indicated that there is a certain value of the height of the coil frame that gives the highest voltage.

The effect of inserting steel sheet of 0.25 mm thickness under PA surface is illustrated in Fig. 6. Voltage generated from contact and separation as well as sliding of PTFE, coating insulated copper wires coil of 0.2 mm diameter and 100 turns, on PA coating aluminum film and steel substrate recorded relatively higher values than that displayed without steel substrate. The highest voltage were observed at height of the coil frame ranging from 20 to 30 mm. Voltage values were 3350, 2920 and 990 mV for transverse sliding, longitudinal sliding and contact-separation respectively. It seems that the relative voltage increase is due to increase of the magnetic field offered by the steel sheet.

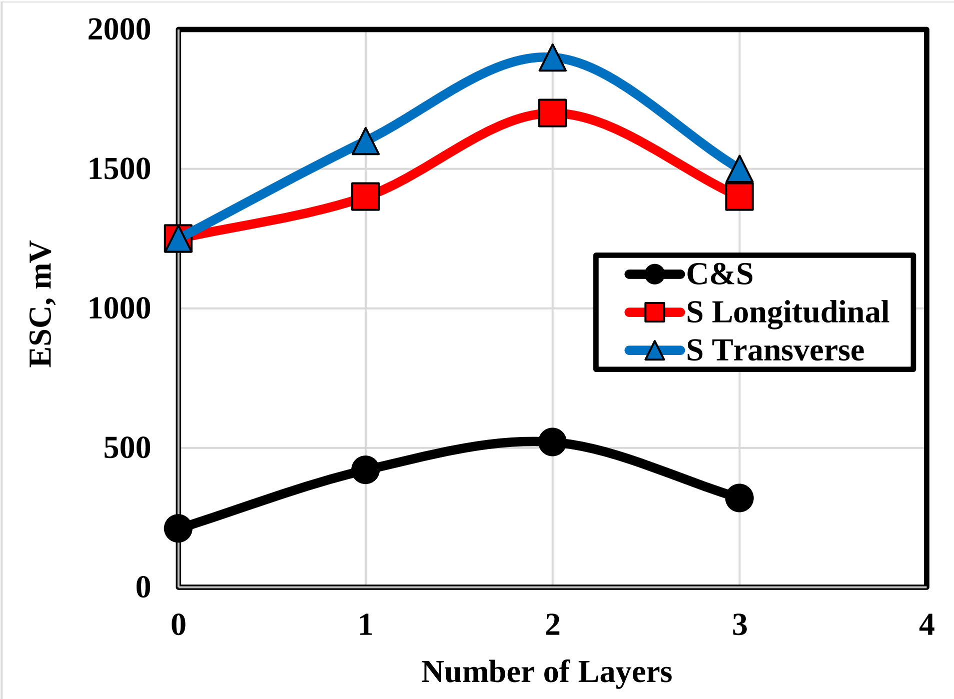

Fig. 7 Voltage generated from contact and separation as well as sliding of PTFE coating insulated copper wires coil of 0.1 mm diameter and 80 turns on PA.

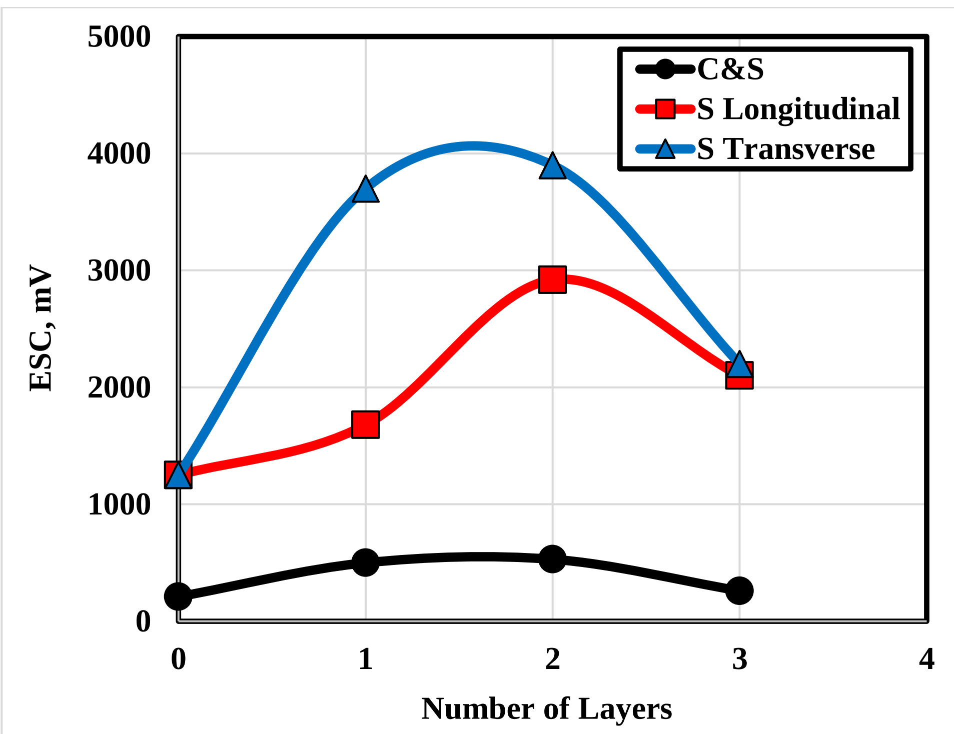

Fig. 8 Voltage generated from contact and separation as well as sliding of PTFE coating insulated copper wires coil of 0.1 mm diameter and 160 turns on PA.

Further experiments were carried out to investigate the influence of the number of the layers of the copper wire coils on the generated voltage, Fig. 7. Voltage generated from contact and separation as well as sliding of PTFE coating insulated copper wires coil of 0.1 mm diameter and 80 turns on PA textile showed the highest values for two layers of the coil. As the number of layers increased voltage decreased. Variation of the voltage may be from the influence of the electric field induced by the coil. The transverse sliding of PTFE on PA displayed the highest voltage (1900 mV) followed by longitudinal sliding (1700 mV) and Contact and separation (520 mV).

Increasing the number of turns of the copper coil showed significant increase in the values of the generated voltage. Voltage difference between the two contacted surfaces of PTFE and PA is illustrated in Fig. 8. The voltage values were 530, 2920 and 3900 mV recorded for contact-separation, longitudinal and transverse sliding. The significant voltage increase may be attributed to the increase of electric field due to increase of the copper wire turns to 160. The highest voltage values were observed at two layers of copper coil.

CONCLUSIONS

1. Voltage significantly increased up to maximum then drastically decreased with increasing the height of the frame containing the copper coil.
2. Contact and separation represented the lowest voltage values, while transverse sliding showed the highest ones.
3. When steel sheet was inserted under PA surface, voltage displayed relatively higher values than that recorded without steel substrate.
4. Voltage showed the highest values for the two layers of the coil, then decreased with increasing the number of layers.

REFERENCES

1. Gielen D., Boshell F. and Saygin D., "Climate and energy challenges for materials science", Nat. Mater. 15 (2), pp. 117 - 120, (2016).
2. Fan F. R., Tian Z. Q. and Wang Z. L., "Flexible triboelectric generator", Nano Energy 1 (2), pp. 328 - 334, (2012).
3. Schiermeier Q., Tollefson J., Scully T., Witze A. and Morton O., "Electricity without carbon", Nature 454 (7206), pp. 816 - 823, (2008).
4. Al-Kabbany A. M. and Ali W. Y., "Contact and Separation of Kapton and Polymethylmethacrylate Triboelectric Nanogenerator", Journal of the Egyptian Society of Tribology, Vol. 19, No. 4, October 2022, pp. 63 – 74, (2022).
5. Ameer A. K., Al-Kabbany A. M., Ali W. Y. and Hamdy K., "Influence of Surface Roughness on the Output Voltage of a Triboelectric Nanogenerator", Journal of the Egyptian Society of Tribology, Vol. 19, No. 3, July 2022, pp. 45 – 52, (2022).
6. Ali A. S., Youssef M. M., Ali W. Y. and Elzayady N., "Triboelectric Nanogenerator Based on Contact and Separation as well as Sliding of Polyamide on Polytetrafluoroethelene", Journal of the Egyptian Society of Tribology, Vol. 20, No. 1, January 2023, pp. 31 – 39, (2023).
7. Lowell J. and Truscott W. S., "Triboelectrification of Identical Insulators: II. Theory and Further Experiments", J. Phys. D: Appl. Phys., 19, pp. 1281-1298, (1986).

8. Baytekin H. T. and Patashinski A. Z., Branicki M., Baytekin B., Soh S. and Grzybowski B. A., "The Mosaic of Surface Charge in Contact Electrification", Science, 333, pp. 308 – 312, (2011).
9. Zou H., Zhang Y., Guo L., Wang P., He X., Dai G., Zheng H., Chen C., Wang A. C., Xu C. and Wang Z. L., "Quantifying the triboelectric series", Nature communications, Vol. 10, No. 1, pp. 1427, (2019).
10. Diaz, A. F., and Felix-Navarro R. M., "A semi-quantitative tribo-electric series for polymeric materials: the influence of chemical structure and properties", Journal of Electrostatics, Vol. 62, No. 4, pp. 277-290, (2004).
11. Burgo, Thiago AL, Galembeck F., and Pollack G. H., "Where is water in the triboelectric series?", Journal of Electrostatics Vol. 80, pp. 30 - 33, (2016).
12. Zhang R. and Olin H., "Material choices for triboelectric nanogenerators: a critical review." EcoMat, Vol. 2, No. 4, pp. 120 - 132, (2020).
13. Al-Kabbany A. M., and Ali W. Y., "Reducing the electrostatic charge of polyester by blending by polyamide strings.", Journal of the Egyptian Society of Tribology, Vol. 16, No. 4, pp. 36-44, (2019).
14. Yang Y., Zhu G., Zhang H., Chen J., Zhong X., Lin Z. H., Su Y., Bai P., Wen X. and Wang Z. L., "Triboelectric nanogenerator for harvesting wind energy and as self-powered wind vector sensor system.", ACS nano, Vol. 7, No. 10, pp. 9461 - 9468, (2013).
15. Zhang H., Yang Y., Su Y., Chen J., Adams K., Lee S., Hu C. and Wang, Z. L., "Triboelectric nanogenerator for harvesting vibration energy in full space and as self-powered acceleration sensor.", Advanced Functional Materials, Vol. 24, No. 10, pp. 1401-1407, (2014) .
16. Cheng P., Guo H., Wen Z., Zhang C., Yin X., Li X., Liu D., Song W., Sun X., Wang J. and Wang Z. L., "Largely enhanced triboelectric nanogenerator for efficient harvesting of water wave energy by soft contacted structure.", Nano Energy, Vol. 57, pp. 432 - 439, (2019).
17. Wang X., Niu S., Yin Y., Yi F., You Z. and Wang Z. L., "Triboelectric nanogenerator based on fully enclosed rolling spherical structure for harvesting low-frequency water wave energy.", Advanced Energy Materials, Vol. 5, No. 24, 1501467, (2015).
18. Jin T., Sun Z., Li L., Zhang Q., Zhu M., Zhang Z., Yuan G., Chen T., Tian Y., Hou X. and Lee C., "Triboelectric nanogenerator sensors for soft robotics aiming at digital twin applications.", Nature communications, Vol. 11, No .1, pp, 1-12, (2020).
19. Qin K., Chen C., Pu X., Tang Q., He W., Liu Y., Zeng Q., Liu G., Guo H. and Hu C., "Magnetic array assisted triboelectric nanogenerator sensor for real-time gesture interaction.", Nano-micro letters, Vol. 13, No. 1, pp. 1 - 9, (2021).
20. Zhou Q., Pan J., Deng S., Xia F. and Kim T., "Triboelectric Nanogenerator-Based Sensor Systems for Chemical or Biological Detection", Advanced Materials, Vol. 33, No. 35, 2008276, (2021).
21. Dhakar L., Pitchappa P., Tay F. E. H. and Lee C., "An intelligent skin based self-powered finger motion sensor integrated with triboelectric nanogenerator", Nano Energy, Vol. 19, pp, 532-540, (2016).

22. Zhu G., Lin Z. H., Jing Q., Bai P., Pan C., Yang Y., Zhou Y. and Wang Z. L., "Toward large-scale energy harvesting by a nanoparticle-enhanced triboelectric nanogenerator.", Nano letters, Vol. 13, No. 2, pp. 847 - 853, (2013).

23. Chen J., Zhu G., Yang W., Jing Q., Bai P., Yang Y., Hou T. C. and Wang Z. L., "Harmonic-resonator-based triboelectric nanogenerator as a sustainable power source and a self-powered active vibration sensor." Advanced materials, Vol. 25, No. 42, pp. 6094-6099, (2013).

24. Wang S., Lin L., Xie Y., Jing Q., Niu S. and Wang Z. L., "Sliding-triboelectric nanogenerators based on in-plane charge-separation mechanism.", Nano letters, Vol. 13, No. 5, pp. 2226 - 2233, (2013).

25. Lin L., Wang S., Xie Y., Jing Q., Niu S., Hu Y. and Wang Z. L., "Segmentally structured disk triboelectric nanogenerator for harvesting rotational mechanical energy.", Nano letters, Vol. 13, No. 6, pp. 2916 - 2923, (2013).

26. Ali A. S., Khashaba M. I., "Effect of Copper Wires Reinforcing Polyethylene on Generating Electrostatic Charge", EGTRIB, Vol. 13, No. 4, October 2016, pp. 28 – 40, (2016).

27. Ali A. S., Youssef Y. M., Khashaba M. I. and Ali W. Y., "Electrostatic Charge Generated From Sliding of Polyethylene Against Polytetrafluoroethylene", EGTRIB Journal, Vol. 14, No. 3, July 2017, pp. 34 - 49, (2017).

28. Ali A. S., Youssef Y. M., Khashaba M. I. and Ali W. Y., "Dependency of Friction on Electrostatic Charge Generated on Polymeric Surfaces", EGTRIB Journal, Vol. 14, No. 3, July 2017, pp. 50 - 65, (2017).

29. Alahmadi A., Ali A. S. and Ali W. Y., "Electrostatic Charge Generated from Sliding of High Density Polyethylene Against Air Bubble Sheet of Low Density Polyethylene", EGTRIB Journal, Vol. 14, No. 4, October 2017, pp. 27 – 39, (2017).