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AN ANALYSIS ON THE PROCESS OF MOISTURE EXTRACTION IN THE RAW COTTON AND ITS COMPONENTS

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ABSTRACT

The cotton raw material and its components refer to varieties of capillary porous materials, with some special characteristics that distinguishes them from the other known porous materials, such as coal, sand, wood, hemp, flax, etc. Transfer of moisture in the raw cotton and fibrous mass is rather a complicated process, the moisture conductivity here depends on the structure of the material and the nature of the bond of moisture with its pores, etc. The theoretical aspects of the process of moistening cotton of raw cotton are considered in the article, by modelling it with a multi component medium with a structural structure where both internal mass transfer and mass exchange with the external environment are taken into account. This approach allows us to develop a general model for moistening cotton raw, which is close to real situations, thus ensuring the best adequacy of the accepted design scheme

KEYWORDS: Moisture Extraction, Raw Cotton, Fiber, Seeds, Mixture, Moisture Exchange Process & Kinetics

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Original Article

1. INTRODUCTION

Moisture in the mass of the raw cotton is a complex process, for the study of which it is required to perform a large amount of experimental and theoretical work [1-5]. Raw cotton refers to a multicomponent thermodynamic environment, the structural structure of which essentially depends on the type of technological impact. Therefore, direct analysis of the state of raw cotton from the standpoint of the mechanics of a continuous medium is difficult, here approaches and concepts are needed that apply to environments that have parameters that depend on the type and nature of the processing of raw cotton [1, 2].

In the drying process, the fibers have weak moisture bonds, while the raw cotton can have stronger moisture bonds and therefore it can be argued that, under the same conditions, it is possible for the fiber to be lighter and deeper than cotton and its seeds. Isotherms of sorption of seeds and raw cotton show that, at a relative humidity of 50%, the equilibrium moisture content of both raw cotton and seeds are almost the same and are at the level of 7%. Therefore, the selection of moisture from the mass of cotton raw material depends on the formation and development of moisture-exchange processes in its components, the nature of the drying agent and the drying regime [3, 4]. In this case, exchange processes can be realized: due to surface heat and mass exchange between the components of cotton raw according to Newton's law; internal convective exchanges between the components of the material and the heated air mass (thermal agent); transfer of heat and moisture as a result of flow in the pores of raw cotton; transfer of heat and moisture by diffusion phenomena occurring in each component of the material. The most interesting is the case of surface heat and the mass of exchanges between the components as a result of the motion of the heat agent in the space occupied by cotton raw, which is the subject of the article presented.

2. METHODS

Let us consider several model problems of the kinetics of moisture pick-up in a layer of the cotton raw material with a thickness that is modelled by a multicomponent medium when a heat flow (agent) is applied to it. We consider the layer to be thin, and denote by W_0, W_x, W_v and W_c respectively, and the average thickness of moisture in the air (agent), raw cotton, fiber and seeds. We believe that the change in moisture over time (the kinetics of moisture extraction) in cotton raw, moisture and seeds is proportional to the difference between them and air (agent). If we do not take into account the moisture exchange processes between the components, then the changes in moisture over time (balance equations) in the cotton raw, pulp and seeds are described by equations

$$\frac{dW_x}{dt} = \alpha_{0x}(W_0 - W_x), \tag{1}$$

$$\frac{dW_v}{dt} = \alpha_{0v}(W_0 - W_v), \tag{2}$$

$$\frac{dW_c}{dt} = \alpha_{0c}(W_0 - W_c), \tag{3}$$

Where, $\alpha_{0x} = \beta_{0x} / h$, $\alpha_{0v} = \beta_{0v} / h$, $\alpha_{0c} = \beta_{0c} / h$ are coefficients of moisture exchange between air cotton in raw (β_{0x}), fibers (β_{0v}) and seeds (β_{0c}), (m/s). If we consider cotton raw as a mixture of two components of fiber and seeds, and take into account the moisture exchange processes between them, the balance equation for each component is written in the form

$$m\frac{dW_v}{dt} = m\alpha_{0v}(W_0 - W_v) + \alpha_{vc}m(1-m)(W_c - W_v) \tag{4}$$

$$(1-m)\frac{dW_c}{dt} = (1-m)\alpha_{0c}(W_0 - W_c) + \alpha_{vc}m(1-m)(W_v - W_c) \tag{5}$$

where m and 1-m, the proportion of fibers and seeds, respectively, $\alpha_{vc} = \frac{\beta_{vc}}{h}$, β_{vc} - the coefficients of moisture exchange between them.

For the "fiber-seed" mixture

$W_\alpha = mW_v + (1\text{-}m)W_c$

in the aggregate state, the equation is written in the form

$$\frac{dW_a}{dt} = \alpha_{0v}m(W_0 - W_v) + \alpha_{vc}(1-m)(W_0 - W_c) \tag{6}$$

For m = 1 and m = 0 we obtain equations (2) and (3) respectively.

In the equations (1) - (3), the exchange processes between the raw cotton components are not taken into account, and their solutions are of interest in studying the process of moisture extraction from individual cotton raw cotton components or from raw cotton with a reduced moisture extraction coefficient α_{0x} taking into account the internal structure of the raw material.

Consider a mixture of raw cotton consisting of two components, the process of moisture selection of which is described by equations (4) and (5). The moisture content of the mixture will be determined as soon as the moisture content of each component and their proportional content in the mixture are known. In formula (6), the moisture content of W_v and W_c is determined by solving equations (4) and (5) which, under the initial conditions, $W_v = W_{0v}$, $W_c = W_{0c}$ have the form

$$W_x = C_1 \exp(-K_1 x) + C_2 \exp(-k_2 x) + A_1,$$

$$W_c = \gamma_1 C_1 \exp(-k_1 x) + \gamma_2 C_2 \exp(-k_2 x) + A_2$$

Where

$$C_1 = \frac{\gamma_2 (W_{0v} - A_1) - W_{0c} + A_2}{\gamma_2 - \gamma_1}, \quad C_2 = \frac{\gamma_1 (W_{0v} - A_1) - W_{0c} + A_2}{\gamma_1 - \gamma_2}, \quad \gamma_i = (k_i + a_1)/b_1$$

$$A_1 = W_0 \frac{\alpha_{0v} a_2 + \alpha_{0c} b_1}{\Delta}, \quad A_2 = W_0 \frac{\alpha_{0c} a_1 + \alpha_{0v} b_2}{\Delta}, \quad \Delta = a_1 a_2 - b_1 b_2, \quad k_{1,2} = \frac{a_1 + a_2 \pm \sqrt{(a_1 + a_2)^2 - 4(a_1 a_2 - b_1 b_2)}}{},$$

$a_1 = \alpha_{0v} + \alpha_{vc}(1\text{-}m)$, $a_2 = \alpha_{0c} + \alpha_{vv} m$, $b_1 = \alpha_{vc}(1\text{-}m)$, $b_2 = \alpha_{vc} m$

The formula (6) in accordance with the representations of moisture W_v and W_c is written in the form

$$W_a = W_{1a} = [C_v \rho_v (1-m) W_{1v} + C_c \rho_c m W_{1c}]/[C_v \rho_v (1-m) + C_c \rho_c m]$$

$$W_a = W_{2a} = [C_v \rho_v (1-m) W_{2v} + C_c \rho_c m W_{2c}]/[C_v \rho_v (1-m) + C_c \rho_c m]$$

3. RESULTS

The calculations were carried out for the following values of the moisture capacities and densities of the raw cotton components: $\alpha_{0v} = 0.055\,\text{min}^{-1}$ $\alpha_{0c} = 0.02\,\text{min}^{-1}$, $\alpha_{vc} = 0.001\,\text{min}^{-1}$. The initial moisture content of the fiber and seeds was determined by the formulas proposed in [5] $W_{0v} = 0.7 W_{0x}$, $W_{0c} = 0.46((W_{0x})^{1.275}$, Where W_{0x} is the moisture content of the raw cotton entering the drying drum.

In the Figure 1. The graphs of the process of moisture extraction from the fiber (curve -1), seeds (curve-2) and mixtures of "fiber-seeds" (curve-3) for different values of fiber content in the mixture are given. From the analysis of the curves it follows that the curves parallel to each other and with increasing humidity time in the components of the mixture and aggregate decrease according to a law that is close to linear. In this case, the curves for changing the moisture content for the mixture pass higher than the humidity curves of the fibers, but lower than the curves corresponding to the moisture content of the seeds

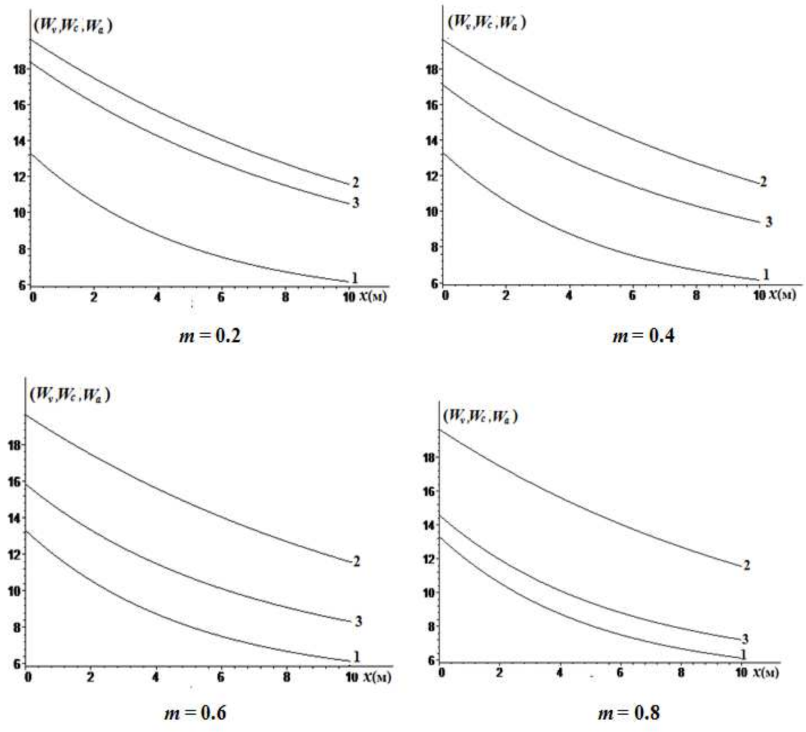


Figure 1: Christy Moisture Sampling from Fibers W_v (Curve 1), Seeds W_c (Curve 2) of Mixture W_a (Curve 3) with $W_{0x} = 19\%$ for Two Values of the Percentage of Seeds m

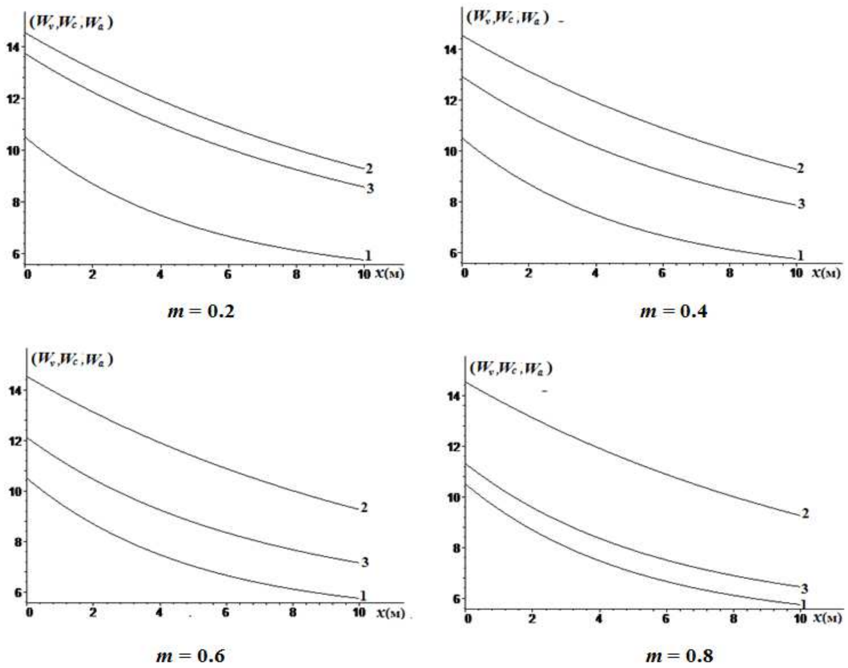


Figure 2: Curves of Moisture Extraction From Fibers W_v (Curve 1), Seeds W_c (Curve 2) of Mixture W_a (Curve 3) at $W_{0x} = 15\%$ for Two Values of the Percentage of Seed m

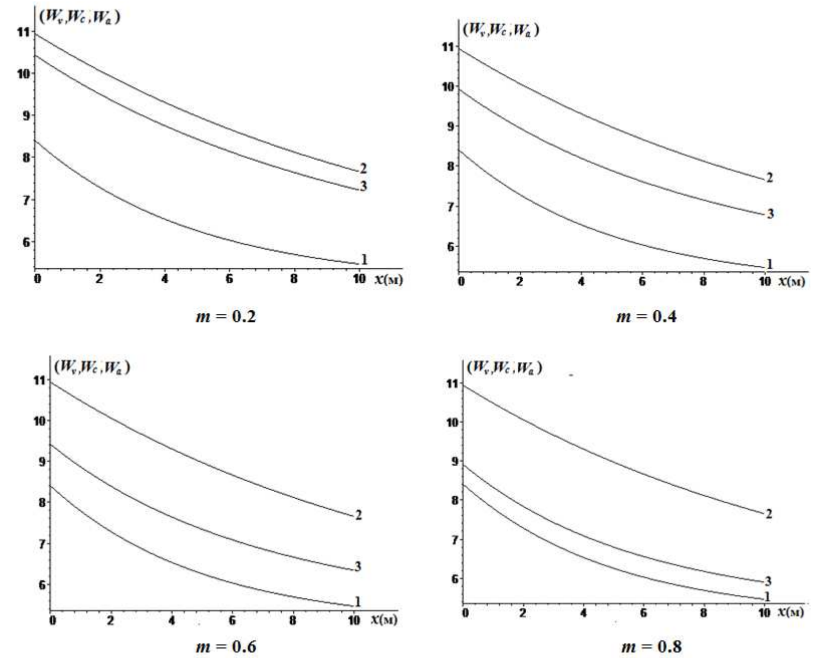


Figure 3: Curves of Moisture Extraction From Fibers W_v (Curves 1), Seeds W_c (Curves 2) of Mixture W_a (Curves 3) at $W_{0x} = 12\%$ for Two Values of the Percentage of Seed m

The proposed calculation technique is used to determine the law of moisture distribution along the drying drums, the descriptions of which are presented in [4-8]. The process of drying the raw cotton in the drums is determined by the amount and intensity of moisture taken from it. In this case, the mechanism for drying the wet cheese is mainly determined by the form of moisture binding to the material and the drying regime, or by the conditions of evaporation of moisture with the surface of the raw material into the environment.

In particular, the main parameters and operating principle of the drying drums are given. As indicated in [3-5], in practical conditions, the filling of the dryer essentially depends on the operating mode of the dryer. The tasks of drying large quantities of raw cotton are most appropriate for dryer designs with a capacity of $10000kg / hour$ or more and moisture harvesting of up to 10% or more, and therefore these types of dryers are currently the basis for further development of drying technology in the cotton industry. Let's give a procedure for calculating the humidity and temperature of the drying drum in the case of a stationary drying regime. We establish the origin of coordinates in the initial section of the drum and direct the axis Ox along its axis and denote by $t_v = t_v(x)$ and $t_x(x)$ the temperatures of the coolant and the cotton of the raw material in an arbitrary section of the drum. Let us isolate the element dx ($м$) from the zone of interaction of the raw material with the heat carrier, with the volume $dV_в = \pi D^2 dx / 4$, assuming a temperature uniformly distributed over the cross section of the drum and determine the hourly heat consumption for the selected element [5, 6]

$$dQ == \alpha_v K \Delta T dV_в = \pi \alpha_v K \Delta T D^2 dx / 4 \quad (7)$$

where $\alpha_v -$ is the total volume heat transfer coefficient $kJ/(\mathrm{m}^2 \cdot h \cdot grad)$, the number K takes into account a part of the dryer volume occupied by the blades, which will have a lower volumetric heat transfer coefficient, D is the drum diameter $м$, $\Delta T -$ is the average temperature difference between the drying agent and the cotton in the bulk of the element $dV_в$

$$\Delta T = \Delta T(t_v, t_x) = \frac{(t_{v0} - t_v) - (t_{x0} - t_x)}{\ln \dfrac{t_{v0} - t_v}{t_{x0} - t_x}}$$

Where (t_{v0}, t_{x0}) and $(t_x, t_v) -$ are respectively the temperatures of the coolant and raw cotton (in Kelvin) in the initial and arbitrary section of the drum.

Cotton raw material is represented as a mixture of "fiber-seed - heat carrier", we denote by W the productivity of the dryer by moisture ($kg/hour$) of the adopted unit. Then the amount of evaporated moisture from the volume $dV_в$, according to [5], will be

$$dQ = dW(q_1 + q_2) \tag{8}$$

Where $q_1 -$ is the heat consumption for evaporation of 1 kg moisture in section x [4], $kJ/(kg \cdot vapor\ \ moisture)$,

$$q_1 = q_1(t_v) = 2491.1 + 1.97(t_v - 273) - c_0(t_{x0} - 273)$$

$q_2 -$ Is the heat consumption for evaporation of 1 kg moisture in section x

($kJ/(kg \cdot vapor\ \ moisture)$),

$$q_2 = q_2(t_x) = \frac{\Pi_2}{W} c_x (t_{x0} - t_x)$$

$c_x -$ Is the specific heat of raw cotton in $kJ/(kg \cdot \deg)$:

$$c_x = \frac{c_0 + 0.01 c_в w}{1 + 0.006 w}$$

Where $w(x)$ is the moisture content of the raw cotton in the permissible section of the drum, $c_0 = 1.549$ and $c_в = 4.1868$ respectively the specific heat of the absolutely dry cotton of the raw material and the water absorbed by the cotton in A, Taking into account (8) of (7), we reduce it to the form

$$dW(q_1 + q_2) = \pi \alpha_v K \Delta T D^2 dx / 4$$

By supplying q_1 and q_2, we obtain a differential equation for determining the amount of evaporated moisture in an arbitrary section of the drying drum

$$\frac{dW}{dx} = \frac{\pi \alpha_v K \Delta T(t_v, t_x) D^2}{4[q_1(t_v) + q_2(t_x)]} \quad (9)$$

According to the known amount of moisture $W(x)$, the productivity of the dried cotton raw Π_2 ($kg / hour$) and the initial moisture content of the raw cotton w_0, one can find the current moisture content of the raw cotton [5]

$$w = \frac{\Pi_2 w_0 - 100W}{W + \Pi_2}$$

and according to the known moisture content of the raw cotton of equation (4) and (5), when W_0 is replaced by $w(x)$, it can be written in the form

$$m\frac{dW_v}{dt} = m\alpha_{0v}(w - W_v) + \alpha_{vc} m(1-m)(W_c - W_v) \quad (10)$$

$$(1-m)\frac{dW_c}{dt} = (1-m)\alpha_{0c}(w - W_c) + \alpha_{vc} m(1-m)(W_v - W_c) \quad (11)$$

Equations (9) and (11) form a system for determining the moisture content of mixture W_a and fiber W_v at known temperatures of raw cotton t_x and t_v fibers (K). To determine these temperatures, we use the stationary heat conduction equations for the coolant and raw cotton, taking into account the heat exchange processes between them, as well as with the drum wall.

$$c_v v_в \frac{dt_v}{dx} = \alpha_{vx}(t_x - t_v) + \beta_{vc}(t_c - t_v) l_v \quad (12)$$

$$c_x v_x \frac{dt_x}{dx} = \alpha_{vx}(t_v - t_x) + \beta_{xc}(t_c - t_x) l_x \quad (13)$$

where c_v is the specific heat of the heat carrier, $kJ/(kg \cdot \deg)$, $v_в$ and v_x - is the flow velocity of the coolant and raw cotton in the drum, α_{vx} is the coefficient of heat exchange between the coolant and cotton, $kJ/(kg \cdot \sec \cdot \deg$, β_{vc} is the heat transfer coefficient between the heat carrier and the drum wall $kJ/(kg \cdot m \cdot \sec\ vapor\ moisture)$, β_{xc} is the heat exchange coefficient between cotton and raw drum $kJ/(kg \cdot m \cdot vapor\ moisture)$, l_v and l_x - the length of sections of the contour of the drum cross-section contacting the drum wall M, which are calculated by the formulas $l_v = ml$, $l_x = (1-m)l$, $l = \pi D/2$ - the length of the contour of the cross section of the drum, m - the fractional part of the circuit, l which are in contact only with the coolant drum wall, t_c is the temperature of the drum wall (in Kelvin).

The final moisture content of the raw cotton can be determined through the initial moisture w_0, the amount of evaporated moisture in the section $x = L$ (L is the length of the drum, m) Π_2, and the capacity of the drum by the dried cotton Π_2, by formula

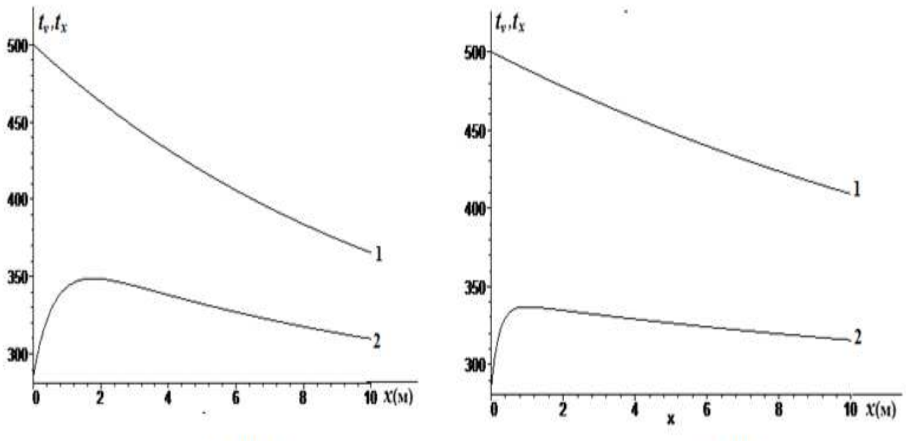
$$w_2 = \frac{\Pi_2 w_0 - 100W(L)}{W(L) + \Pi_2}$$

The calculations are performed for the following parameter values

$v_в = 1.25\, m/s$, $W_0 = 15\,\%$ $v_x = 0.014\, m/s$, $L = 10\, m$, $D = 3\, m$, $\Pi_2 = 2.78\, kg/sec$ $c_v = 4.182\ kJ/(kg \cdot \deg)$, $c_x = 2\ kJ/(kg \cdot \deg)$ $\alpha_v = 325\ kJ/(m^2 \cdot hour \cdot \deg)$, $K = 1.2$, $\alpha_{vx} = 0.019\ kJ/(kg \cdot \sec \cdot \deg)$, $\beta_{vc} = 0.01\ kJ/(kg \cdot m \cdot s \cdot vapor\ \ moisture)$, $\beta_{xc} = 0.02\ kJ/(kg \cdot m \cdot vapor\ \ moisture)$

The systems of equations (11) and (12) were integrated under the following initial conditions $t_v(0) = 500\ K$, $t_x(0) = 285\ K$, $t_0 = 280\ K$.

In Fig. 4 shows the distribution curves along the drum axis of the temperature of the coolant and raw cotton for two values of the proportion of the coolant n. It can be seen that with a decrease in the value of this, the temperature of raw cotton along the drum can be substantially reduced, which leads to a decrease in the rate of moisture extraction from the volume of the dryer. At the same time, in the initial section of the drum, the temperature of the cotton under the action of the heat carrier field increases partly and has a maximum at a distance of 0.5-1.5 m, and then it tends to decrease.



$n = 0.65$ $n = 0.3$

Figure 4: Curves of Distribution of Coolant Temperature (Curve 1) and Raw Cotton (Curve 2) in Kelvin Along the Length of the Drum for Two Values of the Fractional Content of Coolant n.

To determine the moisture content of fibers and seeds, one can use the empirical formulas presented in [5]

$W_v = 0.7w$, $W_c = 0.46w^{1.275}$

In Figure 5 shows the moisture distribution curves of raw cotton (curves-1), fibers (curves-2) and seeds (curves - 3) along the length of the drum

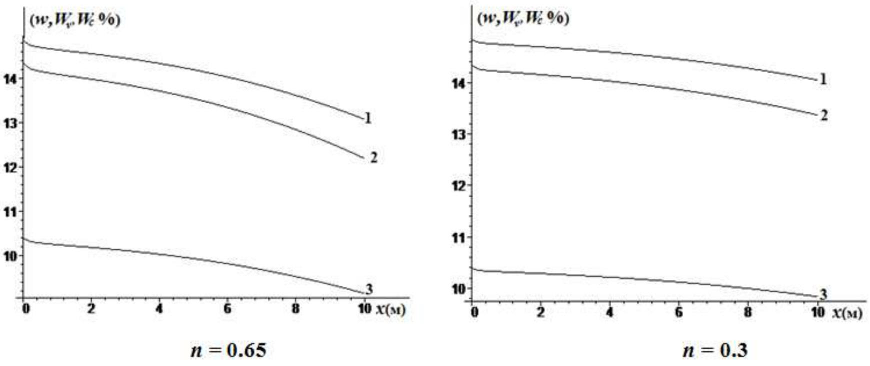


Figure 5: Creep Distributions of Humidity in Cotton Raw (1), Fiber (2) and Seeds (3) for Two Values of Coolant Content n.

4. ANALYSIS OF RESULTS

The process of mass exchange between the components of the raw cotton (Figure 3) is characterized by the arrangement of the curves of moisture change in the "fiber-seed mixture" between two curves that separately describe changes in moisture in fibers and seeds, while the curves for moisture change for the mixture pass higher than moisture curves fibers, but lower than the curves corresponding to the moisture content of the seeds.

The analysis of numerical calculations of heat exchange processes between the heat agent and the raw cotton (Figure 4), indicates a significant temperature drop in the air flow moving in the drum at high values of the porosity of the air-cotton mixture of the raw material. Intensive heat exchange processes in crude occur at low speeds of the agent. At high speeds, the temperature of raw cotton varies slightly, and therefore, the moisture is not very much extracted from it and the moving air has a moisture that is close to that of raw cotton. Reducing the porosity in the mixture the temperature of the raw cotton along the drum can be significantly reduced, which leads to a decrease in the rate of moisture extraction from the dryer volume. At the same time, in the initial section of the drum, the temperature of the cotton under the influence of the heat carrier field increases partly and has a maximum at a distance of 0.5-1.5 m, and then it tends to decrease.

5. CONCLUSIONS

A calculation technique is proposed for determining the law of moisture distribution along the drying drums, the descriptions of which are presented in [4-8]. To describe the moisture-exchange processes in the "fiber-seed mixture", the thermodynamic equilibrium condition is used to determine the amount of heat transferred in the drum. To determine the temperatures in the components of the mixture, surface heat transfer was used in them according to Newton's law. It is established that the presence of heat and moisture exchange processes in raw cotton and its components, a low fraction of the volume of the heat carrier, leads to the preservation of additional moisture both in the aggregate and in cotton raw material components consisting of pulp and seeds. This pattern is more pronounced in individual components of raw cotton. So, for example, with a decrease in the proportion of the volume of the heat carrier from $n = 0.65$ to $n = 0.3$, the additional moisture in the seeds is stored around $2.5 - 3\%$, in the fibrous mass near $1.5 - 2\%$, and about 2% in the raw cotton (in the aggregate state). Thus, the intensification of moisture extraction from raw cotton is determined by the patterns of heat transfer and the substance in the mixture and between the surfaces of the components and the environment. To understand properly the mechanism of these processes under thermal action, a thermophysical model of raw cotton should be developed that describes heat and mass transfer processes both between the components (fiber and seeds) and the thermal agent.

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