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MOISTURE ABSORPTION CHARACTERISTICS OF YARNS IN VARIOUS ENVIRONMENTS

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Abstract
This article examines the capacity of yarns to absorb moisture under different environmental conditions. The study focuses on yarn structure, moisture absorption and retention properties, and the influence of environmental factors such as temperature, relative humidity, and pressure. The article delves into the mechanism of moisture absorption in yarns and explores ways to optimize these parameters. The findings are significant for enhancing productivity and improving product quality in the textile industry.

Keywords Moisture absorption, Yarn physical properties, Environmental conditions, Textile industry, Material-moisture interaction.

INTRODUCTION

Moisture absorption indicators of fabrics are one of the important factors determining the quality of materials. These indicators directly affect the comfort, durability and functionality of the fabric. Depending on the type of thread, its structure and environmental conditions, such as temperature and humidity, the moisture absorption properties can vary significantly. Modern research is focused on the deeper study of the mechanisms of moisture absorption, with the aim of creating innovative fabrics. This article analyzes important information on moisture absorption properties using scientific papers on the subject.

In the study, comfort properties of fibers were studied under standard atmospheric conditions. Properties of "rapid moisture absorption and evaporation" are noted [1]. The importance of structural changes to improve these indicators is emphasized. Studying the modification of polyester fibers with alkaline and surfactants, he noted "significant improvement in moisture absorption performance" [2]. This approach is promising for creating fabrics resistant to wet environments. Considering the methods of extracting nanofibers from agricultural waste using environmentally friendly methods, it was noted that these fibers are "sensitive to moisture and require special processing methods" [3]. studied the properties of "moisture absorption and wetting" of silk fibers and noted that they have high functionality and aesthetic advantages [4]. studied ultrahigh molecular polyethylene fibers under different temperature and humidity conditions and found "significant changes in moisture absorption properties" [5]. analyzed the structure and properties of silk fibers and showed "significant influence of external temperature and humidity on moisture absorption and mechanical properties" [6]. studied fabrics intended for medical clothing and concluded that their "good air permeability and moisture absorption properties ensure long-term comfort" [7]. analyzed textile ropes and emphasized the importance of their "moisture absorption properties for flexibility and functionality in various conditions" [8]. studied membranes based on fibers and concluded that they "enable evaporation of moisture and passive cooling" [9]. studied woven fabrics for sportswear and found that they "effectively wick away moisture and provide comfort for athletes" [10].

Theoretical part

The following model can be proposed to represent the process of moisture absorption for pile fabrics made of cotton fiber in the form of a time differential equation taking into account temperature, relative humidity and pressure.

Markings:

- M(t)— amount of moisture in the tissue at time ttt (% or kg water/kg dry matter).
- Meq(T,RH,P)— equilibrium moisture content under given temperature (T), relative humidity (RH) and pressure (P) conditions.
- k(T,RH,P)— moisture absorption rate constant, depending on temperature, relative humidity and pressure (1/s).

Rate constant k(T,RH,P):

The rate constant depends on temperature, relative humidity, and pressure, and is usually expressed as a function of temperature using the Arrhenius equation:

$$k(T) = k_0 e^{-\frac{E_a}{RT}} \quad (1)$$

Here:

- k0 is a pre-exponential factor (1/s).
- Ea - activation energy (J/mol).
- R is the universal gas constant (8.314 J/mol·K).
- T is absolute temperature (K).

Pressure and relative humidityto take into account k can be determined experimentally and empirically related functions can be added to it.

Equilibrium moisture content Meq(T,RH,P):

GAB model(Guggenheim-Anderson-de Boer model) is a widely used physicochemical model for describing moisture sorption isotherms. It was developed on the basis of the BET model (Brunauer-Emmett-Teller), which allows for a more accurate description of the moisture absorption properties of materials.

Limitations of the BET model:

Although the BET model takes into account the monolayer and multilayer processes of adsorption, it does not perform well under conditions of high relative humidity (>0.5). To overcome these limitations, the GAB model was developed.

Basics of the GAB model:

The GAB model is based on the following key assumptions:

1. **Monolayer adsorption:** On the surface of the adsorbent, the molecules form the first layer, the energy of this layer is the lowest.
2. **Multilayer adsorption:** After the first layer, high-energy layers are formed, in which adsorbate molecules interact with each other and with the adsorbent.
3. **The relationship between water activity and equilibrium moisture content:** The adsorption process depends on the water activity aw.

The GAB model thus provides a deeper analysis of the physico-chemical basis of adsorption and allows for a more accurate description of moisture sorption isotherms.

Equilibrium moisture content is represented by sorption isotherms. For example, the GAB (Guggenheim-Anderson-de Boer) model:

$$M_{eq} = \frac{M_0 C K_{aw} a_\omega}{(1-K_{aw}a_\omega)(1-K_{aw}a_\omega+CK_{aw}a_\omega)} \tag{2}$$

Here:

- M0, C, Kaw are empirical constants.
- awa - water activity,

  $a_w = \frac{P_{H_2o}}{P_{H_2o}{}^0}$, where is the partial pressure of water vapor, and is the saturated vapor pressure of water. $P_{H_2o} P_{H_2o}{}^0$
- RH is relative humidity (%), and =RH/100. a_w

Changes in humidity over time, taking into account temperature, relative humidity and pressure:

$$\frac{dM(t)}{dt} = k_0 e^{-\frac{E_a}{RT}}\left[\mathrm{M}_{eq}(\mathrm{T,RH,P}) - \mathrm{M(t)}\right] \tag{3}$$

Pressure affects the boiling point of water and the partial pressure of water vapor. The Antoine equation is used to express the effect of pressure:

For it, we determine the partial pressure of water:

$$P_{H_2o} = \frac{RH}{100} P_{sat} \tag{4}$$

The activity of water is determined depending on the pressure:

$$a_\omega = \frac{P_{H_20}}{P} \tag{5}$$

From these equations we get the following equation.

$$log_{10} P^0_{H_20} = A - \frac{B}{C+T} \tag{6}$$

Here A, B, C are Antoine's constants, T is temperature (°C or K). The saturated pressure of water vapor is determined by this equation and varies depending on the pressure. $P^0_{H_20}$

The rate constant k(T,RH,P) looks like this:

The rate constant may also depend on the pressure. We write it taking into account the Arrhenius equation and the effect of pressure:

$$k(T,RH,P) = k_0 \left(\frac{P}{P_0}\right)^\gamma e^{-\frac{E_a}{RT}} \tag{7}$$

Here:

- k0 is a pre-exponential factor (1/s).
- P0 - standard pressure (Pa).

- g is a pressure-dependent indicator (determined empirically).
- Ea - activation energy (J/mol).
- R is the universal gas constant (8.314 J/mol·K).
- T is absolute temperature (K).

As pressure increases, the kinetic energy of molecules and the rate of diffusion can change, which affects$k(T, RH, P)$

The basic differential equation for moisture absorption taking pressure into account looks like this:

$$\frac{dM(t)}{dt} = k_0 \left(\frac{P}{P_0}\right)^{\gamma} e^{-\frac{E_a}{RT}} \left[\frac{M_0 C K_{aw} a_{\omega}}{(1-K_{aw}a_{\omega})(1-K_{aw}a_{\omega}+CK_{aw}a_{\omega})} - M(t)\right] \quad (8)$$

This equation describes the process of moisture absorption of pile fabrics made of cotton fiber as a function of temperature, relative humidity and pressure.

The GAB model describes moisture sorption isotherms on a physicochemical basis and has a convenient mathematical expression to account for the effect of pressure. The basic differential equation of moisture absorption written in terms of pressure provides a more accurate modeling of the moisture absorption process for pile fabrics made of cotton fibers.

This equation can be solved analytically.

First of all, we remember the last created differential equation and write it in a simplified form.

The basic differential equation is:

$$\frac{dM(t)}{dt} = k(T, RH, P)\left[\mathrm{M}_{eq}(\mathrm{T, RH, P}) - \mathrm{M(t)}\right] \quad (9)$$

According to the GAB model:

$$M_{eq} = \frac{M_0 C K_{aw} a_{\omega}}{(1-K_{aw}a_{\omega})(1-K_{aw}a_{\omega}+CK_{aw}a_{\omega})} \quad (10)$$

Rate constant k(T,RH,P):

$$k(T, RH, P) = k_0 \left(\frac{P}{P_0}\right)^{\gamma} e^{-\frac{E_a}{RT}} \quad (11)$$

However, to simplify the analysis, we simplify the differential equation as follows:

1. kand Meq as constants (assuming that temperature, relative humidity, and pressure do not change over time).
2. We write the equation as follows:

$$\frac{dM(t)}{dt} = k\left[\mathrm{M}_{eq} - \mathrm{M(t)}\right] \quad (12)$$

This differential equation is a first-order linear differential equation that can be solved analytically.

We write the equation:

$$\frac{dM(t)}{dt} + kM(t) = kM_{eq} \quad (13)$$

Let's make it simple to integrate.

This equation is a linear differential equation, the general solution of which is found as follows:

We determine the integration factor m(t):

$$\mu(t) = e^{\int kdt} = e^{kt} \quad (14)$$

We multiply the equation by the integration factor:

$$e^{kt}\frac{dM(t)}{dt} + ke^{kt}M(t) = kM_{eq}e^{kt} \quad (15)$$

We write the left side as a complete derivative:

$$\frac{d}{dt}[e^{kt}M(t)] = kM_{eq}e^{kt} \quad (16)$$

Let's integrate both sides over time:

$$\int \frac{d}{dt}[e^{kt}M(t)] = \int kM_{eq}e^{kt} \quad (17)$$

Let's simplify

$$e^{kt}M(t) = kM_{eq}\int e^{kt}\,dt + C \quad (18)$$

Here C is the integration constant.

Let's integrate the right side:

$$e^{kt}M(t) = kM_{eq}\left(\frac{e^{kt}}{k}\right) + C \quad (19)$$

Let's simplify:

$$e^{kt}M(t) = M_{eq}e^{kt} + C \quad (20)$$

We subtract from both sides:e^{kt}

$$M(t) = M_{eq} + Ce^{-kt} \quad (21)$$

We use the initial condition: moisture content at time t=0 (here - initial moisture content).$M(0) = M_0' M_0'$

We put the initial condition in the equation:

$$M(0) = M_{eq} + Ce^{-k0} = M_{eq} + C \quad (22)$$

From this:

$$C = M(0) - M_{eq} = M_0' - M_{eq} \quad (23)$$

The final analytical solution will look like this:

$$M(t) = M_{eq} + (M_0' - M_{eq})e^{-kt} \quad (24)$$

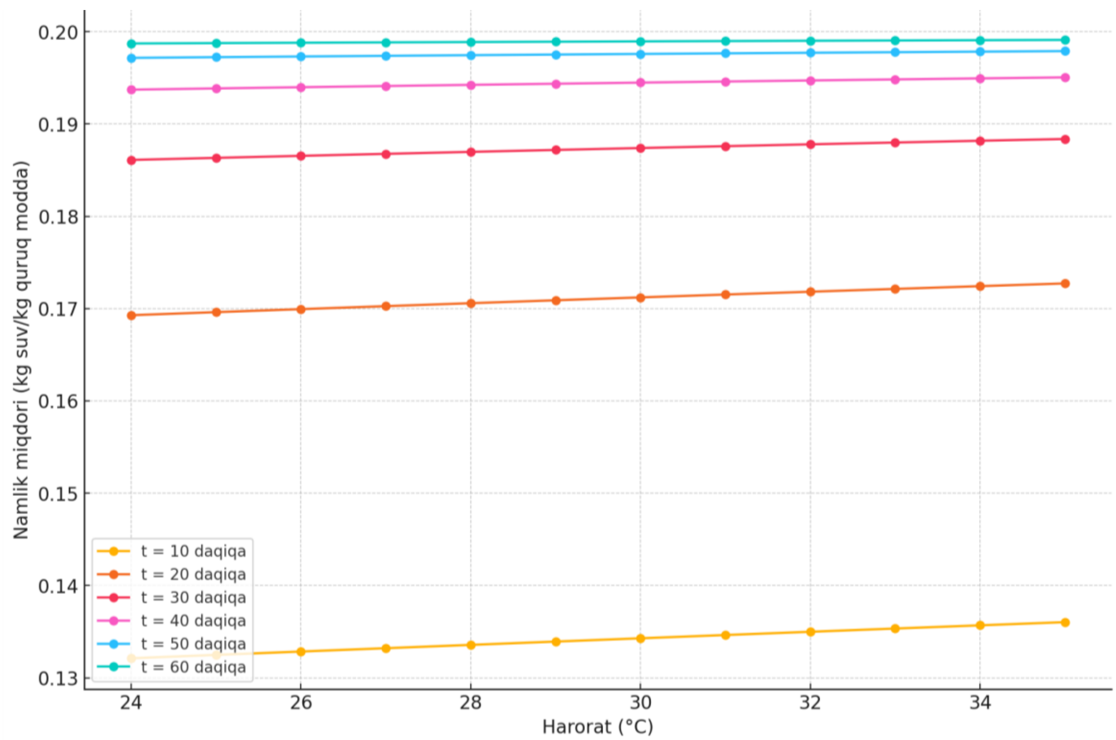
- M(t)— amount of moisture in the tissue at time t.
- Meq— equilibrium moisture content, moisture content tends to this value over time.

- M_0'— initial moisture content.
- k— moisture absorption rate constant; the larger, the faster the moisture absorption process.

Analysis of results and conclusion

As you can see from my solution:

- The value decreases exponentially over time.e^{-kt}
- If t→∞, then and M(t)→Meq.$e^{-kt} \to 0$
- The moisture content approaches the equilibrium value over time.



Picture 1.The rate of moisture absorption with temperature changes

In the graph above (Picture 1) at different time points (10, 20, 30, 40, 50, and 60 minutes) depicted the rate of moisture absorption with temperature changes. Each line shows the change in moisture content as a function of temperature at a specific time point.

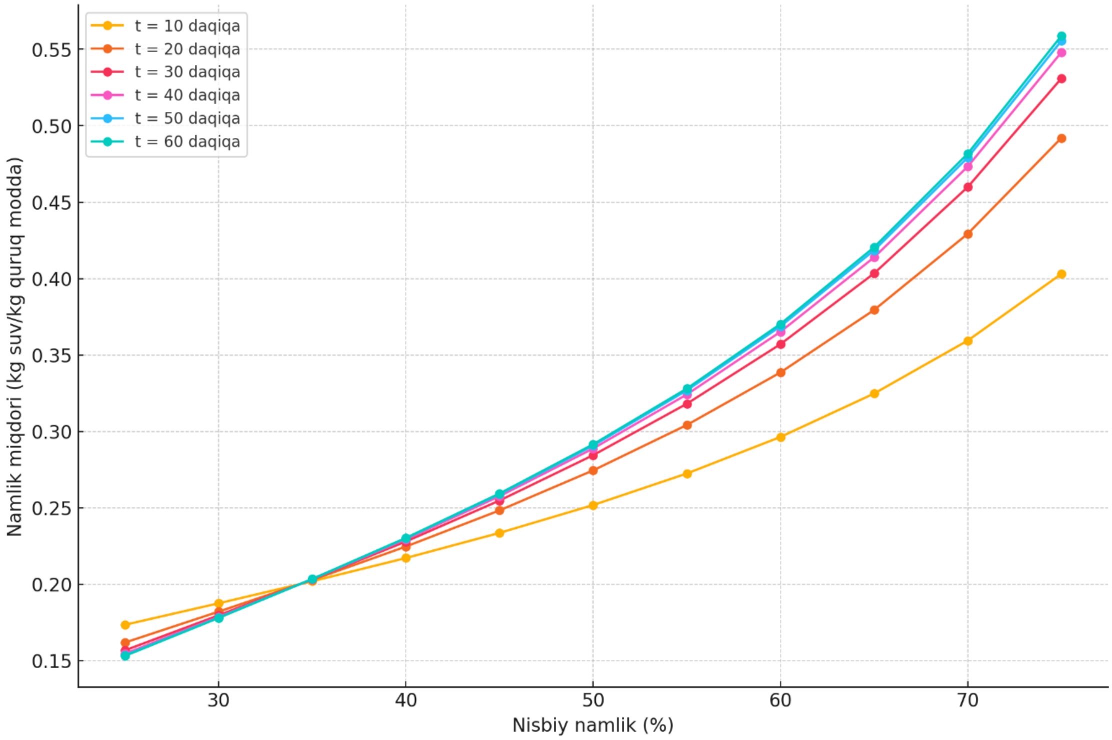


Figure 2. Changes in relative humidity.

In the graph above (Figure 2)shows how the moisture absorption rate of the yarn changes (10, 20, 30, 40, 50 and 60 minutes) with the change of relative air humidity from 25% to 75%. Each line shows the change in moisture content relative to relative humidity at a specific time point.

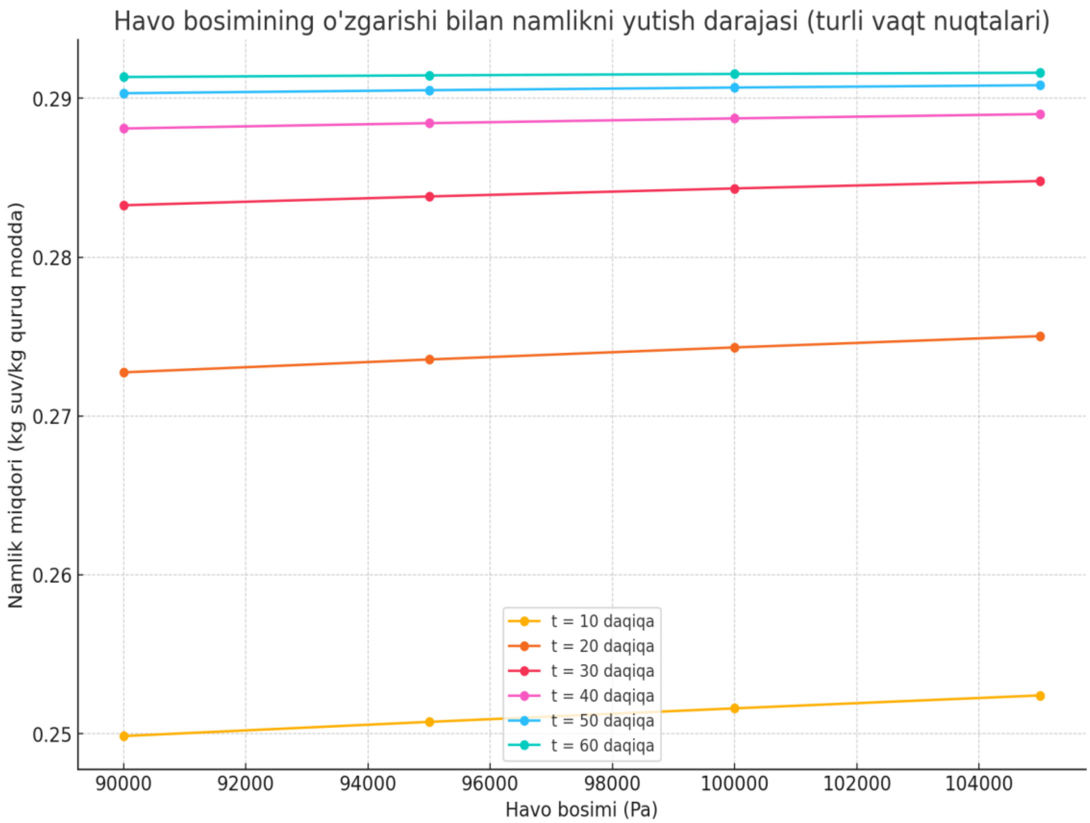


Figure 3. The degree of moisture absorption of threads with changes in air pressure

The graph above (Figure 3) shows how the moisture absorption rate of the yarn changes (10, 20, 30, 40, 50 and 60 minutes) as the air pressure changes from 90,000 Pa to 110,000 Pa. Each line shows the change in moisture content as a function of air pressure at a specific time point.

As the pressure increases, the rate constant kkk also changes, which affects the moisture absorption process.

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