Materiały Wysokoenergetyczne / High Energy Materials, **2023**, *15*: 105 − 112; DOI 10.22211/matwys/0245
ISSN 2083-0165

Research paper / Praca doświadczalna

Evaluation of protective clothing for use in the manufacture of explosives in accordance with the requirements for protection against static electricity set out in PN-E-05205:1997

Ocena odzieży ochronnej przeznaczonej do stosowania przy produkcji materiałów wybuchowych według wymagań ochrony przed elektrycznością statyczną zawartych w PN-E-05205:1997

Małgorzata Wróblewska-Piórkowska

Łukasiewicz Research Network – Institute of Industrial Organic Chemistry,
6 Annopol St., 03-236 Warsaw, Poland
** E-mail:* malgorzata.wroblewska@ipo.lukasiewicz.gov.pl

ORCID Information:
Wróblewska-Piórkowska M.: 0000-0002-6363-7661

Abstract: *The requirements of PN-E-05205:1997 for antistatic protection and methods of testing and evaluating the antistatic properties of selected items of protective clothing, such as sweatshirts, trousers, aprons, overalls, intended for employees working with explosives, are presented. These test methods are used in the Laboratory of Chemical Safety and Static Electricity of the Łukasiewicz Research Network – the Institute of Organic Industry.*

Streszczenie: *Przedstawiono wymagania ochrony antyelektrostatycznej oraz metody badań właściwości antyelektrostatycznych wybranych elementów odzieży ochronnej, takich jak np. bluzy, spodnie, fartuchy, kombinezony, przeznaczonej dla pracowników wykonujących czynności technologiczne z użyciem materiałów wybuchowych, według wymagań PN-E-05205:1997. Prezentowane metody badań stosowane są w Laboratorium Bezpieczeństwa Chemicznego i Elektryczności Statycznej Sieć Badawcza Łukasiewicz - Instytutu Przemysłu Organicznego.*

Keywords: *protection against static electricity, antistatic protective clothing, explosives*
Słowa kluczowe*: ochrona przed elektrycznością statyczną, antystatyczna odzież ochronna, materiały wybuchowe*

1. Introduction

The requirement to implement measures to protect against static electricity in the production, storage, transport and use of explosives, results from the requirements of normative acts, including the Regulation of the Minister of Economy, Labour and Social Policy of 9 July 2003 on occupational health and safety in the production, intra-company transport and movement of explosives, including pyrotechnic products (consolidated text: Journal of Laws of 2016, item 262). Effective protection against static electricity increases occupational safety in the production and handling of explosives, as well as during their transport and storage. According to PN-E-05205:1997 [1], protection against static electricity must be applied in rooms and outdoor spaces where explosives with a minimum ignition energy (*MIE*) ≤ of 1 J are handled. Irrespective of the minimum ignition energy of the explosive, protection shall also be applied if other flammable media, e.g. organic solvents, whose presence can create an explosive atmosphere, are used in the area under consideration at the same time. Polish Standard PN-E-05205:1997 formulates a number of basic principles of protection against static electricity in relation to facilities, production premises, processing plants and equipment, transport, storage and personnel, who play a key role in maintaining safety. An electrically charged human body can be a source of fire and explosion hazards in spaces where explosives are handled. Excess electrostatic charge can be created on the body of a worker by the triboelectric effect, during activities such as getting up from a chair, removing clothing, walking on an insulating floor, and by contact with an electrified piece of equipment or material (e.g. when manually emptying containers containing liquids or bulk materials). The human body can also become charged by electrostatic induction from an electrified object. A sufficiently high electrical charge potential a worker's body can create dangerous spark discharges, e.g. as a result of a hand coming close to an earthed part of equipment. A spark discharge is created between two conductive objects with different potentials of charge generated on them, one of which could be the human body. The energy of a spark discharge can reach up to several hundred millijoules. These discharges are capable of igniting mixtures of gases, vapours and flammable liquids with air and aerosols [2]. Protection against static electricity is, fundamentally, a comprehensive risk assessment of the possibility of electrostatic hazards and the selection and application of appropriate measures to prevent them. One of the basic elements of worker protection in the workplace is protective clothing. When selecting garments to protect against the effects of static electricity, it is important to consider the requirements for protection against static electricity as well as the basic requirements of occupational health and safety. Protective clothing used in the manufacture of explosives must not become charged or cause the body of the worker wearing it to become charged. Protective clothing in this case must meet the specific requirements set out in the normative documents.

The cited Polish Standard PN-E-05205:1997, was developed at the Institute of Organic Industry, where research was also conducted into improving test methods for protective clothing with criteria being developed for the evaluation and qualification of clothing in terms of antistatic protection requirements [6-8].

2. Requirements and qualification of selected items of protective clothing for workers employed in the manufacture of explosives

According to Polish Standard PN-E-05205:1997 p. 3.5, the requirements for protective clothing used in the manufacture of explosives relate to the values of surface or volume resistance and electrical resistivity of the materials from which the clothing is made. The purpose of measuring the resistance / electrical resistivity of a material is to assess its ability to maintain an electrified state. This assessment forms the basis of the decision that a garment can be used safely. The requirements set out in PN-E-05205:1997 are as follows:

a) In rooms where initiating explosives or the products obtained by reloading initiating explosives (e.g. electric igniters), black powder and pyrotechnic materials are handled, the following requirements apply:

- Protective clothing and underwear should be made of fabrics with a specific volume electrical resistivity $\rho_v \leq 1 \cdot 10^4$ Ωm and/or surface specific electrical resistivity $\rho_s \leq 1 \cdot 10^7$ Ω, so that the following conditions are met:
  – surface electrical resistance $R_s \leq 10^6$ Ω, measurement according to PN-E-05203:1992 [3] section 2.4.3
  – or volume electrical resistance $R_v \leq 10^6$ Ω, measurement according to PN-E-05203:1992 section 2.4.4.

  Preference is given to fabrics made from cotton, linen or viscose fibres, and it may also be permissible to use fabrics which meet the above conditions at the lowest relative air humidity prevalent in the manufacturing facilities.
- Protective clothing should be stored at a relative humidity not lower than that of the work premises.
- In protected areas, it is forbidden to put on or take off clothes, wear loose or unfastened clothes. Cleaning of clothes (wiping, sweeping, vacuuming) is also prohibited.

The assessment of the anti-electrostatic properties of protective clothing in this case comes down to checking whether the surface or volume electrical resistance / resistivity of the fabric from which the garment is made meets the aforementioned requirements. However, the conditioning and testing of clothes should be carried out at the lowest relative humidity which is maintained in the work premises.

b) In rooms where high explosives, nitrocellulose and nitroglycerine powders and their products are handled, protective clothing made of fabrics meeting the following requirements are permitted:
   – surface electrical resistance $R_s \leq 10^9$ Ω, measurement according to PN-E-05203:1992 section 2.4.3
   – or volume electrical resistance $R_v \leq 10^8$ Ω, measurement according to PN-E-05203:1992 section 2.4.4,

   provided that the protection criteria according to PN-E-05201:1992 [4] section 2.1 a), c) or d) and according to PN-E-05202:1992 [5] section 3.1 are met at $k = 10$ and the $MIE = 10^{-4}$ J.

The qualification of protective clothing in this case consists of two stages. In the first stage, surface or electrical resistance tests are carried out and, if the criteria according to item b) are met, the second stage of testing is carried out using the methods described in Annex B to PN-E-05205:1997. These involve testing the charging of a human body, using various triboelectrification techniques, and then measuring the electrostatic voltage formed on that body. Tests are performed on three randomly chosen individuals. The aim is to determine the potential for dangerous charging of the human body as a result of wearing a particular type of protective clothing. Three trials are carried out consecutively.

Trial I – involves inducing electrific charge on the human body by manually rubbing the outer surface of the protective clothing worn by the individual using selected friction materials moving in a reciprocating motion on the back of the person taking part in the test, and then measuring the electrostatic charge on the body.

The choice of friction materials depends on what materials the protective clothing may come into contact with during use. Under operating conditions, one should, above all, take into account the possibility of contact and associated friction with the material of other garments (fabrics: flannel, denim) or with the material of the processing equipment (steel), as well as contact with objects or materials which can be used, for example, to remove dust or other impurities from the surface of the product (brush). A conceptual diagram of the measurement system is shown in Figure 1. The results of tests conducted in trial I [7], carried out under the conditions: $t = 23$°C, RH = 42%, $C = 150$ pF – electrical capacitance of the human body involved in the trial and $C_u = 160$ pF, are specified in Table 1.

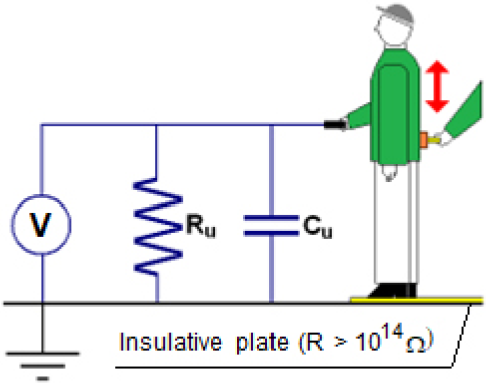

Figure 1. Conceptual diagram of a system for measuring the electrostatic voltage generated on the human body by manually rubbing the outer surface of clothing, where: R_u – electrical resistance of the system [Ω], C_u – electrical capacitance of the system [F]

Table 1. **Test** results of human body electrification when rubbing the outer surface of the clothing

Type of clothing	**Potential of electrostatic charge generated on the human body (V_c) [V]**	
	Type of friction material	
	Wool 100%	**Natural bristles**
Protective clothing blouse made of fabric D44	+210 +251 +307 +248 +305 +309 +310 +359 +377 +399 $V_{c\ mean}$ = +308 $V_{c\ max}$ = +399	+506 +656 +645 +637 +621 +601 +576 +552 +528 +518 $V_{c\ mean}$ = +584 $V_{c\ max}$ = +656

Trial II – involves removing the upper part of the protective clothing (e.g. a blouse) from the worker's body – the test subject, connected to an electrostatic voltmeter, vigorously removes the upper part of the clothing, which is followed by measuring the potential of electrostatic charge generated on his or her body.

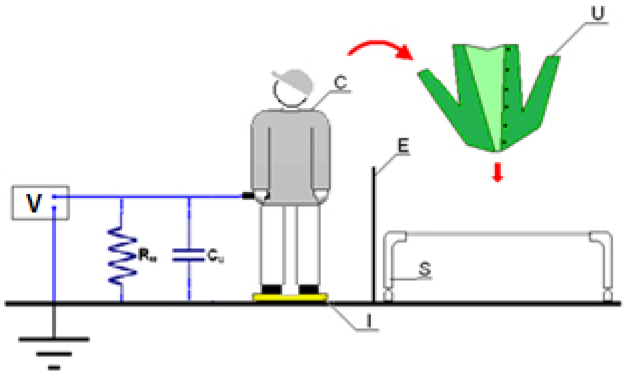

Figure 2. Conceptual diagram of a system for measuring the electrostatic voltage generated on the human body by vigorously removing the upper part of protective clothing: C – human, I – insulation board ($R_{iz} \geq 10^{14}$ Ω), U – removable clothing part, S – table, E – grounded screen, WE – electrostatic voltmeter, R_u – electrical resistance of the system [Ω], C_u – electrical capacitance of the system [F]

Typical results of tests performed in Trial II [7], carried out under the conditions: t = 21-23 °C, RH = 31-43%, C = 150 pF – the electrical capacitance of the human body involved in the test and C_u = 160 pF are summarised in Table 2.

Table 2. Test results of human body electrification during removal of the upper part of protective clothing

Type of removable clothing	Potential of electrostatic charge generated on the human body (V_c) [V]
Protective clothing blouse made of fabric D44	+400 +100 +320 +200 +80 +280 +420 +400 +390 +410 $V_{c\ mean}$ = +300 $V_{c\ max}$ = +410

Trial III – The test subject sits on a chair, holding a wire connected to an electrostatic voltmeter. The potential on the human body is measured when standing up vigorously from the chair.

Figure 3. Measurement station for measuring the electrostatic voltage generated on the human body when standing up from a chair. The test subject has an insulating board under their feet ($R_{iz} \geq 10^{14}$ Ω)

The results of tests conducted in Trial III, carried out under the conditions: $t = 23$ °C, RH = 40%, $C = 150$ pF – electrical capacitance of the human body involved in the trial, $C_u = 160$ pF, are summarised in Table 3.

Table 3. Test results of human body electrification as a result of standing up from a varnished wooden chair

Type of clothing	Potential of electrostatic charge generated on the human body (V_c) [V]
Denim trousers	+250 +200 +210 +250 +250 +230 +200 +220 +180 +250 $V_{c\ mean} = +224$ $V_{c\ max} = +250$

Each of the tests described above is repeated ten times and the maximum values of the electrostatic voltages generated on the human body are recorded. The actual value of the electrostatic voltage U_c generated on the human body is calculated using the equation:

$$U_c = U \cdot C_u / C_c \ [\text{V}] \tag{1}$$

where: U – the measured (maximum) value of electrostatic voltage on the human body [V], C_u – electrical capacitance created by the "human body-electrostatic voltmeter" system in relation to earth [F], C_c – the electrical capacitance of the human body, as determined by the equation $C_c = C_u - C_v$ [F], C_v – the electrical capacitance of electrostatic voltmeter including leads [F].

Evaluation of test results pursuant to the safety condition acc. PN-E-05202:1992 section 3.1 [5], with the assumed electrical capacitance of the human body C_c and $MIE_{min} = 10^{-4}$ J protective clothing may be qualified for use in areas where blasting explosives, nitrocellulose and nitroglycerine powders and their products are handled if the maximum electrostatic voltage generated on the human body does not exceed, in any of the three trials carried out, the value of:

$$U_{c.\ max} = 300 \text{ V} \tag{2}$$

An important aspect of protection to note is protective footwear and flooring, which, if made of materials with sufficiently high electrical conductivity (low electrical resistivity), will enable the electrostatic charge generated on a worker's body to dissipate quickly. PN-E-05205:1997 specifies the following requirement in this respect:
"The electrical leakage resistance of the human body must not exceed 1 MΩ ($1 \cdot 10^6$ Ω)

$$R_{l\ hum.} \leq 1\ \mathrm{M\Omega} \tag{3}$$

where: $R_{l\ hum.}$ – sum of the electrical leakage resistance of the footwear and the floor."
However, the electrical leakage resistance of the human body must be checked before entering a hazard zone or directly at the workstation, before carrying out processing operations.

3. Summary

- ♦ Results of research [6-8] carried out at the Institute of Organic Industry regarding testing the electrification of protective clothing have contributed to the development of methodologies and evaluation criteria for clothing, which are used when the electrical resistance of fabrics exceeds permissible values. This ensures that garments with such parameters are not immediately rejected. Positive electrification test results make it possible to qualify the protective clothing as a product meeting the protection requirements against static electricity.
- ♦ When selecting anti-electrostatic protection measures, it is necessary to consider the possibility of electrification of the body of a worker performing processing activities and to equip them with suitable protective clothing and footwear which will ensure sufficiently rapid discharge of electrostatic charges to earth.
- ♦ The testing of the anti-electrostatic properties of protective clothing described in the article is conducted at the Laboratory of Chemical Safety and Static Electricity Łukasiewicz Research Network – Institute of Organic Industry, which has many years of experience in this field.

References

[1] PN-E-05205:1997: *Protection Against Static Electricity. Protection Against Static Electricity in the Manufacture and Use of Explosives. Requirements.* (in Polish), **1997**.
[2] Kowalski J.M. *Protection Against Static Electricity. Principles of Forecasting, Assessing and Eliminating Threats. Guide*. 1st ed. (in Polish) Gdańsk, Automatic Systems Engineering, **2015**.
[3] PN-E-05203:1992 *Protection Against Static Electricity – Materials and Articles for Use in Facilities and Zones Exposed to Explosion Hazard – Testing Methods for Electrical Resistance and Leakage Resistanc*e. (in Polish), **1992**.
[4] PN-E-05201:1992 *Protection Against Static Electricity – Methods for Assessing Hazards Caused by Electrification of Solid Dielectric Materials – Methods for Assessing Fire and/or Explosion Hazards.* (in Polish), **1992**.
[5] PN-E-05202:1992 *Protection Against Static Electricity – Fire and/or Explosion Safety – General Requirements.* (in Polish), **1992**.
[6] Kowalski J.M., Wróblewska M. *Development of Procedures for Testing the Properties of Materials and Products in the Aspect of Protection Requirements Against Static Electricity, Contained in Relevant Normative Documents. Stage II: Procedures for Testing the Electrification Capacity of Materials, Products, Devices and Facilities.* (in Polish) IPO Report No. EMC 010900012, Warsaw, **2005.**
[7] Kowalski J.M., Wróblewska M. D*evelopment of an Evaluation Method and Criteria for the Functional Qualifications of Clothing, in Terms of Antistatic Protection Requirements. Part III Classification/*

qualification Tests of Selected Fabrics and Protective Clothing According to the Procedures Included in the Draft Standards PN-E-206 and PN-E-207 (Verification of the Methodology). (in Polish) IPO Report No. EMC 011600012, Warsaw, **2003**.
[8] Kowalski J.M., Wróblewska M. *Development of a Method for Assessing Threats Arising from the Electrification of Protective Clothing*. (in Polish) IPO Report No. EMC 030900012, Warsaw, **2007**.

Received: September 23, 2023
Revised: December 19, 2023
First published on line: December 21, 2023