Influence of plasma modification on hygienic properties of textile fabrics with nonporous membrane coating

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Abstract. The work investigated the possibility of using plasma modification to improve the hygienic properties of textile materials with nonporous membrane coating to improve vapor-, air-permeability and water-resistant. Determined that, after plasma modification changes degree of supramolecular orderliness of the polymers nonporous membrane coating and the base fabric.

1. The Introduction
Over the past decades, textile materials with membrane coating have become very popular among consumers due to the expansion of the range of membrane coatings and the operational capabilities of fabrics. Textile materials with membrane coating are used for making workwear used in adverse weather conditions, such as strong wind, rain, snow, frost. Working clothes regulate the thermal state of the body, protecting it from overheating and overcooling, helps to prevent colds, and also meet certain operational requirements: be comfortable, strong enough, waterproof and frost-resistant. Correctly selected for certain conditions, work clothes contribute to the prevention of injuries and occupational diseases [1]. The unique capabilities of products from these materials to protect from the atmospheric precipitation outside, and at the same time to transport the moisture emitted with a body to the external environment, essentially expand borders of comfort in comparison with the traditional waterproof clothing made of the ordinary fabrics with water repellent impregnation. Despite the modern variety of polymeric membranes, the option of combining membrane materials with fabrics and a variety of brands created both by producers of fabrics, and producers of finished products. The key indicators of quality of membrane material are high parameters of water-resistance, vapor-permeability and air permeability. In the domestic market, textile materials with nonporous membrane coating are used for sewing the top overalls. This is due to the low-cost production of such materials, their high strength and resistance to aggressive chemical compounds, compared to textile materials with nonporous membrane coatings, whose production is associated with costly multi-stage processes. However, textile materials with nonporous membrane coating have a rather serious drawback is a low vapor-permeability. The actual way to eliminate this disadvantage is the modification of membrane materials. Analysis of modern technologies used in the textile industry has shown that modification of tissues by nonequilibrium low-temperature plasma (NLTP) is widely used not only in scientific research, but also for solving specific production and technological problems [2-4]. Plasma modification is a universal way to regulate the properties of materials, while it does not degrade their protective characteristics. The purpose of this study was to modify textile materials with nonporous membrane coating in NLTP to improve their hygienic properties.
2. Materials, methods and equipment

The fabrics of the company «Tchaikovsky Textile»: a two-layer polyester fabric with a polyurethane (PU) nonporous membrane coating that is printed on the back side, Climate 3 and a three-layer polyester fabric with PU coating Climate 3+, which additionally has a lining fabric from the membrane side, were chosen as the objects of research [5]. On the fabric side of the fibers, the impregnating composition of the organofluorine preparation of water- and oil-water repellent finish is applied to the tissue.

The experiments were performed on an industrial radio-frequency capacitive plasma (RFC) plant [6]. The industrial plant consists of the following main parts: a vacuum chamber with internal equipment, placed on a single frame base, a sliding door with a cart on which the machine for rewinding fabrics is based, a vacuum evacuation system, a cooling system, a radio-frequency generator (RF generator), a control panel. The rectangular chamber is made of carbon steel and is welded. The walls of the chamber have stiffeners. The camera body is hidden by decorative panels. A more detailed description of this setup is presented in the article [6].

Since we are dealing with materials with diametrically opposite surface properties on both sides, the fabrics were modified in two stages: from the membrane coating in the air medium, and on the side of the base fabric, the material was processed in argon-acetylene medium. Based on previous studies [4-6], it is known that the modification of RF plasma in a nitrogen or air medium increases the hydrophilic properties of the surface and in the hydrocarbon gas medium, hydrophobic properties. Parameters of plasma treatment discharge: power ($W_p$) 1000-1500 W, working gas pressure ($P$) 21.6-20.5 Pa, processing time ($t$) 10-40 min, gas flow rate ($G$) 0.02-0.1 G/s, air and a mixture of argon-acetylene were used as the plasma-forming gas.

To assess of the changes in the hygienic characteristics of textile materials with nonporous membrane coating after modification in NLTP, the following studies have been carried out: determination of vapor-permeability, air-permeability, water-resistance [7-9]. To study the changes in the supramolecular structure of the membrane layer and the base fabric after the NLTP treatment was used X-ray diffraction analysis (XRD) [10].

3. Results

At the first stage of work two-factor optimization of parameters of two-stage plasma processing of textile materials with nonporous membrane coating has been carried out [11].

The optimum mode of plasma treatment on the side of the membrane coating for the selected materials is $W_p = 1200-1500$ W, $P = 22$ Pa, $t = 15$ min, $G_{air} = 34.5$ g/s, and on the base fabric side is $W_p = 1300-1500$ W, $P = 22$ Pa, $t = 7$ min, $G_{Ar/C_2H_2} = 29.6$ g/s.

The change in values of indicators of hygienic properties of materials after two-stage plasma treatment in optimal modes is presented in table 1.

| Material  | Sample               | Vapor-permeability, g/m² for 24 hours | Air-permeability, mm/s | Water-resistance, Pa |
|-----------|----------------------|---------------------------------------|------------------------|----------------------|
| Climate 3 | Before modification  | 1740                                  | 2.6                    | 98100                |
|           | After modification   | 1955                                  | 3.4                    | more 100000          |
| Climate 3+ | Before modification | 2500                                  | 5.2                    | 85300                |
|           | After modification   | 2720                                  | 8.0                    | more 100000          |

The obtained data show that after two-step plasma modification in optimal modes there is an increase in hygienic properties, namely water vapor-permeability material Climate 3 - 12.3% and material Climate 3+ by 8.8%; air-permeability of the material Climate 3 by 31% and material Climate 3+ by 54%; the water-resistance of the material Climate 3 by 1.9% and the material Climate 3+ by 17.2%. Consequently, the plasma treatment of textile materials with nonporous membrane coating for the production of special clothing improves the transport of moisture vapor from the susceptible space to the outer surface of the materials, which ensures the maintenance of normal functions of the human body thermoregulation and the waterproof properties of materials due to ion bombardment of the surface, which presumably leads to the rearrangement of intermolecular van der waals and hydrogen bonds.
Substantial changes in the microstructure of the materials after treatment with NLTP according to the confocal microscopy (CM) data are not observed (Fig.1), the changes appear in some smoothing of the microrelief of the membrane coating.

![Figure 1. CM images (×200) of surface morphology: PU membrane coating of the material Climate 3 before (a) and after (b) NLTP treatment](image)

The results of the X-ray diffraction analysis (Fig. 2) demonstrate decrease in the intermolecular ordering of the PU coating in the air environment, due to the breakdown of intermolecular hydrogen and van der waals bonds, which is confirmed by an increase in the vapor- and air-permeability of the materials.

The modification of fabric-based in argon-acetylene medium results in degassing the impregnating composition of the organofluorine preparation with water and oil-water repellent finish, fixing the functional groups of the hydrophobizer on the surface of the fabric fibers, ordering the amorphous phase, and increasing the crystalline phase, which explains the increase in the water resistance of the materials.

![Figure 2. Diffractograms of PU membrane coating (a) and polyester fabric-based material (b) Climate 3 before (1) and after (2) NLTP treatment](image)

4. Conclusions

Textile membrane materials with an increased complex of hygienic properties have been experimentally obtained. As a result of the studies, the following conclusions can be drawn:

1. Optimum regimes of two-stage plasma modification are established: on the side of the membrane coating is \( W_p = 1200-1500 \) W, \( P = 22 \) Pa, \( t = 15 \) min, \( G_{air} = 34.5 \) g/s, and on the fabric-based side is \( W_p = 1300-1500 \) W, \( P = 22 \) Pa, \( t = 7 \) min, \( G_{Ar/C_2H_2} = 29.6 \) g/s.

2. After modification in NLTP, the hygienic properties increase, namely: the vapor-permeability of the material Climate 3 by 12.3% and the material Climate 3+ by 8.8%; air-permeability of the material Climate 3 by 31% and material Climate 3+ by 54%; water-resistance of the material Climate 3 by 1.9% and the material Climate 3+ by 17.2%.

3. The effect of NLTP on the membrane coating reduces the degree of ordering of the supramolecular structure of the PU membranes due to conformational transformations and the separation of the supramolecular structure, which is consistent with the results of the permeability of materials due to
intermolecular diffusion, and on the side of the fabric-based leads to the ordering of the amorphous phase and an increase in the crystalline phase, consequence of this is an increase of water resistance.

Through this study, it can be concluded that the plasma treatment is quite gentle modification method for textile fabrics coated nonporous membrane obtained multifunctional materials may be recommended for sewing comfortable waterproof clothing for human.

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