INTENSIFICATION AND INCREASE OF THE UNIFORMITY OF DRYING THIN STEMS AND TEXTILE FIBERS

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The article presents the results of an analytical and experimental investigation of the drying of a layer of thin stems and textile fibers under variable conditions. The progressive character of the proposed drying method for a wide range of raw materials of the textile industry is shown.

The processes of drying thin stems and textile fibers after their heat and moisture treatment (retting, washing, dyeing, etc.) are acquiring increasing importance for the technology of the textile industry in connection with the introduction of continuous production lines and automation of production processes. High requirements are imposed on drying: along with an intensification of the process, it is necessary to provide uniform drying of the material throughout the entire volume. In the overwhelming majority of cases the indicated materials are dried by blowing the layer of untied stems or fibers with hot air (gas). This method

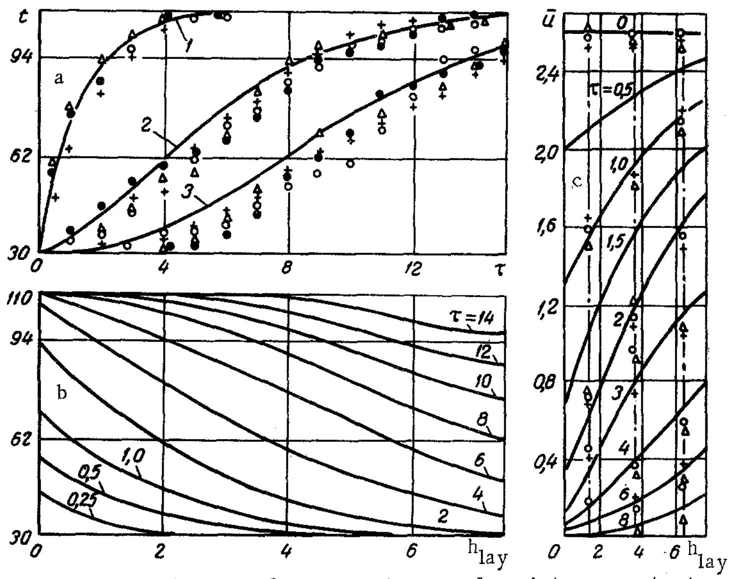

Fig. 1. Distribution of temperature and moisture content (c) of material over the height of the layer (b) and in time (a) in the case of unidirectional blowing of the drying agents through the layer (τ, min; h, cm; u, kg/kg): 1) temperature at air inlet into layer, $v_x = 0$, $x = 0$; 2) temperature in middle of layer, $v_x = 3$, $x = 0.04$ m; 3) temperature at air outlet from layer, $v_x = 6$, $x = 0.08$ m (drying conditions: $t_1 = 110°C$, $w_1 = 1.5$ m/sec, $\varphi_1 = 2\%$, $P_d = 2.5$ kg/m², $h_{lay} = 0.08$ m, $\bar{u}_0 = 2.65$ kg/kg). The numbers near the curves in b and c indicate drying time.

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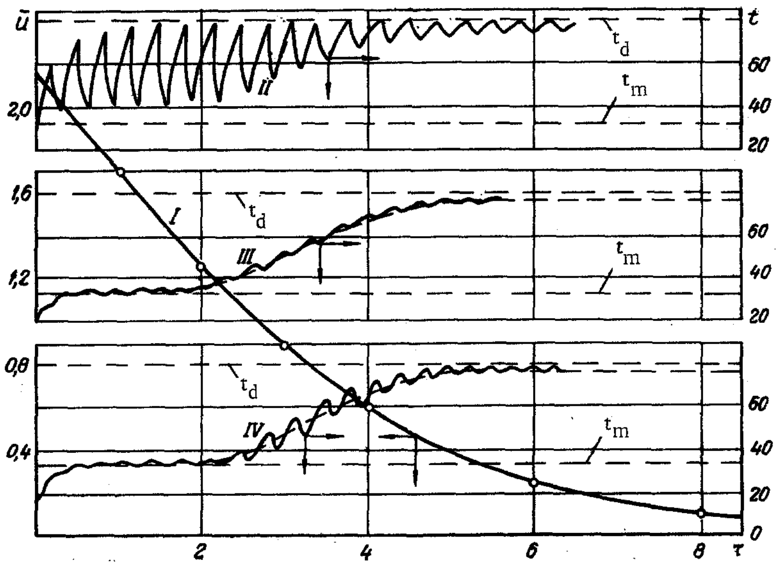

Fig. 2. Drying curve and temperature curves of material in the case of repeated reversal of the air being blown through the layer (drying conditions: $t_1 = 80°C$, $\varphi_1 = 5\%$, $w_1 = 2$ m/sec, $P_d = 2$ kg/m^2, $\tau_r = 20$ sec): I) drying curve; II) air temperature before layer (bottom or top); III) temperature of material in middle of layer; IV) temperature of material in 2nd, 3rd rows of stems (bottom or top).

provides a high productivity of the drying process, since there is a large surface of heat and mass transfer of the material with a drying agent filtering through it. As a consequence of the small thickness of the material, the drying rate is almost wholly determined by the parameters of the drying agent passing through the layer and velocity of blowing it. However, a further increase of the temperature of the drying agent in order to intensify the process is limited owing to the nonuniformity of drying and heating of the material in the layer and the deterioration of the quality of the material after drying related with this. An increase of the velocity of the air being blown upward to more than 2 m/sec lifts the material, which leads to the formation of a tangle, disruption of the layer, and leakage of air through the bare spots. When the air is delivered downward the layer of material being blown is compacted and the duration and nonuniformity of its drying increase. To outline ways for the further increase of productivity of the process and uniformity of drying throughout the layer of material, it is necessary to analyze the process. This analysis can be carried out on the basis of solving a system of differential equations describing heat and mass transfer in the layer.

A system of differential equations exactly describing heat and mass transfer in a layer is given in monograph [1]. In the case where the potential gradients of heat and mass transfer within the particles of the layer are small and they can be disregarded without appreciable loss of the accuracy of the result obtained, the indicated system of differential equations is greatly simplified and reduces to the following system of two differential equations approximately describing heat and mass transfer in a layer of thin stems or fibers [3]:

$$c\gamma_0 \frac{\partial \vartheta}{\partial \tau} - r\gamma_0 \frac{\partial u}{\partial \tau} = \frac{\alpha}{R_v}(t - \vartheta), \tag{1}$$

$$\frac{\partial t}{\partial \tau} + \omega_g \frac{\partial t}{\partial x} = \frac{\alpha(1-m)}{c_g \gamma_g R_v m}(t - \vartheta). \tag{2}$$

The solution of system (1), (2) under conditions that a) at the initial instant of time the temperatures of the material and the drying agent are the same and equal throughout the volume of the layer and b) the temperature and velocity of the drying agent before the layer are kept constant during the drying process, has the following form [2, 3]:

$$\Theta = \frac{\vartheta - \vartheta_0}{t_1 - \vartheta_0} = e^{-v_x} \int_0^{u_\tau} e^{-u_\tau} I_0\left(2\sqrt{v_x u_\tau}\right) du_\tau. \tag{3}$$

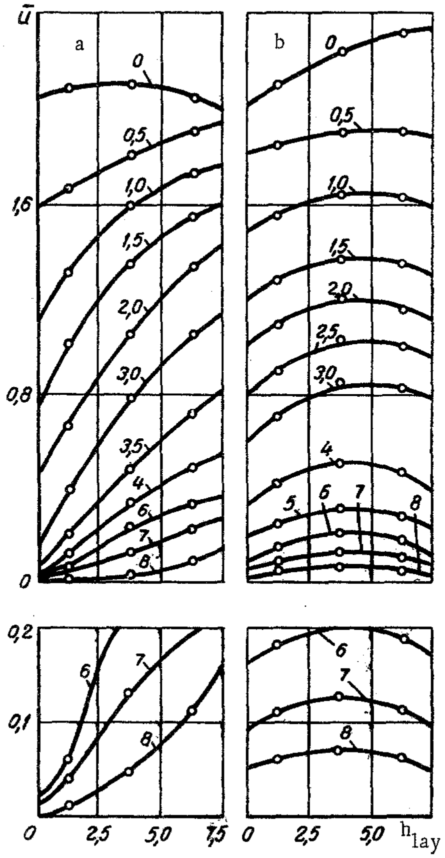

Fig. 3. Distribution curves of the moisture content of the material over a layer of flax stock during drying: a) with unidirectional air blowing; b) with repeated reversing of air (drying conditions: t_1 = 80°C, φ_1 = 5%, w_1 = 2 m/sec, P_d = 2.5 kg/m² τ_r = 20 sec). The numbers near the curves indicate drying time in minutes.

The experimental check of solution (3) given in [3] showed that the heating curves of moist stems of flax stock during their layer drying correspond to temperature curves plotted according to Eq. (3) (Fig. 1). Calculations by Eq. (3) permit establishing the heating time of elements of the layer up to the maximum allowable temperature. For example, for drying conditions t_1 = 120°C, φ_1 = 10%, w_1 = 2.5 m/sec, u_0 = 2.0 kg/kg, the heating time of the extreme stems to 90°C is about 40 sec. The temperature of the fiber on the surface of the stem will be even higher at this time. From an examination of the temperature curves in Fig. 1 follows the suggestion of organizing the process of drying a layer of stems or fibers with a variable delivery of the air into the layer upward and downward, i.e., organizing reverse drying. In this case the period of reversing the air is determined by the drying conditions, and its optimal value can be established by analyzing the reverse drying process. System of Eqs. (1), (2) is obtained irrespective of the direction of the air through the layer. On reversing the air only the initial conditions of heat transfer in the layer will change. In the first period of drying the layer, when the surface of the stems (fibers) is saturated with water, the distribution of the temperature over the height of the layer, described by Eq. (3), is approximated nicely by an exponential curve of the following form:

$$\Theta(v_x,\ 0) = ae^{v_x}, \qquad (4)$$

where a is the dimensionless temperature of the material at the outlet of the air from the layer in the first drying period. As a result of solving system of Eqs. (1), (2) with initial condition (4) and the same boundary conditions as at the start of blowing the layer, we obtain the following expression:

$$\Theta = a\exp\left(v_x - \frac{u_\tau}{2}\right) + e^{-v_x}\int_0^{u_\tau} e^{-u_\tau} I_0\left(2\sqrt{v_x u_\tau}\right) du_\tau + ae^{-v_x - u_\tau} I_0\left(2\sqrt{v_x u_\tau}\right)$$

$$- ae^{-v_x}\int_0^{u_\tau}\sqrt{\frac{v_x}{\xi}}\sqrt{e^{-(u_\tau-\xi)}}\, e^{-\xi} I_1\left(2\sqrt{v_x \xi}\right) d\xi - ae^{-v_x - \frac{u_\tau}{2}}. \qquad (5)$$

For the drying conditions being used for thin stems and fibers the third, fourth, and fifth terms of Eq. (5) are very small in comparison with the first two and we can neglect them. The value of the first terms rapidly decreases with time. Therefore the temperature field of the material by the end of the second half-period of reversal is almost a mirror image of the temperature field at the end of the first half-period. Thus, within the first drying period the temperature field of the material will be described approximately by Eq. (3). Experimental investigations of the temperature fields of the material and air during drying of wet flax stock with reverse movements of air through the layer [4] confirm the described model of heat and mass transfer (Fig. 2). We see from an examination of the temperature curves in Fig. 2 that the heating rate of the layer is almost the same throughout its thickness. It is completely obvious that to preserve the quality of the fiber the frequency of reversing the air should, other conditions being equal, increase with increasing temperature of the drying agent, i.e., during intensification of the process by using more drastic drying conditions. The use of air reversal when drying a layer of thin stems and textile fibers is not new. However, so far infrequent reversing has been used – 3- and 4-fold air reversal during the entire drying period of the material. In this case fundamental differences of heat and mass transfer are not created in the layer of material in comparison with unidirectional blowing of the layer. The use of frequent reversal of the drying agent, as we see from Figs. 2 and 3, creates the possibility of intensifying the drying process by increasing the temperature of the drying agent while simultaneously preserving the quality of the material. In the case of frequent air reversal the phenomenon of heat and moisture conduction in stems is used to prevent overdrying, overheating, and spoilage of the fiber on the stem sturface, since the material passes through drying with fluctuating temperature conditions.

Another possibility of increasing the productivity of the process and uniformity of drying the material arises when organizing reverse drying with frequent reversal.

Zonewise reversing of the air makes it possible to obtain a wavelike movement of the material. It was established experimentally that in the zone of blowing the material upward with a high velocity, the layer is heaved by the dynamic pressure of the air, expands, and increases the active surface of heat and mass transfer of the material.

We also suggest nozzle blowing with a low flow rate of the air as an auxiliary means to the main flow of the drying agent for aerodynamic loosening and redistribution of the material on the grating in order to increase the uniformity and productivity of the drying process. Several pairs of nozzles, spaced over the travel path of the material through the drier, direct counterstreams of the drying agent into the layer. In this case the kinetic energy of the stream is used for loosening the compacted portions of the layer and for equalizing its thickness.

These measures decrease the drying time of materials under industrial conditions and greatly increase the productivity and uniformity of the drying process of a wide range of materials in the textile industry.

Approximate calculations of the economic effect show that the introduction of the described progressive method of drying flax stock at primary flax processing plants can effect a considerable economy for the country. Economy is obtained owing to uniform drying of the raw material and improvement of the quality of the flax fiber obtained.

NOTATION

ϑ is the temperature of material;
t is the temperature of drying agent;
γ_0 is the specific weight of dry material;
c is the heat capacity of material;
r is the heat for water evaporation;
τ is the time;
α is the heat transfer coefficient;
R_V is the hydraulic radius;
u is the moisture content of material;
w_g is the velocity of drying agent;
x is the coordinate in the direction of blowing the drying agent;
m is the free volume of the layer;
c_g is the heat capacity of gas
γ_g is the specific weight of gas;
$v_x = \alpha x(1-m)/c_g\gamma_g w_g m R_V$;
$u_\tau = \alpha(1-\varepsilon_0)\tau/c\gamma_0 R_V$;
$\Theta = (\vartheta - \vartheta_0)/(t_1 - \vartheta_0)$;
$1 - T = (t_1 - t)/(t_1 - \vartheta_0)$.

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