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Research of Hygienic Properties and Choice of Materials for Workwear at Electricity Industry

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Abstract**:** ***One of the main tasks solved at the stage of designing workwear is the choice of materials whose hygienic properties correspond to specific operating conditions. By occupation and depending on climatic conditions, a person can be exposed to various kinds of negative and dangerous influences. Given this, this article is devoted to the study of hygienic properties and the choice of workwear materials for electric power engineers. Analysis production conditions of enterprises of the electric power industry, showed that the presence of distributed electric charges that create electrostatic fields, cause a high electrostatic hazard and negatively affect the human body. The article presents the results of laboratory tests of air permeability, hygroscopicity, moisture conductivity and thermal resistance of materials, gives recommendations for selection optimal thickness of materials for workwear and operation in hot climates. Based on the results of the analysis of works devoted to the development of clothing for hot climatic conditions, the results of thermophysical studies are given.***

Keywords**:** ***Hygienic Properties, Operating Conditions, Air Permeability, Absorbability, Moisture Conductivity, Thermal Resistance, Vapor Permeability, Moisture Transfer, Capillarity, Optimal Material Package.***

I. INTRODUCTION

The formation of rational workwear materials is a complex, multifactorial task, which is associated with determining the composition and characteristics of the structure of materials and requires a comprehensive assessment of their hygienic and operational properties. This task is quite fully presented in the form of a structural diagram that reflects the interconnection of the elements and properties of special clothing, its materials, environmental conditions, and human requirements (Fig. 1).

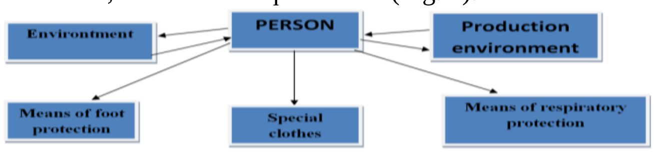

Fig.1. The structural diagram of the relationship of the elements and properties of special clothing, its materials, environmental conditions, human requirements

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By the nature of professional activity and depending on climatic conditions, a person can be exposed to various kinds of negative and dangerous influences. Therefore, the creation of special clothing that should protect a person in production is an important task for light industry enterprises. An analysis of the production conditions of the enterprises of the electric power industry, as the largest and most rapidly developing, showed that the presence of distributed electric charges, which create electrostatic fields, cause a high electrostatic hazard and negatively affect the human body. In addition, as a result of detonation of explosions and fires, tragic cases occur and production damage is caused. According to statistics, the cause of explosions of vapor mixtures in 27% of cases was static electricity.

Today, the electric power industry is developing rapidly in Uzbekistan, modern and powerful nuclear power plants are under construction, for example, a nuclear power plant in Jizzakh, and a power station is operating in the city of Navoi. Most of the already developed and promising areas of electric power stations and substations are located in the desert regions of Uzbekistan, and these are areas with extremely high temperatures in the summer months and dry ambient air above average. Atmospheric conditions contribute to increased electrification of clothing materials; therefore, special anti-electrostatic clothing is required. In general, to ensure safe working conditions at the enterprises of the electric power complex, it is necessary to use special clothing to protect against high temperatures and static electricity.

Today, there is a fairly wide range of antistatic materials for special clothing designed to protect against electricity and electromagnetic radiation (Fig. 2).

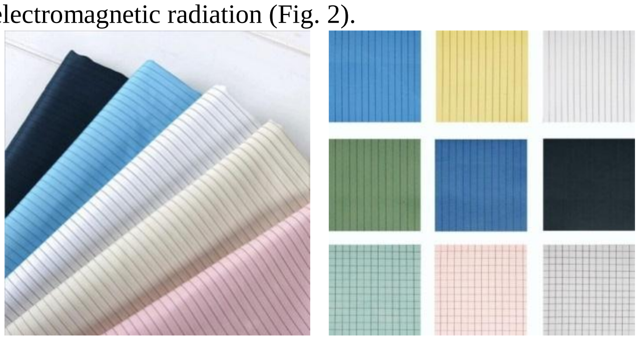

Fig. 2. Fabrics with antistatic synthetic fibers

These are fabrics with anti-static synthetic fibers and stainless-sub-conductive and silver threads. Antistatic fabrics can eliminate static electricity from clothing and the human body. These fabrics are currently widely used to design antistatic clothing. But, from the point of view of operation in extreme climatic conditions, the question arises - do these fabrics comply with hygienic requirements in a dry hot climate?

It was indicated above that in a dry, hot climate, heat transfer between the body of a person and the environment occurs mainly due to the evaporation of moisture (sweat) from the surface of the skin. In this regard, the main function of workwear materials designed for hot climatic conditions is to absorb moisture from the surface of the skin and gradually transfer it to the environment.

The ability of clothes to provide unhindered evacuation of heat by evaporation of sweat from the clothes area can be realized both due to the moisture conductivity of materials, and by ventilation of the clothes area. Ventilation of the working space is achieved by increasing the air permeability of materials and due to the design.

II. LITERATURE REVIEW

Currently, the considered properties of materials are evaluated by a number of separate indicators of hygroscopic properties and vapor permeability. However, many researchers [1-5] believe that the accepted separate study of the moisture properties of materials does not fully reflect their ability to remove moisture and does not allow us to evaluate the moisture transfer process through a package of clothing materials.

In recent years, methods for a comprehensive assessment of the hygienic properties of materials have been developed in research papers. In particular, in [1], a thorough study of the total process of moisture permeability through layers of clothing materials was conducted and it was found that the rate of moisture removal from human skin is determined mainly by three factors: the amount of moisture passing through the tissue; moisture absorbed by the tissues during the transfer from the clothes area and the time of the onset of the dynamic equilibrium of the moisture transfer process. The total moisture permeability of cotton and wool fabrics is high, it is absent in synthetic fiber fabrics.

The author [2] recommended a method for the joint assessment of moisture-conducting and heat-shielding properties of materials using the coefficients of convective-radiation heat transfer and moisture conductivity. The paper considers a comprehensive indicator of permeability to air and steam. A more theoretically justified solution to the problem of moving moisture is described in the works, the authors of which evaluate the moisture-conducting properties of materials through mass transfer characteristics, such as sorption capacity, diffusion coefficients, moisture conductivity, etc., which determine the intensity of the moisture exchange process and are the main for its calculation and regulation.

According to the author [3], in conditions of a dry hot climate, the main hygiene indicators that play a role in the process of heat transfer by sweat evaporation are: absorbability, capillarity, vapor permeability. The absorbability of clothing materials affects the rate of moisture absorption and moisture loss, which depend on their density, thickness and sorption properties of the fibers. The denser and thicker the materials, the slower they absorb and give off moisture and the better they ensure the constant humidity in the bag.

The capillarity of the materials promotes the removal of moisture from the clothing area and depends on the porosity, size and shape of the pores in the tissues. The work indicates that the high capillarity of clothing materials can compensate for the low level of their absorbability.

Vapor permeability characterizes the ability of materials to pass moisture in the form of water vapor from the clothing area. It was indicated in the works that fabrics with cotton, linen, wool, viscose fibers in the structure have high vapor permeability regardless of their density, and vapor permeability of synthetic fiber fabrics mainly depends on their density. Moisture recovery is the ability of materials to release moisture into the environment. As the results of the work show, with the rapid absorption of moisture and its slow release, the heat-protective properties of clothes made from such materials are reduced.

The air permeability of clothing materials in hot climates is one of the most important indicators, because air passage through the fabric of clothes determines the ventilation of the clothing area and the removal of underclothing carbon dioxide and other products released during gas exchange through the skin. The air permeability coefficient of tissue B determines the amount of air in dm3 passing through 1 mm2 of its surface within 1 s. at a certain pressure drop ΔP on both sides of the fabric:

$$B = \frac{V}{St}$$

where: V- is the amount of air passed through the pattern dm3;

S- is the area of the test pattern, m2;

t- is the duration of air passage, s.

Protecting a person from overheating is the most difficult task; it is further complicated by the development of special protective clothing, when its protective functions are put forward in the first place. The use of tissues with specified protective properties, as a rule, leads to a change in their physicochemical properties that impair heat transfer between the human body and the environment due to a decrease in efficiency sweating. The latter should be compensated for by an improvement in the design of clothing (increased ventilation of the clothing area), as well as regulation of the time for continuous use of clothing.

When operating special clothing in hot climates, an important factor affecting the thermo physical properties of clothing fabrics is solar radiation. Radiation properties of various tissues were studied by many scientists [4]. The author of developed the theory of surface light scattering, according to which textile materials, having a dispersed (porous) structure, occupy an intermediate position between mirror and diffusion reflections by the nature of the reflection of rays. The ability of tissues to absorb the radiation incident on them can be determined by the formula:

$$£ = 1 - (\rho + \tau)$$

where: £. P, τ are, respectively, the ability of materials to absorb, reflect and transmit radiation incident on them.

The results of [3] made it possible to establish that cotton fabrics are more resistant to radiation in comparison with fabrics of other fibrous composition. In works [3-4], it is indicated that the reflectivity of satin-weave cotton fabrics gives a spatial distribution of light similar to mirror.

According to the authors of [4], the transmission of radiation through the tissue is determined mainly by its porosity and the ratio between the transmission of rays and the porosity of the tissue is linear.

According to the author [4], the reflectivity of clothing materials depends on their color. The brighter and lighter the surface of the fabric, the more it reflects and absorbs less solar radiation.

Studies of the influence of fabric colors on their reflectivity have shown that black clothing can only reflect 10-15% and absorb 83-90% of the sun's rays, and white clothing absorbs only 20% of the rays and reflects 80%. It was established [4] that in conditions of a dry hot climate in clothes, the transmittance of sunlight to black fabrics turned out to be several times less than white, which is explained by weaker radiation scattering by black fabrics.

The authors [4-5] indicate that the integrated reflectivity of military-camouflage clothing in khaki in the summer, when the insolation reaches 230 kcal\m2, is approximately 43%, black - 12%, and white - 80%. Studies have established that the highest level of weighted average skin temperature (34.70C) at a temperature under clothing of 39.40C is observed in workers dressed in clothes made of black lavsan-viscose fabric.

The thermo physical properties of clothing materials also depend on the type and intensity of a person's physical activity. According to research [5], due to the physical work of a person in the open air in a dry, hot climate, the air circulation inside the clothes is accelerated, it is several times greater compared to a calm person. Depending on the type and intensity of work the magnitude of the air flow passing into the clothes area changes. Although, during physical work, as a rule, the heat production of a person increases, the air flow that occurs during work partially compensates for the heat load of a person. It is necessary to note that, in connection with the latter, clothing design is of great importance: loose-fitting clothing with sufficient openings reduces the temperature and humidity of air layers and skin temperature.

Studies of these characteristics of materials are of particular interest in the development of workwear designed for use in hot climates at the design stage.

Thus, the problem of the formation of rational materials for special clothing for hot climatic conditions is a complex and multi-factorial task, providing for a comprehensive assessment of the physiological, hygienic and operational properties of materials and clothing in general, the determination of rational packages of materials and the development of a rational design, the solution to this problem is most effective using a systematic approach.

III. RESEARCH METHODS

The results of the study of hygienic properties and the choice of workwear materials: Based on the results of the analysis of works devoted to the development of clothing for hot climatic conditions [6] in order to ensure comfortable microclimate conditions under clothes, we faced the task of choosing rational workwear materials.

To solve the problem of choosing the optimal structure and hygienic parameters of workwear materials, we studied the dependence of hygienic properties on its structure and thickness. Samples were made from satin-weave cotton in various thicknesses.

A total of 10 options were selected. The limits of thickness change are established on the basis of an analysis of the literature [6]. Works [6] established that the most significant indicators in assessing the hygienic properties of clothing designed for hot climatic conditions are air permeability, moisture conduction, moisture loss, and total thermal resistance. Therefore, the assessment of the hygienic properties of the selected materials was carried out according to these indicators.

IV. RESULTS AND DISCUSSION

Problem solving and analysis of results: The studies were carried out in the Certification Laboratory for testing materials of the Uzbek-Chinese joint-venture "Bukhara Brilliant Silk". To determine the thickness, a TTM device was used, with which it is possible to measure the thickness of textile materials from 0.1 to 400 mm with an accuracy of ±0.001 mm. The thickness was measured at a pressure of P=196 Pa (2 gf/cm^2). The arithmetic average of 6 measurements with rounding to 0.01 was taken as an indicator of the thickness of the test sample. The measurement results are presented in Table 1.

Table 1. Characteristics of the properties of satin-weave cotton fabrics

№	Name of fabric and degree of protection against radiation	Thickness of fabric, mm	Breaking load of fabric not less, N (kgf)		Structure	Weight g/m2
			on frame	on canard		
1	Metallized fabric "Sunrise", attenuation of radiation is 40-65 dB	1,9	1177 (120)	785 (180)	90% - polyester, 9.5% - copper, 0.5% - silver	156
2	WEAR shielding fabric, attenuation of radiation is 30 dB	1,8	1030 (105)	588 (60)	90% cotton, 9.5% copper, 0.5% silver	70
3	Shielding stretch fabric SILVER-ELASTIC, radiation attenuation of 50 dB	1,5	441 (45)	568 (180)	80% spandex, 20% silver	130

4	POLYSHIELD shielding fabric, attenuation of radiation is 35 dB	1,4	1177 (120)	1344 (137)	90% polyester, 9% copper, 1% silver	127
5	Antistatic fabric ScreenTex240 article 89001, attenuation of radiation is 50 dB	1,5	1030 (105)	834 (65)	40% cotton, 30% polyester, 30% stainless Steel	217
6	Fabric antistatic article of EZ-CX245, attenuation of radiation makes 245 dB	1,5	445 (35)	578 (110)	83% polyester, 16% copper, 1% silver	116
7	Fabric antistatic article EZ-CX100, attenuation of radiation makes 100 dB	1,6	710 (62)	577 (58)	60% - cotton, 30% polyester, 10% - stainless steel	113
8	Fabric antistatic article EZ-CX130, attenuation of radiation makes 130 dB	1,6	321 (35)	425 (170)	83% polyester, 16% copper, 1% - silver	155
9	Shielding fabric HNG100, radiation attenuation is 100 dB	1,7	411 (42)	524 (110)	83% polyester, 16% copper, 1% silver nickel	107
10	STEEL-GRAY shielding fabric, radiation attenuation is 35 dB	1,8	411 (42)	524 (110)	40% - cotton, 30% - polyester, 30% - stainless steel	220

The air permeability of the tissues was determined on a VPTM-2 device at a pressure drop of 49 Pa (GOST 12088-77) [7]. The air permeability of each point sample was calculated by the formula:

$$B = \frac{V_m * 10000}{S}\ dm^3/m^2c \quad (1)$$

where V_m - the average air flow rate for one point sample, dm^3 c

S - test area, m^2

The test results are shown in Table 2.

Table 2.

Fabric thickness mm	Air permeability dm^3 / m^2 c	Absorbability, %	Moisture return, %	Total thermal resistance, m^2 ^{0}S/vt
1,9	284.0	13.9	93.29	0.075
1,8	287.0	15.1	93.91	0.090
1,5	297.0	15.8	94.92	0.097
1,4	298.0	16.7	95.08	0.10
1,5	299.0	17.0	95.61	0.109
1,5	299.0	18.6	96.32	0.114
1,6	297.0	19.7	96.51	0.119
1,6	292.0	20.3	96.58	0.122
1,7	288.0	22.1	97.99	0.134
1,8	276.0	24.4	99.59	0.156

Processing of the results was carried out by the least squares method /9/. The calculated and tabulated values of the F-criterion were 65.03 and 5.32, respectively ($F_{calc} > F_{0.95}$), which indicates the reliability of the calculations for dependence (1). The dependence of the air permeability of the packets on the thickness is shown in Fig. 3.

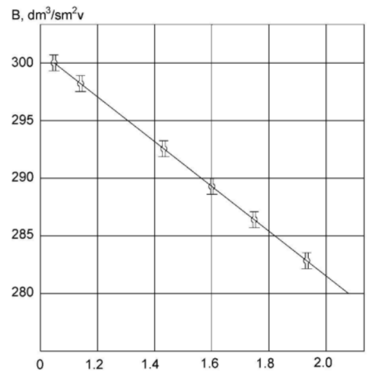

Fig. 3. Dependence of air permeability of materials on thickness

As mentioned above, in cases of excessive sweating, moisture conductivity of clothing materials is important in the formation of a person's thermal state. The main ways of returning moisture from the surface of the human body are the evacuation of moisture through the air gap and direct contact of the wet body with the material.

The ability of the material to give vaporous moisture from the clothing area is characterized by its absorbability and vapor permeability. The results of studies [6] showed that vapor permeability and air permeability correlate well with each other (correlation coefficient 0.96). This fact allows us to characterize the first indicator indirectly through the second one, that is judges vapor permeability by air permeability. Therefore, in this work, the moisture conductivity index of materials was evaluated by their absorbability and moisture yield.

Absorbability and moisture loss tests of the packages were carried out in accordance with GOST 3816-61 [8].

Absorbability was determined by the formula:

$$W_a = \frac{m_B - m_C}{m_c} \cdot 100, \% \quad (2)$$

where m_B is the mass of sample moisture, g

m_c - sample weight after drying, g.

The test results are given in Table 2.

The dependence of the absorbability of packets on their thickness is shown in Fig.2. The calculated and tabulated values of the F-criterion were 1148.16 and 5.32, respectively ($F_{calc} > F_{0.95}$), which indicates the reliability of the calculations for dependence (2).

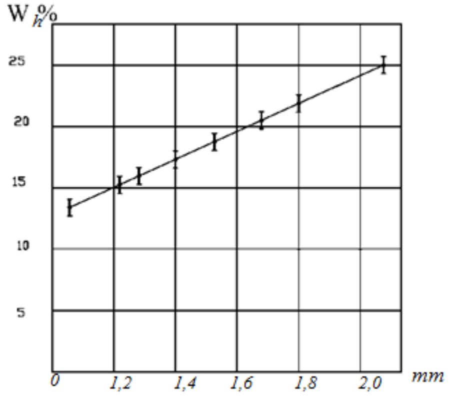

Fig. 4. The dependence of the absorbability of materials on their thickness

Moisture loss was calculated by the formula:

$$W_o = \frac{m_B - m_{cэ}}{m_c} \cdot 100, \% \qquad (3)$$

where $m_{cэ}$ is the mass of the sample aged for 4 hours in a dry desiccator, g.

The test results are presented in Table 2.

The dependence of the moisture loss of the packages on their thickness is shown in Fig. 3.

The calculated and tabulated value of the F-criterion was 533.08 and 5.32, respectively ($F_{calc} > F_{0.95}$), which indicates the reliability of the calculations for dependence (3).

The main indicator determining the thermal properties of clothing materials for hot climatic conditions, according to most authors [9], is thermal resistance. The total thermal resistance was calculated by the formula:

$$R_c = \frac{\delta}{\lambda} \; [m^2 \cdot °C\,/W] \qquad (4)$$

where: δ is the thickness, m

λ is the coefficient of thermal conductivity of materials, W/deg, m

Calculation results are given in Table 2.

The dependence of the total thermal resistance of materials on their thickness is shown in Fig.5.

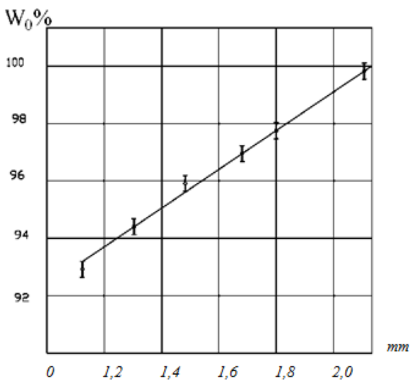

Fig. 5. The dependence of the moisture loss of materials on their thickness

The calculated and tabulated values of the F - criterion were 425.85 and 5.32, respectively ($F_{calc} > F_{0.95}$), calculations for dependence (4).

The obtained dependences (1-4) allow us to carry out a rational selection of materials for the manufacture of special clothes with specified hygienic indicators by calculation [10].

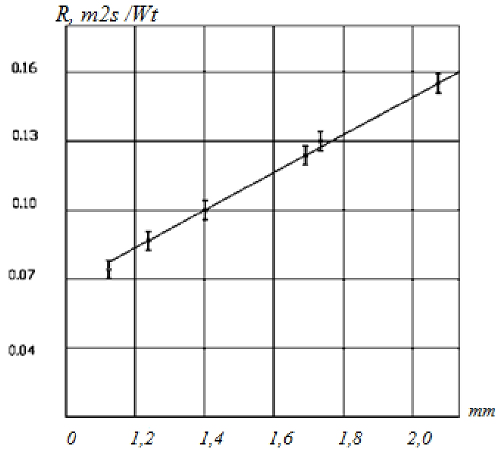

Fig.6. The dependence of the total thermal resistance of materials on their thickness

V. EXPERIMENT AND RESULT

An analysis of the results of studies of materials made it possible to establish that the use of fabrics with a thickness of up to 1.6 mm does not reduce the performance of air permeability, while the absorbability and thermal resistance of the bags are significantly increased.

Taking into account indicators of hygienic properties, as well as restrictions on material consumption and tissue weight, the most rational are fabrics 1.5 and 1.6 mm thick.

VI. CONCLUSIONS

Thus, according to the results of thermophysical studies, the relationship between the hygienic parameters of special clothing and the thickness of its materials is determined. Based on the mathematical processing of the test results, it was found that the most rational for the climatic conditions of Uzbekistan is the antistatic fabric article EZ-CX100 with a thickness of 1.6 mm. In our further researches while developing a mathematical model of the “man-overalls-environment” system, hygiene parameters δ - 1.5 mm were used as initial parameters, as the most rational for the climatic conditions of Uzbekistan.

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