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МОДЕЛЮВАННЯ РЕАЛЬНОГО ПРОЦЕСУ ПРОХОДЖЕННІ РІДИНИ КРІЗЬ МАТЕРІАЛИ

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АНОТАЦІЯ *Традиційно вважається, що процес сорбції характеризується константою дифузії матеріалу. Запропоновано вважати коефіцієнт дифузії лінійною функцією від концентрації рідини в матеріалі. У цьому випадку для опису процесу сорбції необхідні дві константи матеріалу. Диференціальне рівняння сорбції в цьому випадку стає нелінійним. У статті розроблені методи вирішення такого рівняння. Наведено рішення для крайових умов абсолютного змочування з одного боку матеріалу. Отримане рішення повністю відповідає всім відомим експериментальним даним. Воно може застосовуватися для опису процесу сорбції в довільному матеріалі.*

Ключові слова: *сорбція, коефіцієнт дифузії, нелінійне рівняння, концентрація рідини.*

АННОТАЦИЯ *Традиционно считается, что процесс сорбции характеризуется константой диффузии материала. Предложено считать коэффициент диффузии линейной функцией от концентрации жидкости в материале. В этом случае для описания процесса сорбции необходимы две константы материала. Дифференциальное уравнение сорбции в этом случае становится нелинейным. В статье разработаны методы решения такого уравнения. Приведено решение для краевых условий абсолютного смачивания с одной стороны материала. Полученное решение полностью соответствует всем известным экспериментальным данным. Оно может применяться для описания процесса сорбции в произвольном материале.*

Ключевые слова: *сорбция, коэффициент диффузии, нелинейное уравнение, концентрация жидкости.*

SIMULATION OF THE REAL PROCESS OF PASSING WATER THROUGH THE MATERIAL

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ABSTRACT *The use of materials subject to the sorption of water recently expanded. Distribution of these materials is hampered by lack of theoretical bases of their creation and operation. Traditionally it is considered that the sorption process is characterized by the diffusion constant of the material. Experimental data demonstrate the dependence of the concentration of water in the material times. Another characteristic is the dependence of the concentration rate over time. In this paper the technique of solving the linearized differential equation of sorption is developed. The solution is obtained in the form of concentration versus depth and time. Analysis of the solution showed a partial agreement with the experimental data. It has been suggested to represent diffusion coefficient as a linear function of the concentration of liquid in the material. In this case the description of sorption process requires two material constants. The first line corresponds to the diffusion coefficient. The second factor corresponds to changes during the accumulation of moisture sorption in the material. The differential equation of sorption in this case becomes nonlinear. The paper developed methods for solving this equation. The solution for the boundary conditions for the absolute wetting one side of the material is presented. The solution comprises two constants that are analogues of diffusion constants. The resulting solution is fully consistent with all known experimental data. It can be used to describe the adsorption in arbitrary material. Using this equation also allows to predict the time of accumulation of moisture in the material and to select the material with predetermined properties sorption.*

Keywords*: sorption, diffusion coefficient, nonlinear equation, the concentration of the liquid.*

Introduction

Analysis of global trends in textile materials demonstrates the high priority research and development related to production of modern textile engineering purposes. A significant number of technical textile materials used as a geotextile material (drainage, insulation, separation), materials for construction (noise isolation, interior - to absorb the noxious fumes in hospitals and public buildings), medical supplies (operational textile linings for severe patients) etc. [1-3]. In this regard, there are some questions about the impact of the commodity composition and structure of textile fabrics for heat and mass transfer processes including the appointment of products.

Innovative line of multifunctional materials - combining in one package type of "sandwich" of materials with different capillary-porous structure that allows mass transfer purpose fully change processes, including adjust the intensity of heat transfer, humidity, noise. This gives ample opportunity to vary the properties of textile composites by the individual properties of each functional layer [4, 5].

The mechanisms of water absorption described in a number of studies [6, 7]. However, a reliable mathematical models for them have not been established. Such models can significantly develop the perspectives of materials by absorbing water.

The proposed calculation model [8, 10] built on a linear basis and does not correspond to the actual experimental data.

Aim of the work

Develop a model of the passage of moisture through the material, based on the account of non-linear effects, which most closely matches the experimental data to predict the process of water absorption in any case.

Development of the methodic

Creating multifunctional multilayer materials with predictable properties requires determination of individual properties of each element of the package and taking into account when designing a product designation. This necessitates the study of structure and regularity water absorption and other physical properties of individual source of textile fabrics, depending on their structure and fiber composition.

Typical dependence of water absorption occasionally shown in Fig. 1, 2.

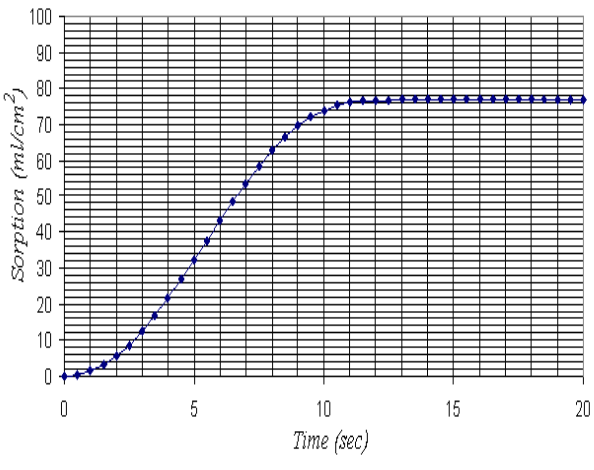

Fig.1 – Typical dependence of water sorption

For all indicators studied paintings U_{max}; V_{max} and , $V_{30\text{-}70\%}$, determined with an accuracy of 3-6%, 12.7% and 12.7% respectively.

Data from the kinetic curves of water absorption are fairly complete description of sorption properties of textile materials. We can assume that such characteristics of water absorption as U_{max}; $V_{max;}$ t_{max} for each textile material is its constants.

Note that these curves show data macroexperiments in which sorption parameters obtained for the entire material layer. It remains an unknown question, what happens inside the material.

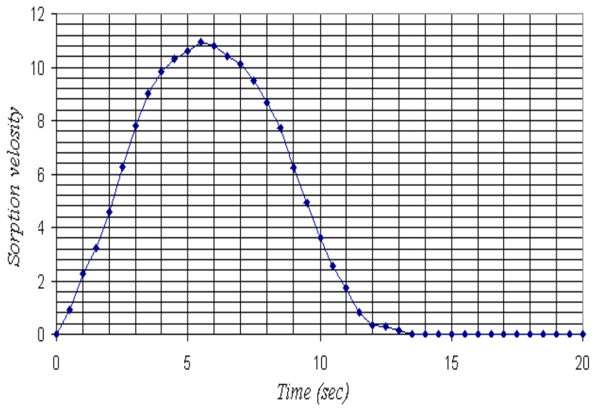

Fig.2 – Typical dependence of water sorption velocity

The answer to this question is important in the mathematical prediction of sorption through several layers of material (Fig. 3)

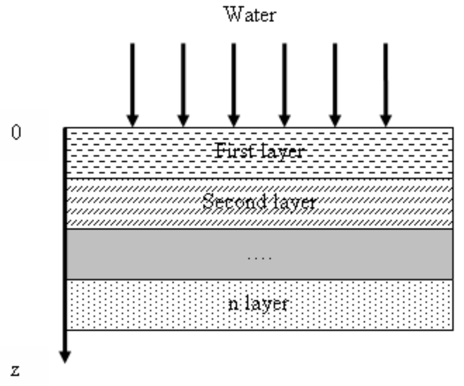

Fig.3 – Scheme of passage of moisture through the layers of material

To determine the total sorption need to know the function of the concentration change of moisture through the thickness of each material.

Differential equation of moisture passing through the material has the form [10].

$$\frac{\partial U}{\partial t} = \frac{\partial}{\partial z}\left\{D(U,z)\frac{\partial U}{\partial z}\right\}, \qquad (1)$$

where U - the concentration of moisture;
z - coordinate that goes from the top to the bottom surface of the material,
t – time;
D - diffusion coefficient.

As we know from many experimental studies [8-10], diffusion coefficient of liquid in porous body depends on its concentration. But to understand and simplify the process of finding solutions of (1) conventionally, in a first approximation, taking the coefficient of diffusion constant value. Then the differential equation becomes:

$$\frac{\partial U}{\partial t} = D\frac{\partial^2 U}{\partial z^2}\,. \qquad (2)$$

To solve the problem let's get to dimensionless coordinates:

– coordinate z varies from zero to one,

– concentration varies as a function of time unit on a surface in contact with moisture, to a certain current value to its opposite surface.

Imagine searched concentration in a series that is the product of two functions:

$$u = \sum_{i=1}^{\infty} V_i \cdot W_i\,, \qquad (3)$$

where V_i - a function of concentration, depending only on time;

W_i - a function of concentration, depending only on coordinates,

i - the number of Fourier series.

Given boundary conditions, a single member of several functions W, which depends only on coordinates, represented as

$$W_i = C_i\left(1 - \sin\frac{\pi z(2i-1)}{2}\right), \qquad (4)$$

where C_i - constant that appears at integration.

Approximate solution in this case has form

$$U = 1 - \sum_{i=0}^{\infty}\frac{4e^{-\frac{D}{4}\pi^2(2i-1)^2 t}\cdot\sin\left(\frac{\pi z(2i-1)}{2}\right)}{\pi(2i-1)}\,. \qquad (5)$$

Let's give the diffusion coefficient of some arbitrary value and build some graphs that reflects the changes in the concentration of moisture in the material as a function of time

Specific concentration around the layer of material:

$$\bar{U}(t) = \int_0^1 U(z,t)dt\,. \qquad (6)$$

After the integration process, we get:

$$U(t) = \left.\left(z + \sum_{i=1}^{\infty}\frac{8e^{-\frac{D}{4}\pi^2(2i-1)^2 t}\cdot\cos\left(\frac{\pi z(2i-1)}{2}\right)}{\pi^2\cdot(2i-1)^2}\right)\right|_0^1\,. \qquad (7)$$

Substituting the boundary, we get the equation of moisture absorption layer material:

$$U(t) = 1 - \sum_{i=1}^{\infty}\frac{8e^{-\frac{D}{4}\pi^2(2i-1)^2 t}}{\pi^2\cdot(2i-1)^2} \qquad (8)$$

and the equation of concentration change in thickness (absorption rate):

$$\frac{dU}{dt} = \sum_{i=1}^{\infty} 2De^{-\frac{D}{4}\pi^2(2i-1)^2 t}\,. \qquad (9)$$

Calculated curve of moisture absorbing of material layer in time can be presented graphically dependence curve Fig. 4, and speed of absorption of moisture - in Fig. 5.

Comparison of calculated curves of the form (Fig.4 and Fig. 5) and experimental [8-10] shows that the mathematical model with constant coefficient of diffusion is not the real data. But this assumption is made exclusively for us finding ways of solving equations of fluid motion, taking into account the nonlinearity of the process. Finding and solving an equation of the liquid in the general case when the diffusion coefficient depends on the amount of accumulated fluid will be shown below.

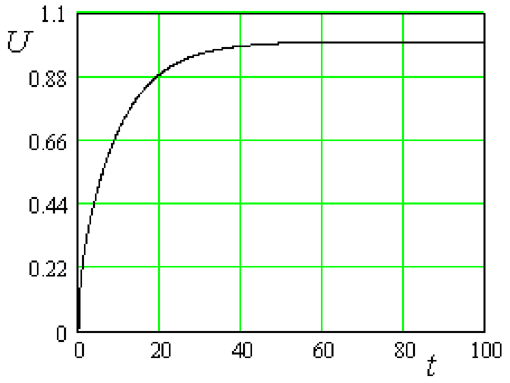

Fig.5 – The curve of material moisture absorbing for the model with constant diffusion coefficient

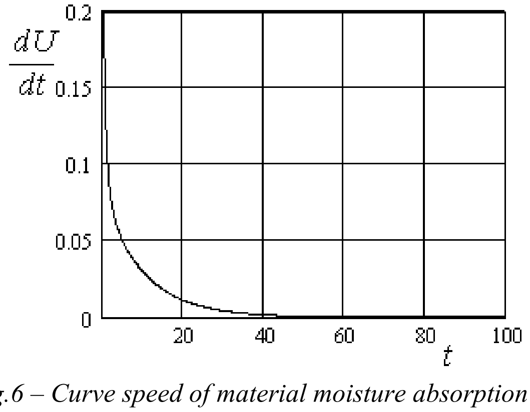

Fig.6 – Curve speed of material moisture absorption for the model with constant diffusion coefficient

Analysis of nonlinear model

Let's go back to the main form of transmission of moisture (1).

In a number of sources [2, 10] determined that the diffusion coefficient can be represented as:

$$D(U) = D_0(1 + \sigma U)\,, \tag{10}$$

where U - the concentration of moisture at some point the material layer;
x - coordinate of a point at a time;
t - time;
D - diffusion coefficient;
D_0 - the initial diffusion coefficient;
σ - coefficient of nonlinearity.
In this case equation (8) rewritten as:

$$\frac{\partial U}{\partial t} = \frac{\partial D}{\partial x}\cdot\frac{\partial U}{\partial x} + D\frac{\partial^2 U}{\partial x^2}\,. \tag{11}$$

We get the solution of equation in form

$$U(z,t) = 1 - \sum_{i=1}^{\infty}\frac{4\cdot e^{-A(2i-1)t^B}\cdot\sin\left[\dfrac{(2i-1)\pi z)}{2}\right]}{\pi(2i-1)}\,. \tag{12}$$

The unknown coefficients A and B are in explicit form in the equation (12), allowing them to operate freely. In particular, taking the specific meaning, you can find a function of concentration changes depending on the thickness and time (Fig. 7 and Fig. 8)

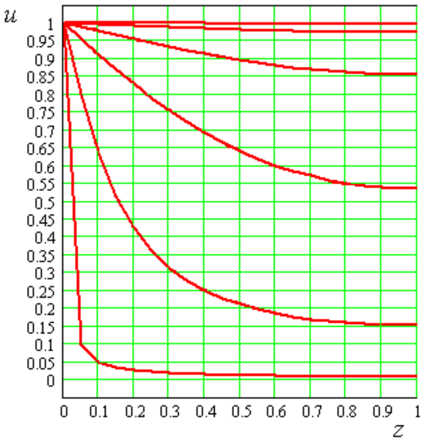

Fig. 7 – Changing the concentration of moisture in the layer thickness of material for different times ***($t_1 < t_2 < \ldots < t_6 < \ldots \leq t_{max}$)***

Change of concentration rate in thickness as a function of time, you can find during differentiation of expression (12) for concentration:

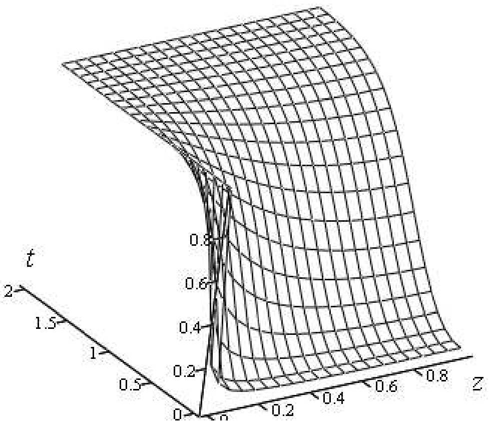

Fig. 8 – Dependence of concentration of moisture in the material coordinates and time

$$\frac{dU}{dt} = \sum_{i=1}^{\infty}\frac{4}{\pi}A\cdot B\cdot e^{B-1}\cdot e^{-A\cdot(2i-1)\cdot t^B}\cdot\sin\left[\frac{(2i-1)\cdot\pi z)}{2}\right]. \tag{13}$$

For some material, characterized by specific values of coefficients A and B, depending on location and speed time is shown in Figure 2.

Since the coefficients obtained in explicit form, you can find the dependence of concentration and speed since the average thickness

$$U(t) = \int_0^1 U(z,t))dz = 1 - \sum_{i=1}^{\infty}\frac{8e^{-A(2i-1)t^B}}{\pi^2\cdot(2i-1)^2}\,, \tag{14}$$

$$V(t) = \frac{dU}{dt} = \sum_{i=1}^{\infty}\frac{8ABt^{B-1}e^{-A(2i-1)t^B}}{\pi^2\cdot(2i-1)}\,. \tag{15}$$

Charts that show the dependence of these randomly selected coefficients A and B are shown in Figure 8, Figure 9. Qualitatively they are close to experimental.

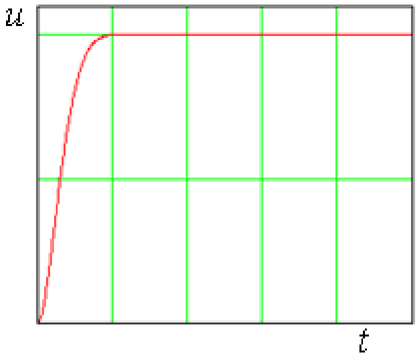

Fig. 9 – Change of moisture concentration for a single layer of material

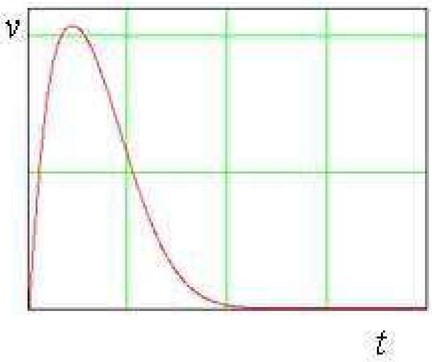

Fig. 10 – Speed change of water sorption for one layer of material

These nonlinear relationships are very close to the experimental data. This fact allows to recommend methodology of nonlinear expressions (14, 15) to describe the water absorption in material.

Conclusions

It is shown that the solution of linear equations of fluid passage does not match experimental data.

A non-linear equations of unsteady transfer of moisture perpendicular to the plane textile material is proposed, which takes into account the dependence of the diffusion coefficient of moisture content in the material at any given time at a given point. The equation contains two constants (A and B), which are the characteristics of the material and take into account the braking process water sorption durong the accumulation of moisture.

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