ESTABLISHING PATTERNS OF MASS TRANSFER UNDER THE ACTION OF WATER ON THE HYDROPHOBIC COATING OF THE FIRE-RETARDANT ELEMENT OF A TENT

This paper reports an analysis of the flame retardants for fabrics that has revealed the fact that the meagerness of data to explain and describe the process of fire protection, specifically the neglect of elastic coatings, leads to that the structures made from fabrics are ignited under the influence of a flame. Devising reliable methods to study the fire protection conditions for fabrics results in the design of new types of fireproof materials. Therefore, there is a need to determine the conditions for the formation of a barrier for water mass transport and to establish a mechanism for slowing down water penetration through the material. In this regard, an estimation-experimental method has been constructed for determining mass transfer under the action of water when using a hydrophobic coating, which makes it possible to assess water penetration. Based on the experimental data and theoretical dependences, the intensity of mass flow under the action of water has been determined, which is 0.000177 kg/m², which ensures fabric resistance. The study results have proven that the process of waterproofing the fabric involves inhibition of the mass transfer process under the action of water by insulating the surface of the fireproof fabric with a hydrophobic coating. It should be noted that the presence of a hydrophobic coating leads to blocking the fabric surface from moisture penetration. Such a mechanism behind the effect of the hydrophobic coating is likely the factor in adjusting the process through which the integrity of an object is preserved. Thus, the sample of fireproof fabric coated with a water repellent demonstrated, after exposure to water, that the amount of water absorbed did not exceed 0.00012 kg, and, for a fabric without a water repellent, was 0.01 kg. Thus, there is reason to assert the possibility of targeted adjustment of the processes related to water penetration of the fabric by using hydrophobic coatings that could form a protective layer on the surface of the material, which inhibits the rate of water penetration

Keywords: protective equipment, canvas fabric, mass transfer of water, water penetration, surface treatment of fabric, hydrophobic coatings

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1. Introduction

Analyzing the scope of application of those easily erected structures that are made from textile flammable products reveals a steady tendency to increase their use. This is especially true during the temporary execution of certain tasks by the Armed Forces of Ukraine and units of the State emergency service. When heating such structures, their ignition and

rapid propagation of fire are possible. Operation statistics on easily erected structures revealed a low level of safety due to the use of natural fibers (such as flax, cotton, and mixtures) that are highly sensitive to exposure to high temperatures and fire. In addition, during the operation of such structures, water is likely to penetrate facilities through the fabric, which necessitates the use of water repellents.

At the same time, there is a need to investigate the application of fire-resistant water repellents since the use of combustible ones, such as paraffin, leads to an additional fire load. Thus, even though the outer surface of a structure for the Hartford Circus, Connecticut (USA), was pretreated, a fire broke out during its performance, which led to the mass death of spectators.

Therefore, there is a need to design materials for the protection of structures made from textile products by using the targeted application of an intumescent coating that could resist variable temperature and humidity factors. Specifically, by applying such functional additives and water repellents that would influence the processes of both heat resistance and water penetration, the physicochemical and special properties.

Therefore, it is a relevant task to undertake a study aimed at determining the patterns of inhibiting the process of water penetration through the hydrophobic coating of a fire-resistant element of the tent exposed to water.

2. Literature review and problem statement

Work [1] shows that fire-resistant coatings on an inorganic basis are very effective at improving the fire resistance of textile materials in the production of structures. This composite, reinforced with cement-based fabric, is prepared by filling the porous surface of the three-dimensional fabric. A given material is widely used and has a huge potential for application in emergency equipment, such as the protection of emergency tents and shelters, emergency repairs, and the construction of airport coverage and positional projects. However, it is necessary to improve the compression strength, bending strength, wear resistance, anti-penetration efficiency.

One of the new materials is the hybrid textile modified with carbon nanotubes. In [2], the textile was modified by applying dimethyl phosphate and perfluoro hexyl iodine. It was applied to cotton to obtain fireproof, water-repellent, UV resistant, and permeable multifunctional fabric. The flame retardants were synthesized using the introduced dimethyl phosphate and perfluorohexyl chain and applied to cotton by immersion drying. The properties of ignition were evaluated using a micro-scale combustion heater, conformity test, and TGA analysis. The hydrophilicity of the surface and the hydrophobicity of the surface of the fabric were characterized by a static angle of contact, and the resistance of the fabric against UV radiation was the value of UPF. Based on data from miniature combustion heaters, both the value of the maximum heat transfer speed and the total heat generation was about 65 % lower than that of untreated cotton fabric. Cotton fabric resistant to ultraviolet radiation was a model for use in outdoor sports such as clothing and tents. The modified fabric has fireproofed, UV resistant and permeable properties. However, to confirm that process, there were no relevant physicochemical data on washing out during operation.

Recently, nanotechnology has been able to bind a wide range of functional tissues. Study [3] is aimed at modifying graphene oxide by introducing dimethyl phosphate and perfluoro hexyl iodine. During the match test, the protection retained the original contours of the fabric. In images from scanning electron microscopy emitting fields, it was found that the residue of the fabric burned by the match method was more compact, and the lamellar structure of the graphene remained more complete. Although the hydrophobic effect was much more pronounced than the effect in the untreated cotton fabric, its hydrophobic effect was not satisfactory, which may be due to the fact that the content was low. This modifying technique could be used in any of the multifunctional textile preparation processes. The modified fabric has fireproof, UV resistant, and hydrophobic properties. However, it was not indicated which classes of operation those substances belong to.

Paper [4] reports a study aimed at protecting against ultraviolet radiation and hydrophobic tissue by modifying cotton fabric with graphene oxide and silane binding agent. The graphene oxide and silane binding agent were fixed to cotton fabric by a stable chemical bond. The graphene oxide was prepared by the modified Hammer method. The fabric sample was treated with graphene oxide and a silane binding agent using a simple immersion-gasket-drying method. The dosing effects of graphene oxide, the binding agent of silane, and the curing temperature were determined using a single variable experiment and an orthogonal experiment that characterized the passing in the ultraviolet light of the sample fabric. The method of testing for the angle of contact with water was used to indicate the hydrophobicity of the fabric sample. The structure and surface of the fabric were analyzed using infrared spectroscopy with a Fourier transform, and scanning electron microscopy. As a result, cotton fabric was successfully modified with graphene oxide and a silane binding agent; compared to the untreated fabric, the surface of the fabric was smooth and there were no gaps on the fiber. The graphene oxide, silane binding agent, and cotton fabric are tightly sealed. They had excellent UV protection and hydrophobic properties. Although the silane binding agent and graphene oxide have successfully rendered cotton fabric with good protection against ultraviolet rays and hydrophobic properties, graphene oxide and silane are expensive and must be used in large quantities. After treating with a silane binding agent, the hydrophilic fabric treated with graphene oxide is transferred to the hydrophobic one while graphene oxide is connected to cotton. The modified fabrics also have excellent protection against ultraviolet light. The modified fabrics have both protection against ultraviolet rays and hydrophobic properties. However, the issues related to the protection mechanism remain unresolved. The reason for this may be the subtleties regarding the formation of a protective layer, which, accordingly, makes such studies difficult.

Search for the possible alternatives to conventional flame retardants pushes to find new substances [5]. Nanocomposites, formed from clay cation starch, gave fire-resistant properties to pure cotton fabric by layer-by-layer application. The optical properties and mass of the films were precisely controlled by the number of two layers. In this case, starch and clay multilayer thin films were used to increase the thermal stability of fabrics and improve anti-ignition properties by forming a layer of ceramic coal and a heat-resistant carbon structure at high temperatures. Cone calorimetry revealed a lower total heat output and heat transfer of the fabric covered in two layers. Two-layer coated cotton samples showed a reduced afterglow time when tested on a vertical flame. However, nothing is said about the impact of changing environment on the coating, its destruction over time.

Article [6] proposed a method that assumes solving a system of two equations corresponding to data on the time-temperature characteristics: the Arrhenius model in combination with the principle of superposition of time and temperature, and the Hill triparametric equation. The result of data analysis using that method is interpreted in terms of four parameters: temperature effect, speed, average degradation time, and maximum strength. It was used to compare the effect of accelerated thermal aging on the breaking strength of seven different fabrics used for fire protection. In all cases, there was a very good convergence with both the Arrhenius model and the Hill equation. However, none of the fabrics studied reflected all the characteristics that would be ideal for long-term fire protection.

Work [7] employed a sol-gel method. Tetraethyl-orthosilicate and ethanol served as a solvent, and hydrochloric acid, catalyst, methacryloxypropyltrimethoxysilane as a binder for SiO_2 preparations, phosphorus flame retardant and ash to improve the fire-resistance of cotton fabrics. The immersion-baking process was used to treat cotton fabrics. The morphology of the surface and the distribution of elements, internal crystalline structure, pyrolysis, and the fire resistance of cotton fabrics were characterized by scanning electron microscopy, Fourier-transform-based infrared spectroscopy, X-ray photoelectron spectroscopy. X-diffractogram, thermogravimetric analysis, and restrictive oxygen index were also used. The results show that the treated fabrics have a good synergistic fire protection effect. The cotton fabric treated with hybrid sol demonstrates the best fire-resistant effect, its LOI is 22.8 %. The hybrid sol containing a phosphorus flame retardant can contribute to the formation of a three-dimensional microscopic gel coating and residual coal in the condensed phase. However, no areas of application of those products are specified.

Study [8] considered the use of two different fireproof compounds based on DOPO-Alkoxysilane. Those flame retardants were applied on the surfaces of fabrics made from polyamide to improve thermal stability. The prepared coatings showed a much greater % yield of carbon substances compared to pure material and, at the same time, inhibited the tendency of dripping in the process of vertical combustion. A fabric sample modified with 20 wt. % of the flame retardant showed a significant reduction in the peak rate of heat release, in particular 36 %, while the other only 20 % of the mass. The advantage of the DOPO-APTES-treated fabrics was due to the simultaneous presence of P, Si, and N elements. Here, the DOPO structure showed a tempering effect in the steam phase while Si compounds accelerated the limited DOPO charring in the condensed phase and stabilized coal residues over a higher temperature range. Moreover, the treated fabrics demonstrate some resistance to washing, and, among them, a sample of the fabric treated with 20 % by weight of DOPO-APTES, can withstand tough washing. However, the execution of these operations requires special equipment at the stage of manufacturing materials.

Coatings of surface equipment for fire protection of cotton are increasingly used due to the simplicity of coating application and their effectiveness in preventing the spread of flame and improving resistance to the exposure of irradiating heat flow. Work [9] studied in detail two main approaches, namely coatings obtained by sol-gel and layer nodes. Both approaches can render the treated fabrics outstanding fireproof properties. Despite this, based on the composition of the formulations of sol-gel and the type of layers applied, it is possible to devise multifunctional (for example, hydrophobic and electroconductive) procedures. The cited review focuses on discussing recent achievements in both strategies, highlighting current constraints, open challenges, and possible advances. However, it is not specified how those compositions withstand changes in temperature and humidity fields.

In [10], it is proposed to use, as an alternative flame retardant, the potential of carbon nanomaterials (CNMs) such as carbon nanotubes (CNTs) and material to cover graphene oxide (GO) on polyester fabric. The CNM mass loads on fabrics were checked using programmed thermal analysis. Compared to conventional halogen-containing ones, some CNMs demonstrated similar fire resistance at a lower load weight. The oxygen content in CNM, measured by X-ray photoelectron spectroscopy (XPS), proved to be a critical parameter with a higher oxygen content, which led to a decrease in the fire resistance of the coating. Non-carbon carbon materials of the same size as soot did not demonstrate the same flame retardants as CNMs. Multi-wall carbon nanotubes and amine-functionalized carbon nanotubes required significantly lower mass loads to achieve refractivity similar to conventional halogen-containing ones, so they are promising alternatives that require further research.

Inside premises with many people, the standards require using materials with reduced flammability [11]. Materials containing cellulose are dangerous in the case of a fire. The reported results of the research concern those premises where people live, and the fire load is textile fabrics, chipboard. The influence of fire-resistant additives on weight loss by timber slab samples under the influence of fire has been studied. The effect of type and duration of impregnation on the reduction of combustibleness and drying temperature of impregnated textile materials on the time of their burning was investigated. Therefore, the task is to fix a flame retardant in the material.

In [12], melamine-based resins are noted, which are widely used in fabrics to give fire and heat resistance. Modeled washing experiments suggest that in one round of washing with water, 76–90 % of melamine was removed from clothing. Therefore, the task is to fix a flame retardant in the material.

For fire-protective coating of textiles, metal hydroxides are still little used [13]. To obtain sufficient fire resistance in the coating, one needs to use up to 60 % of metal hydroxides. That leads to a high solid additive, which limits the use of metal hydroxides to several textile applications such as carpet pads and tarpaulin. The dimensions of aluminum hydroxide particles used for the treating of textile products typically range from 1 to $5\,\mu m$. The results of research on the design of fire-resistant nanocomposites consisting of polyolefins or polyamide with included nanoscale metal hydroxides show that the size of nano-additive particles has a decisive effect on the fire-protective effect. The smaller the hydroxide particles, the faster the bound water separates, and, in the event of a fire, water vapor is released. In addition, the combination with synergistic water repellents, such as nanolayer silicates (bentonites, montmorillonites), which is several percent in weight, can reduce the required amount of submicronic metal hydroxides.

Thus, our review of the literary sources revealed that fireproof coatings could be washed from the surface of textile material under the influence of water during operation but require a significant degree of protection and the use of water repellents. In addition, parameters that ensure resistance to the loss of fireproof properties have not been determined. The meagerness of mathematical models to explain and describe the process of fabric protection, neglect of the use of organic

substances for the formation of hydrophobic coatings, lead to inefficient utilization of protective means. Therefore, the task to define parameters for fabric fire resistance and the impact of coatings on this process necessitated our research in this area.

3. The aim and objectives of the study

The purpose of this work is to identify patterns of mass transfer when water is applied to the hydrophobic coating of the fire-proof element of a tent. That would make it possible to substantiate the application of a hydrophobic coating at operating facilities that include fabrics.

To achieve the set aim, the following tasks have been solved:

– to model the process of mass transfer under the action of water on the hydrophobic coating of the fire-proof element of a tent;

– to establish the effectiveness of fabric protection with a hydrophobic coating.

4. The study materials and methods

4. 1. The examined materials used in the experiment

To establish the fireproof efficiency of the fabric using the composition, we examined samples of canvas fabric measuring 100×100 mm (Fig. 1).

The samples were treated with a modified roofing impregnating solution based on the mixture of organic and inorganic substances «Firewall-Attic» manufactured in Ukraine (a mixture of urea, 28...30 %, and phosphoric acids, 23...24 %) but modified with starch in the amount of 20 % [14].

Fig. 1. Model fabric samples for testing

The resulting mass was stirred and applied on a fabric sample in the amount of 137.0...140.0 g/m² [15] on one side. In this case, the fireproof coating penetrated the structure of the fabric and formed an elastic film on the surface, about 20 µm thick. The hydrophobic coating GKZh 94 (polymethyl siloxane), manufactured in Ukraine, was applied to the opposite side.

4. 2. Procedure for determining the indicators of fire protection of fabrics with a composition based on modified phosphorus-ammonium compounds

For our study, we used an installation for determining the degree of fabric hydrophobization, which was additionally equipped with a device for measuring moisture at the sample surface during tests by using an electrical circuit (Fig. 2).

A sample of the fabric treated with a fireproof agent and a water repellent on one side was inserted between the rubber gaskets and fixed with flanges (Fig. 2). After that, we poured water in the amount of 20 ml into the fluoroplastic pipe and turned on the stopwatch simultaneously to determine visual-

ly the time of formation of water drops at the inverse surface of the sample. Based on measured values, water penetration was determined with changes in the coating at the surface of the fabric recorded.
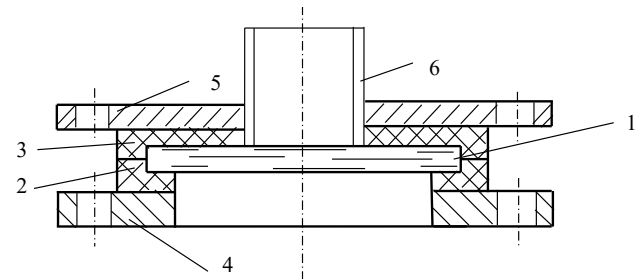

Fig. 2. Device for testing water permeability of waterproof fabric: 1 — fabric test sample; 2, 3 — rubber gaskets; 4, 5 — flanges; 6 — fluoroplastic pipe

Research into modeling the process of mass transfer of fireproof fabric through the hydrophobic coating under the action of water was carried out using the main provisions of mathematical physics [16].

5. The results of studying the process of mass transfer under the action of water on the hydrophobic coating of the fire-proof element of a tent

5. 1. Modeling the process of mass transfer under the action of water on the hydrophobic coating of the fire-proof element of a tent

As a result of treating the fireproof fabric with a water repellent, under the action of water, the direction of mass transfer of water changes, that is, there is the hydrophobization of the layer, which is largely able to withstand water pressure and reduce water transfer to the material.

Given the above, the question arises about studying the mass transfer at the border of two plates «a water repellent film – the fireproof fabric» under the effect of water.

To determine the mass flow of water to the layer of the fire-resistant fabric, a method for solving the problem of mass transfer for a two-part wall with various thermal properties is proposed (Fig. 3). At the initial time point, the outer surface of the coating instantly comes into contact with water C_{max}, which is maintained constant throughout the entire test process. The concentration distribution passes through the film of the water repellent until a critical concentration is reached in the fabric, C_s.
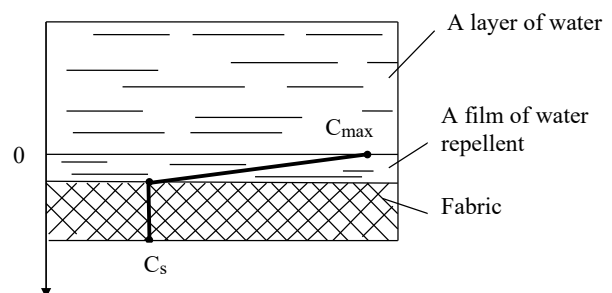

Fig. 3. Schematic of the process of water mass transfer: 1 — a film of the water repellent; 2 — the fire-proof fabric

The differential equations of mass transfer at the border of two plates «a film of the water repellent – the fire-proof fabric» take the following form [17]:

$$\left(\frac{\partial}{\partial t} - D_1 \frac{\partial^2}{\partial x^2}\right)C = 0, \ (-\infty < x < 0), \tag{1}$$

$$\left(\frac{\partial}{\partial t} - D_2 \frac{\partial^2}{\partial x^2}\right)C = 0, \ (0 < x < \infty; \ 0 < t < \infty), \tag{2}$$

under the following initial and boundary conditions:

$$C\big|_{x=-\infty} = C_0, \ C\big|_{x=\infty} = 0, \ C\big|_{x=-\infty} = C\big|_{x=+\infty}, \tag{3}$$

$$\beta_1 \frac{\partial T}{\partial x}\bigg|_{x=-0} = \beta_2 \frac{\partial T}{\partial x}\bigg|_{x=+0}, \tag{4}$$

$$C\big|_{t=0} = \begin{cases} C_0 \ \text{at} \ x \prec 0 \\ 0 \ \text{at} \ x \succ 0 \end{cases}, \tag{5}$$

$$C_0, \ D_1, D_2, \ \beta_1, \ \beta_2 = \text{const}, \tag{6}$$

where D_1, D_2 are the coefficients of water diffusion through a film of the water repellent and fireproof fabric, $\text{m}^2 \cdot \text{s}^{-1}$; β_1, β_2 are the coefficients of mass transfer of water through a film of the water repellent and fireproof fabric, m/s; C is the concentration, kg/m^3; x – coordinate, m.

One can see from the initial and boundary conditions (3) to (6) that at the initial time point, a certain concentration of water (C_0) is created at the surface of the fabric; over time, there is water penetration, the impregnation front moves into the fabric, which is fixed by the amount of water absorbed and the time of its passage (t).

It is necessary to determine the instantaneous value of concentration at the interface «a film of the water repellent – the fire-resistant fabric» C_s, and, accordingly, find the value of a mass flow between the regions:

$$J_0 = \beta_2 \frac{\partial C}{\partial x}\bigg|_{x=+0}. \tag{7}$$

Given that for the upper half-plane $x < 0$, the initial condition is not zero, so let us substitute:

$$C = C_0 - C^*, \tag{8}$$

where C_0 is the maximum concentration of water at the interface «a water repellent film – the fireproof fabric». Given that fire-resistant fabric is capable of instantaneous water permeability, this value can be registered by the amount of water absorbed when drops form at the back surface of the fabric.

After that, the problem of determining the concentration C^* is recorded in the following form:

$$\left(\frac{\partial}{\partial t} - D_1 \frac{\partial^2}{\partial x^2}\right)C^* = 0, \ (-\infty < x < 0, \ 0 < t < \infty), \tag{9}$$

under conditions:

$$C_{x=-\infty} = 0, \ C^*\big|_{t=\infty} = 0. \tag{10}$$

For the region $x < 0$, taking into consideration the Laplace transform, we can record the relationship of the concentration and mass flow in the following form [18]:

$$\left(P^{1/2} - \sqrt{D_1}\frac{\partial}{\partial x}\right) \cdot C^*\big|_{x=0} = 0, \tag{11}$$

where P is the Laplace operator.

Returning to the initial variable C, we obtain:

$$P^{1/2}(C_0 - C_s) = \frac{C_0}{\sqrt{\pi \cdot t}} - P^{1/2} \cdot C_s = -\sqrt{D_1}\frac{\partial C}{\partial x}\bigg|_{x=-0}. \tag{12}$$

For the region $x > 0$, respectively, we have:

$$P^{1/2}C_s = -\sqrt{D_2}\frac{\partial C}{\partial x}\bigg|_{x=+0}. \tag{13}$$

Combining (12) and (13) with the conditions of equal flows (4), we obtain:

$$P^{1/2}C_s = \frac{\sqrt{D_1}}{\sqrt{D_1} + \sqrt{D_2}}\frac{C_0}{\sqrt{\pi \cdot t}}. \tag{14}$$

Given the Laplace transformation, we obtain the value of concentration at the edge of the wall:

$$C_s = \frac{\sqrt{D_1}}{\sqrt{D_1} + \sqrt{D_2}} \cdot C_0. \tag{15}$$

Then, according to (7), the mass flow of water through the interface «a hydrophobic coating – the fire-resistant fabric» is described by the following equation:

$$J_s = \frac{\sqrt{D_1 \cdot D_2}}{\sqrt{D_1} + \sqrt{D_2}}\frac{\beta_2}{D_2}\frac{C_0}{\sqrt{\pi \cdot t}}. \tag{16}$$

This equation characterizes the process of water penetration through a hydrophobic coating to the fabric, depending on the physicochemical properties of both the water repellent and protection but does not take into consideration the area of contact of water.

Then, to more clearly determine water penetration, taking into consideration the contact area, the intensity of the mass flow under the action of water can be expressed by the following equation [19]:

$$q_s = \frac{J_s}{s^2} = \frac{\sqrt{D_1 \cdot D_2}}{\sqrt{D_1} + \sqrt{D_2}} \cdot \frac{\beta_2}{D_2} \cdot \frac{C_0}{\sqrt{\pi \cdot t}} \cdot \frac{1}{s^2}, \tag{17}$$

where s^2 is the water contact area, m^2.

According to the built equation (17), it is possible to determine the intensity of water penetration at the interface «a hydrophobic coating – the fire-resistant fabric» taking into consideration the amount of water absorbed, the area of contact, and the time of passage.

5. 2. Results of determining the water permeability of a sample of the fireproof fabric under the action of water on the hydrophobic coating

To establish the water permeability of a sample of the fireproof fabric, when water is applied to the hydrophobic coating, appropriate studies were carried out, Fig. 4.

The results of studying water permeability by the untreated and treated fabric samples carried out under laboratory conditions are given in Table 1.

Thus, the time of water permeability in a fireproof sample of the fabric treated with a water repellent exceeds that for the untreated one by more than 30 times.

According to [19], the value of D_1 is $1.5 \cdot 10^{-11} \ \text{m}^2/\text{s}$, D_2 – $2.9 \cdot 10^{-5} \ \text{m}^2/\text{s}$, β_2 equals $44.6 \cdot 10^{-3} \ \text{m/s}$. C_0 would correspond to the value in Table 1, and the water contact area

is 0.00053 m^2. Then the intensity of the mass flow under the action of water on the hydrophobic coating, which is calculated from (17), is 0.000177 kg/m^2. The mass flow of water at the border of two plates «a water repellent film – the fireproof fabric» during the action of water, calculated from (16), is 0.009371·10^{-5} kg.

Fig. 4. Testing fabric for water permeability

Table 1

Results of determining the time of water penetration when the fabric is exposed to water

Fire-proof sample	Water penetration time under the effect of water τ, s	Amount of water absorbed, kg
Fabrics without a water repellent	60	0.010
Fabrics treated with the water repellent GKZh 94	1,850	0.0012

6. Discussion of results of studying the process of mass transfer under the action of water on the hydrophobic coating of the fire-proof element of a tent

Our results in Table 1 are explained by the fact that the study of the process of mass transfer, when water is applied to the hydrophobic coating of the fire-resistant element of a tent, has revealed that over time there is water penetration. And, as it follows from the results (Fig. 4, Table 1), it is logical to extend the time of the destruction of the hydrophobic coating and reduce the time of water penetration. This is due to the stability of the hydrophobic coating and the formation of a barrier at the surface of the fire-proof fabric, which slows down the processes of water impregnation.

It should be noted that the presence of hydrophobic coating leads to blockage of the surface of the fabric from moisture penetration. Such a mechanism of the effect of a hydrophobic coating is likely the factor in adjusting the process through which the integrity of the object is preserved. In this regard, the interpretation of the results from determining water penetration by the fabric after exposure to water, namely the amount of water absorbed, makes sense. Since the amount of absorbed water did not exceed 0.00012 kg, and, for a fabric without a water repellent, it was 0.01 kg. That indicates the formation of a barrier for mass transfer under the action of water, which can be identified on the basis of the method of water influence on the examined samples.

That means that taking into consideration this fact opens the possibility for effective adjustment of the properties of fire-proof fabric directly during industrial production.

Our comparison of the experimental studies into water permeability under the action of water and the theoretical research of the transfer of water mass through a hydrophobic coating indicates the inhibition of mass transfer processes. Since the amount of absorbed water, when using a water repellent, was no more than 12 %, and the intensity of the mass flow under the action of water is 0.000177 kg/m^2.

That does not differ from practical data known from works [3, 4], whose authors, by the way, also associate the resistance to washing with the formation of compounds resistant to washing in the formulations. However, unlike the results reported in [3, 4], our data on the effect of the hydrophobic coating and complex flame retardant on the process of inhibiting the mass transfer of water, allow us to state the following:

– the main regulator of the process is not so much the formation of a significant number of water-insoluble complexes since certain fire-resistant coatings are destroyed under the influence of moisture;

– significant impact on the process of protection of natural combustible material when using a fireproof coating is exerted in the direction of waterproofing the surface of the fabric with a polymeric shell resistant to destruction under the action of moisture.

Such conclusions may be considered appropriate from a practical point of view because they make it possible to reasonably approach determining the required amount of a hydrophobic coating. From a theoretical point of view, they allow us to affirm the definition of the mechanism of processes of inhibition of mass transportation, which are certain advantages of this study. However, it is impossible not to note that the results (Fig. 4, Table 1) indicate the ambiguous effect of the hydrophobic coating on a change in water permeability. This is manifested, first of all, by the amount of water absorbed during tests of the fire-proof fabric. Such uncertainty imposes certain restrictions on the use of our results, which may be interpreted as the disadvantages of the current study. The inability to remove these restrictions within the framework of this work gives rise to a potentially interesting area of further research. It could address detecting the time point at which the drop in resistance to water begins. Such a finding would make it possible to investigate the structural transformations in the hydrophobic coating that begin to occur at this time and determine the input variables of the process that significantly affect the onset of such a transformation.

7. Conclusions

1. Based on an estimation scheme, the process of mass transfer under the action of water on the hydrophobic coating of the fire-proof element of a tent has been investigated. The effect of the hydrophobic coating on water resistance has been established; criterial ratios were derived that make it possible to find a change in water penetration at the surface of the fabric, that is, the value when exposed to water over time, characterized by the amount of water absorbed. The calculated intensity of the mass flow under the action of water is 0.000177 kg/m^2; it has been confirmed experimentally by water penetration. At the same time, the mass

flow of water at the border of two plates «a water repellent film – the fireproof fabric» under the action of water is $0.009371 \cdot 10^{-5}$ kg.

2. Features of inhibition of the process of mass transfer under the action of water are related to insulating the surface of the fireproof fabric with a hydrophobic coating. Thus, a sample of the fire-resistant fabric coated with a water repellent after exposure to water showed the amount of water absorbed, which did not exceed 0.00012 kg, and, for a fabric without a water repellent, it was 0.01 kg.

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