Investigation of the influence of the environment on the electrical properties of textile clothing materials

Pavel Cherunov [1*], *Irina* Cherunova [1], *Elena* Nazarenko[1], *Salikh* Tashpulatov [2,3], *Alla* Merkulova [1], and *Gulora* Raximova [4]

[1] Don State Technical University, Shakhty, Russia
[2] Namangan institute of textile industry, Namangan, Uzbekistan
[3] Jizzakh Polytechnic Institute, Jizzakh, Republic of Uzbekistan
[4] Urgench State University, Urgench, Uzbekistan

Abstract. Investigation that Elevated levels of static electricity build-up on the surfaces of work clothes, different technological structures, and polymeric materials can cause disruptions to the techno-bio system, resulting in adverse physiological effects in humans, accidents caused by humans, and environmental disasters. Under conditions of low temperatures, electrostatic charge on polymeric materials is intensively generated. Synthetic materials have an increased ability to electrify. The processes were studied the mechanisms of the occurrence of a electricity an polymer materials of clothing in winter. The logical structure of the model of the formation of an electrostatic field on the surface of polymer materials of objects in environmental conditions during a snowstorm has been developed. A set of materials for experimental thermal protective clothing was investigated. The findings from the investigation into the process of electrification in the layers of materials used to make thermally protective clothing are gathered and given. As follows from the graphs, the limiting value of the electrostatic field strength can occur already with an external field of 15000 V/m. The formation of charges is facilitated by the physical conditions of the snowstorm electrification in the system of polymer structures.

1 Introduction

High levels of static electricity buildup on the surfaces of work clothes, different technological structures, and polymeric materials disrupt the techno-bio-system's overall function and cause adverse physiological effects in people as well as man-made and environmental disasters (e.g., spark-caused explosions at industrial facilities with high concentrations of combustible gases) [1].

Electrostatic charge occurs on a variety of technological equipment due to snowdrift transfer. Moreover, electrostatic charge is strongly created on polymeric materials at low temperatures [2, 3].

* Corresponding author: el_s@list.ru

The clothing is made of several polymer materials. Many polymers make up the variety of textile fabrics available today [4]. Clothing made of combined fibers (natural and synthetic) is widely used in production conditions [5]. Cold and additional weather conditions lead to the accumulation of electrostatic charge on polymer fibers and textile materials. Synthetic materials have an increased ability to electrify [6].
The aim of the paper is to investigate the potential of the electrostatic field on the surface of clothing.

2 Topicality, Scientific Relevancy

In [7], issues pertaining to the bulk density of electrostatic charge in the snow mass were examined. It was found that the electric field in the salting layer had a tension of +30 kV/m at a height of 4 cm above the snow surface. [8].
In additional investigations, the researchers determined the specific density of electric charge in the volumetric mass of snow within the range of +72 to -208 μC/kg, in agreement with the information provided in [8].
The Coulomb forces of contact between charged particles and the force of gravity can be correlated along the surface thanks to this facts.
Table 1 displays the ratio of a particle's size to the threshold charge-to-mass ratio based on the estimate in [9].

Table 1. The snow particle size to mass ratio at the threshold charge-to-mass.

Threshold charge to-mass, q/m [μC/kg]	Size of a snow particle, μm	Threshold charge to-mass, q/m [μC/kg]	Size of a snow particle, μm
120,42	145,23	219,02	202,79
133,50	153,87	236,02	211,22
148,26	163,53	249,95	218,62
160,23	170,31	264,73	225,82
170,26	176,89	280,06	232,60
185,86	185,32	297,91	240,41
202,85	194,57	-	-

According to the estimate in [10], the ratio of the Coulomb force to the force of gravity acting on a separate snowflake is up to 0.2.
These data show the level of energy, which allows to estimate the maximum possible value of the transferred electrostatic charge. This is important for studying and predicting the charge on the surface of clothing in winter [11].
At the present time, it is necessary to thoroughly study the mechanisms of the occurrence of a electricity an polymer materials of clothing in winter.

3 Theoretical part

The acceleration of the "a" force acting on a particle with a charge Q in an electrostatic field with a strength E is as follows, according Coulomb's law [12]:

$$a = - QE/m, \quad (1)$$

where m is the particle's mass in kg;
Q - particle charge, Cl;
E is the electrostatic field's intensity (V/m).

The highest value (Q/m)max ~ 0.2 nCl/mg (for snow particles that come into contact with the surface of clothing) is determined by the calculations of [13]. There is proof that the advent of corona discharges has caused environmental losses to reach their maximum magnitude [10,13, 14].
Based on gradient measurements, the electric field strength at very strong snow conditions (snow rates > 1mm/hr) was found to be around 2,5·10^4 V/m. [15,16].
he acceleration is negative and the forces of electrical origin are directed downward rather than upward if the charge Q and the strength of the electrostatic field E have the same sign. It is thought that the snowfall particle electric charges are positive, with large, heavy particles typically having negative electric charges [16].
Thus, under the conditions of operation of textile products, electrification of tissues, which are dielectric in physical nature, occurs [17, 18].
The amount of generated charge depends on the type of materials, the environment and the speed of separation of materials.
Researchers of the phenomenon of electrification [19] distinguish four ways of forming electrostatic charges on the surfaces of dielectrics: contact, frictional, inductive and capacitive electrification. In the operation of textiles, the first three options are basically implemented.
The mechanism of frictional electrification is the most complex. This is caused both by the complexity of the friction process itself and by its multilateral influence on the electrification process.

4 Practical part

When removing electrified clothing made of highly electrifying materials, a charge remains on the body, creating a potential with respect to the ground [2,10].
Drifted deflation snow at low temperatures is a kind of snow "sand" with well dispersed particles. The triboelectric series of materials is shown in Fig.1 [20-22].

Fig.1. Triboelectric series.

The process of friction of polymers is accompanied by electron emission [17,18].
In order to solve the research problem in a textile polymer system it is necessary to identify the relationship between the parameters of the textile material and the electrophysical values.
Fig.2 shows the logical structure of the model of the formation of an electrostatic field on the surface of polymer materials of objects in environmental conditions during a snowstorm.

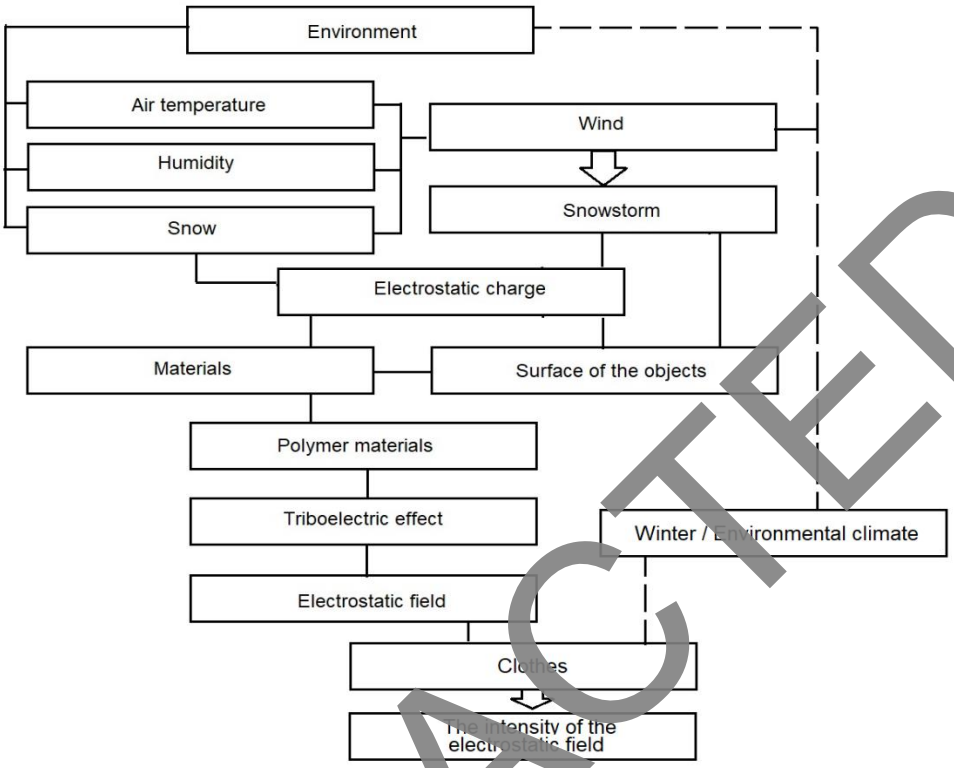

Fig.2. Logical structure of the model of the formation of an electrostatic field on the surface of polymer materials of objects in environmental conditions during a snowstorm.

Theoretical and experimental studies were conducted for heat-protective clothing made of a complex set of textile materials.
A set of materials for experimental thermal protective clothing was investigated. The parameters of the experimental clothing materials are presented in Table 2.

Table 2. The parameters of electrical properties of the experimental clothing materials.

Number of the layer of materials	A layer of materials in heat-protective clothing	Dielectric constant [ε]	Specific surface resistance, Om
1	Underwear Knitwear 100% cotton	96,2	$3{,}0\cdot10^{6}$
2	Lining Calico 100% cotton	7,4	$7{,}5\cdot10^{7}$
3	Insulation 100% wool batting	3,6	$9{,}5\cdot10^{8}$
4	Windproof fabric Dewspoo 100% Polyester	4,5	$8{,}9\cdot10^{12}$
5	Upper fabric "Premier Comfort" 250A	30,0	$1{,}0\cdot10^{6}$

Fig. 3 displays the findings of the investigation into the electrification process in the layers of materials used to make thermally protective apparel.

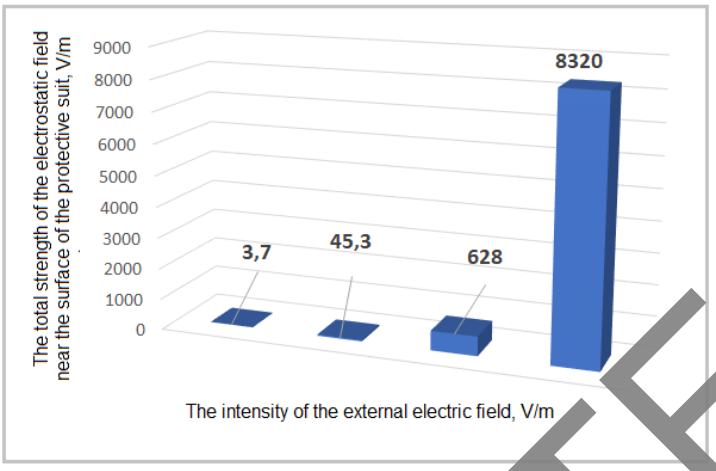

Fig. 3. The total strength of the electrostatic field near the surface of the protective suit, V/m.

5 Conclusions

As follows from the graphs, the limiting value of the electrostatic field strength can occur already with an external field of 15000 V/m.
Electrification processes, contact and frictional electrification, occur in the dynamics when large pressures and temperatures develop briefly on the contact areas, significant deformations of mutual adhesion occur, the adhesion bond of surfaces is established and destroyed, mechanical oscillations are observed in a wide range of frequencies.
The formation of charges is facilitated by the physical conditions of the snowstorm electrification in the system of polymer structures.

References

1. Working with Electricity Static Electricity and its Risks at work, https://hsseworld.com/working-with-electricity-static-electricity-and-its-risks-at-work/, last accessed 2024/03/01.
2. J.Lowell, The electrification of polymers by metals. Journal of Physics D: Applied Physics. **9(11).** 1571 (1976).
3. L.Liu, A. Seyam, W.Oxenham, Frictional Electrification on Polymeric Flat Surfaces. Journal of Engineered Fibers and Fabrics. **8(1).** 126-136 (2013).
4. S. Firšt Rogale, D.Rogale, Advanced Materials for Clothing and Textile Engineering. Materials. **16**. 3407. DOI.org/10.3390/ma16093407 (2023).
5. Ch.Watson, N.Nawaz, W.Wardiningsih, O.Troynikov, Materials used in industrial workwear for hot workplace environments: Thermal and moisture management attributes. Journal of Industrial Textiles. **52.** 1–21. DOI: 10.1177/15280837221141716 (2022).
6. A.Horrocks, S.Anand, Handbook of technical textiles, (Woodhead Publishing Ltd, Cambridge England, 2000).
7. C.DeMichele, F.Avanzi, A.Ghezzi, C.Jommi, Investigating the dynamics of bulk snow density in dry and wet conditions using a one-dimensional model. The Cryosphere. **7**. 433–444 (2013).

8. D.Schmidt, R.Schmidt, J.Dent, Electrostatic force in blowing snow. Boundary-Layer Meteorology. **93**. 29–45 (1999).
9. H.Yu, G.Li, N.Huang, M. Lehning, Idealized Study of a Static Electrical Field on Charged Saltating Snow Particles. Frontiers in Earth Science. **10**. 880466. DOI: 10.3389/feart.2022.880466 (2022).
10. I.Brink, V.Gorchakov, E.Schennikova, A.Kuleshova, T.Kochetkova, The study of methane electricity as a promising renewable source energy for nanoelectronics. Izvestiya vuzov. Electromechanics. **2**. 23-29 (2014).
11. I.Cherunova, G.Kutilina, E.Milyutin, Research and algorithmization of the process for completing clothes by materials with electric properties. IOP Conference Series: Materials Science and Engineering. **680 (1)**. 012007 (2019).
12. M.Abdullahi, Coulomb's Law in Electrostatic, Gravitational and Inertial Forces and Emission of Radiation. Journal of Physics & Optics Sciences. **5(2).** 1-9. DOI: 10.47363/JPSOS/2023(5)181 (2023).
13. A.Dunin, In the kingdom of snow. Man and the environment. (Nauka: Siberian Branch, Novosibirsk, 1983).
14. Y.Cui, Ch.Zhuang, R.Zeng, Electric field measurements under DC corona discharges in ambient air byelectric field induced second harmonic generation. Applied Physics Letters. **115(24).** 244101 (2019).
15. Y.Yaira, Y.Reuvenia, S.Katzd, C.Priced, R.Yanivb, Strong electric fields observed during snow storms on Mt. Hermon, Israel. Atmospheric Research. **215**. 208-213 (2019).
16. S. Schmidt, J.Dent. Measurements of the electric field gradient in a blizzard, https://arc.lib.montana.edu/snow-science/objects/issw-1994-197-202.pdf, last accessed 2024/03/01.
17. I.Cherunova, S.Tashpulatov, S. Kurenova, Treated textile electrostatic properties study. Materials Science Forum**. 992**. 439-444 (2020).
18. A.Merkulova, I.Cherunova, I.Danilenko, Investigation of electrostatic fields by modeling methods. MATEC Web of Conferences.**132**. 04022 (2017).
19. R.Akbarov, R. Zhilisbaeva, S.Tashpulatov, I.Cherunova, R.Bolysbekova, Application of composite materials for protective clothing from exposure electric fields. Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti. **377**. 188-192 (2018).
20. Triboelectric Series, http://physicsed.buffalostate.edu/SeatExpts/resource/tribelec.htm, last accessed 2024/03/02.
21. I.Cherunova, S.Tashpulatov, A.Merkulova, Development of automation algorithm for step of designing technology of static electricity protection clothing. RusAutoCon. **1**. 850182 (2018).
22. Sh. Korabayev and etc. Study of the influence of the output surface of the confusor inside the adapter on the location of fibers in the yarn in a rotor-spinning machine. E3S Web of Conferences **460**, 09006 (2023).