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Heat and Mass Transfer Drying Cotton in Drum Drier

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ABSTRACT: Determination of the regularity of the heat and mass exchange process of drying raw cotton along the length of the drum dryer by experimental means is difficult due to the particular design of the installation. In the article, the regularities of the change in the heat and moisture conditions of raw cotton and the temperature of the drying agent along the length of the drying drum are determined using the results of experimental and theoretical studies.

KEYWORDS: Raw cotton, Drying, Drying regime, Dryer humidity, Heat transfer, Heat capacity, Heating, Drying agent.

I. INTRODUCTION

Moisture in the mass of raw cotton is a complex process, for the study of which requires a large amount of experimental and theoretical work. Raw cotton refers to a multicomponent thermodynamic medium, the structural structure of which essentially depends on the type of technological impact.

Therefore, direct analysis of the state of raw cotton from the viewpoint of continuous medium mechanics is difficult; here approaches and a concept are needed, as applied to environments that have parameters that depend on the type and nature of the processing of raw cotton. The selection of moisture from the mass of raw cotton essentially depends on the formation and development of moisture-exchange processes in its components, the nature of the drying agent and the drying regime.

The intensification of the drying process of raw cotton is determined by the patterns of heat and material transport inside the body (internal heat and mass transfer) and between the body surface and the environment (external heat and mass transfer). To properly understand the mechanisms of these processes under thermal action, a thermophysical model of raw cotton, describing heat and mass-transfer processes between the components (fiber and seed) and the thermal agent (heated air), should be developed [1]. The mechanism of drying porous materials, which can be classified as raw cotton, is analyzed in detail in [2].

II. LITERATURE SURVEY

The process of drying raw cotton is determined by the amount and intensity of moisture taken from it. In this case, the mechanism for drying 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. For the practical implementation of the drying process, various installations and equipment are used, the descriptions of which are presented in [3, 4]. In particular, the main parameters and operating principle of 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 suitable for dryer designs with a capacity of 10000 kg/h and more than 10% or more and moisture removal, and therefore these types of dryers are currently the basis for the further development of drying technology in the cotton industry. This circumstance requires the improvement of existing and the development of new calculation techniques for determining the main parameters of the drying drum. In the literature, there are various approximate calculation formulas establishing the relationship between the initial humidity

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and the final one. At the same time, it is assumed that the geometric data of the dryer, the thermo physical parameters of raw cotton and the laws of heat exchange processes between the coolant and raw cotton are assumed to be known.

III. METHODOLOGY

We establish the origin of coordinates in the initial section of the drum and direct the axis $0x$ along its axis and denote by $t_v = t_v(x)$ and $t_x(x)$ the temperatures of the coolant and the raw cotton in an arbitrary section of the drum. We select 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 [4]

$$dQ = \alpha_v K \Delta T dV_в = \pi \alpha_v K \Delta T D^2 dx/4 \qquad (1)$$

where α_v - is the total volumetric coefficient of heat transfer *kdj/(m²·h·grad)*, the number K takes into account a part of the volume of the dryer occupied by the blades, which will have a lower volume coefficient of heat transfer, D - the diameter of the drum, *m*, ΔT - the average temperature difference between the drying agent and raw cotton in the volume of the element $dV_в$

$$\Delta T = \Delta T(t_v, t_x) = \frac{(t_{v0} - t_v) - (t_{x0} - t_x)}{\ln \frac{t_{v0} - t_v}{t_{x0} - t_x}} \qquad (2)$$

where t_{v0}, t_{x0} - respectively, the initial and final temperatures of the coolant and raw cotton (in Kelvin).

Denote by W the productivity of the dryer by moisture (kg/h). Then according to [4] $dQ = dW(q_1 + q_2)$
where q_1 - heat consumption for evaporation of 1 kg moisture [4], *kdj/*(kg·*evaporation of wet)*

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

q_2 - heat consumption for heating 1 kg raw cotton in section x, *kdj/*(kg·*evaporation of wet)*:

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

c_x - Specific heat of raw cotton in *kdj/(kg·grad)*:

$$- \ c_x = \frac{c_0 + 0.01 c_в w_1}{1 + 0.006 w_1}, \qquad (3)$$

where, $c_0 = 1{,}549$ and $c_в = 4{,}1868$ accordingly the specific heat of absolutely dry raw cotton and raw water absorbed by cotton-raw cotton *kdj/(kg·grad)*, w_1 - is the initial moisture content of raw cotton, %. Taking (2) into account, we reduce (1) 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

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

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Equation (4) is integrated if the temperatures of the coolant t_v and raw cotton t_x are known as a function of the variable x .

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.

$$c_v v_в \frac{dt_v}{dx} = \alpha_{vx}(t_x - t_v) + \beta_{vc}(t_c - t_v) l_v \quad (5)$$

$$c_x v_x \frac{dt_x}{dx} = \alpha_{vx}(t_v - t_x) + \beta_{xc}(t_c - t_x) l_x \quad (6)$$

where - c_v - the specific heat of the heat carrier, *kdj/(kg·grad)*, $v_в$ and v_x - the flow rate of the coolant and raw cotton in the drum, α_{vx} - the heat transfer coefficient between the coolant and the raw cotton *kdj/(kg·sec·grad)*, β_{vc} - the heat transfer coefficient between the coolant and the drum wall *kdj/(kg·m·with evaporation of wet)*, β_{xc} - the heat transfer coefficient between the raw cotton and the drum wall, *kdj/(kg·m· evaporation of wet)*, l_v and l_x - the length of sections of the contour of the drum cross-section contacting with 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 portion of the contour along which only the coolant with the drum wall is contacted, t_c - the drum wall temperature (in Kelvin). The final moisture content of the raw cotton is determined through the initial moisture w_1, the amount of evaporated moisture in the section $x = L$ (L - the length of the drum, *m*) and the capacity of the drum by the dried raw cotton P_2, kg/h according to the formula

$$w_2 = \frac{P_2 w_1 - 100W(L)}{W(L) + P_2} \quad (7)$$

IV. RESULTS AND DISCUSSION

In the calculations, the value of the total volumetric heat exchange coefficient was used in [4]. To determine the coefficients α_{vx}, β_{vc}, β_{xc} we used the results of the calculations given in [4], where it is customary: $D = 3$, $L = 10\,m$, , $w_1 = 19\%$ $t_{v0} = 573\,^0K$, $t_{x0} = 278\,^0K$, $P_2 = 10000$ *kg/h*, $m = 0{,}65$, $v_в = 1{,}25$ *m/s*. The influence of nonlinearity in the dependence (3) on the specific heat from humidity was not taken into account and accepted $c_x = c_x(19) = 2{,}1$ *kdj/(kg·grad)*. The flow rate of raw cotton was calculated using the formula $v_x = 4P_2/\pi\rho_x D^2$ (ρ_x - density of raw cotton). The drum wall temperature is adopted $t_c = 268\,^0K$. The coefficients α_{vx}, β_{vc}, β_{xc}, as well as the density of raw cotton ρ_x (hence, the flow rate of raw cotton) were determined from the coincidence of the results of calculations for the values of the total amount of evaporated moisture W in the drying drum and the final moisture calculated in [2]. In [2] they were equal: $w_2 = 10\%$, $W = 810$ *kg/h*, $\rho_x = 62$ *kg/m³*.

For other values of humidity and productivity, the results of [6, 7], obtained experimentally by the method of the full factor experiment of the FFE type 2^3, carried out on a 2SB-10 dryer at the temperature of the drying agent T, ^{0}C (100<T<200), productivity P, т/h (3,5<P<10) for wet cotton W, % (10,5<W<22,3). The subject of the study was cotton raw varieties C-6524, II industrial grade.

Using the regression equations obtained

For raw cotton moisture: W_{xc}= -3,0306 + 1,045W + 0,2984П + 0,0041T - 0,0016WT;
For the moisture content of the fiber: W_v = 0,1434П + 0,0052T + 0,7656W + 0,01545ПW-0,00234TW - 2,295514;
For the humidity of seeds: W_c= 0,3156П+ 0,00688T+1,1625W-0,00573ПW-0,00132TW-3,5796;

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For the heating temperature of the fiber: T_v = 0,5987П + 0,43269Т +0,9696W-0,00794ПТ-0,0412ПW-0,00946TW-1,2825;
for the heating temperature of the seeds: T_c=0,2019Т-2,13669П-0,191134W + 0,014198ПТ + 0,08657ПW - 0,00063TW - 0,000866ПТW + 20,3138 values are determined above the indicated parameters α_{vx}, β_{vc}, β_{xc}, α_v and are given in the table 1. In the numerator there are calculated, in the denominator, experimental data.

Table 1. Changes in humidity and the temperature of heating of raw cotton, depending on the performance of the drying drum

$W = 15\%,\ t = 200^0 C$ α_{vx}=0,019 *kdj/(kg·sec·grad)*; β_{vc}=0,07 *kdj/(kg·m·with evaporation of wet)*, β_{xc} =0,0112 *kdj/(kg·m·with evaporation of wet)*;												
$P(t/h)$	4	5	6	7	8	9	10	11	12	13	14	15
$T(K)$	337/ 342	337/ 341	337/ 340	337/ 339	337/ 337	338/ 336	338/ 335	338/ 334	338/ 332	338/ 331	339/ 330	339/ 329
$\Delta_T(\%)$	1,6	1,2	0,78	0,36	0,05	0,46	0,87	1,1	1,7	2,11	2,52	2,94
$W(\%)$	9,58/ 9,8	9,9/ 9,8	10,17/ 10,2	10,5/ 10,6	10,8/ 10,8	11,1/ 11,1	11,4/ 11,4	11,7/ 11,7	11,96/ 11,9	12,26/ 12,2	12,56/ 12,5	12,86/ 12,8
$\Delta_W(\%)$	2,24	1,01	0,3	0,1	0	0	0	0	0,05	0,05	0,05	0,05
α_v, *kdj/ (m²·h·grad)*	165	185	200	209	215	220	225	227	228	225	219	205

It can be seen from the table that, theoretically, certain results and experimental results are within the limits of the allowed error values. It can be seen that the heat transfer coefficients between the coolant and the raw cotton, between the coolant and the drum wall, between raw cotton $W = 15\%$ and the drum wall, with the raw cotton moisture $t = 200^0 C$ and the temperature of the drying agent, do not depend on the performance of the drum.

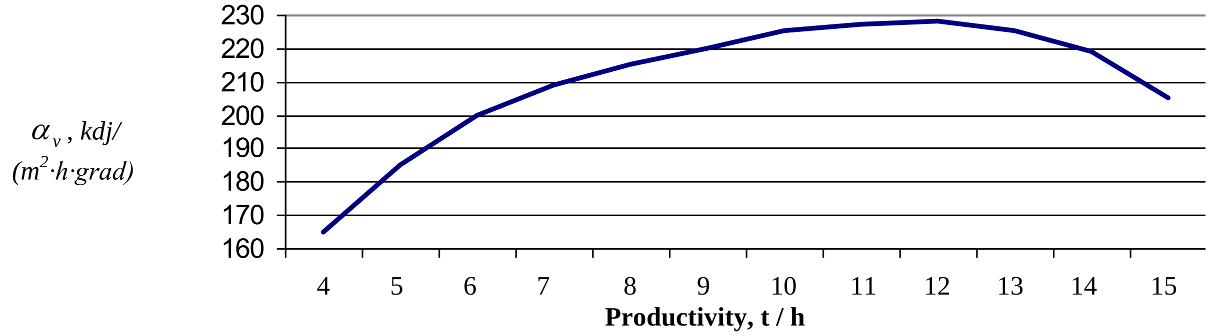

Fig.1. Changes in the volume coefficient of heat transfer α_v depending on the productivity of the drying drum

From the analysis of the graph of the change in the total volumetric heat transfer coefficient depending α_v on the productivity of the drying drum, presented in Fig. 1. it follows that with an increase in the productivity of the drying drum from 4 to 12 t/h the volume heat transfer coefficient α_v increases from 165 to 228 *kdj/(m²·h·grad)* and then decreases to 200 *kdj/(m²·h·grad)*.

In Fig. 2 shows the temperature variation of heated air and the fiber-seed mixture $T_{vc}=mT_v+(1-m)T_c$ (where m is the fraction of the fiber in the mixture) along the length of the drying drum with the raw cotton moisture $W = 15\%$ and

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the temperature of the drying agent $t = 200^0 C$ as a function of the drying capacity drum, where m=0,35. The values of the parameters α_{vx}, β_{vc}, β_{xc}, α_v are taken from Table 1.
Tvc = mTv + (1-m) Tc (m) = 0,35.

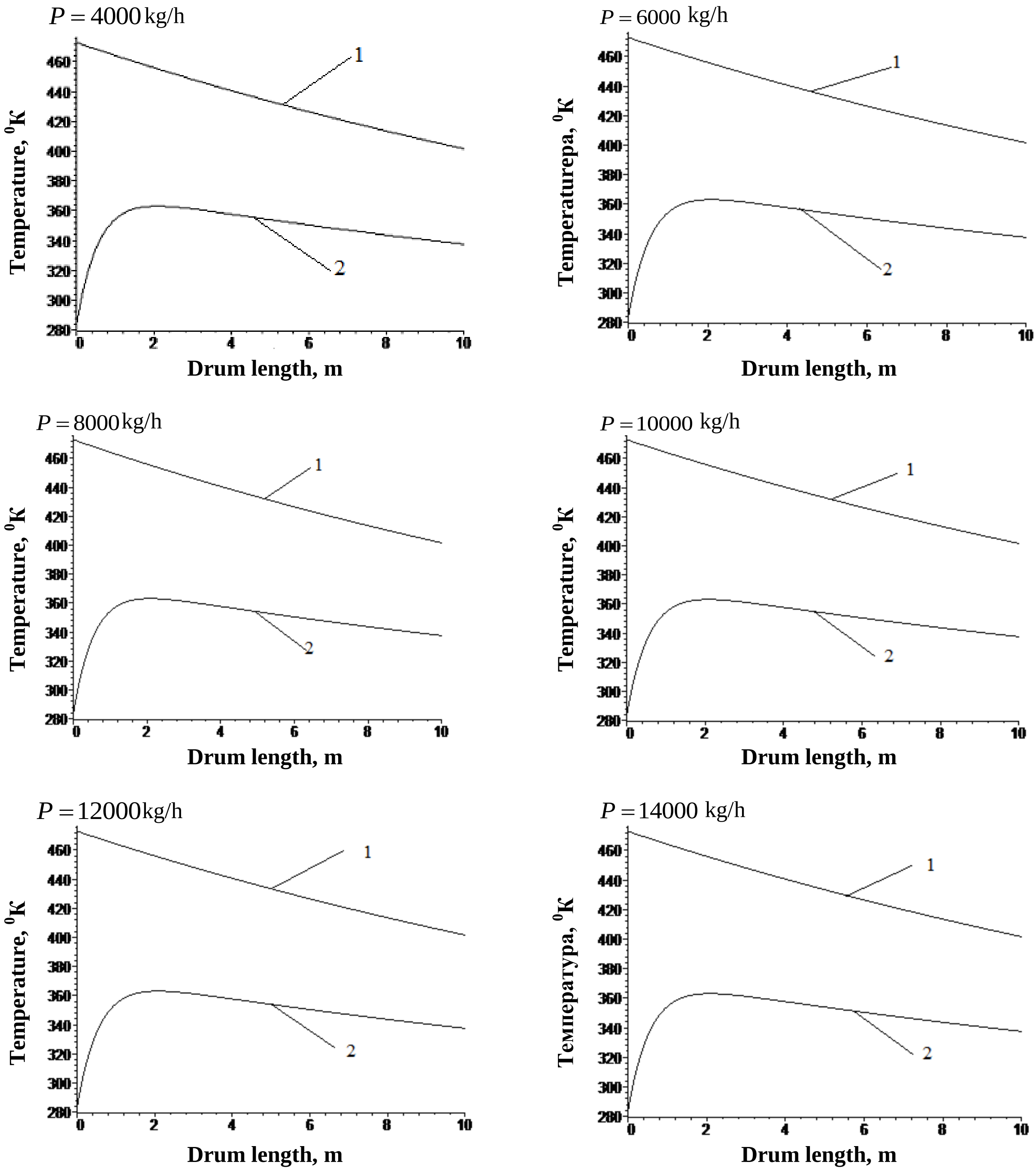

Fig.2. Changes in the temperature of the drying agent (1) and raw cotton (2) along the length of the druma

The analysis of the graphs presented in Fig. 2 shows that the air temperature along the drum length for all values of the drum's performance practically decreases nearly linearly. The temperature of raw cotton along the length of the drum

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first rises sharply, and then there is a slight decrease. This is explained by the fact that in the initial section of the drying drum the raw cotton is intensively heated, reaching a certain temperature the drying process begins, and some of the heat is carried away by the coolant instead of moisture.

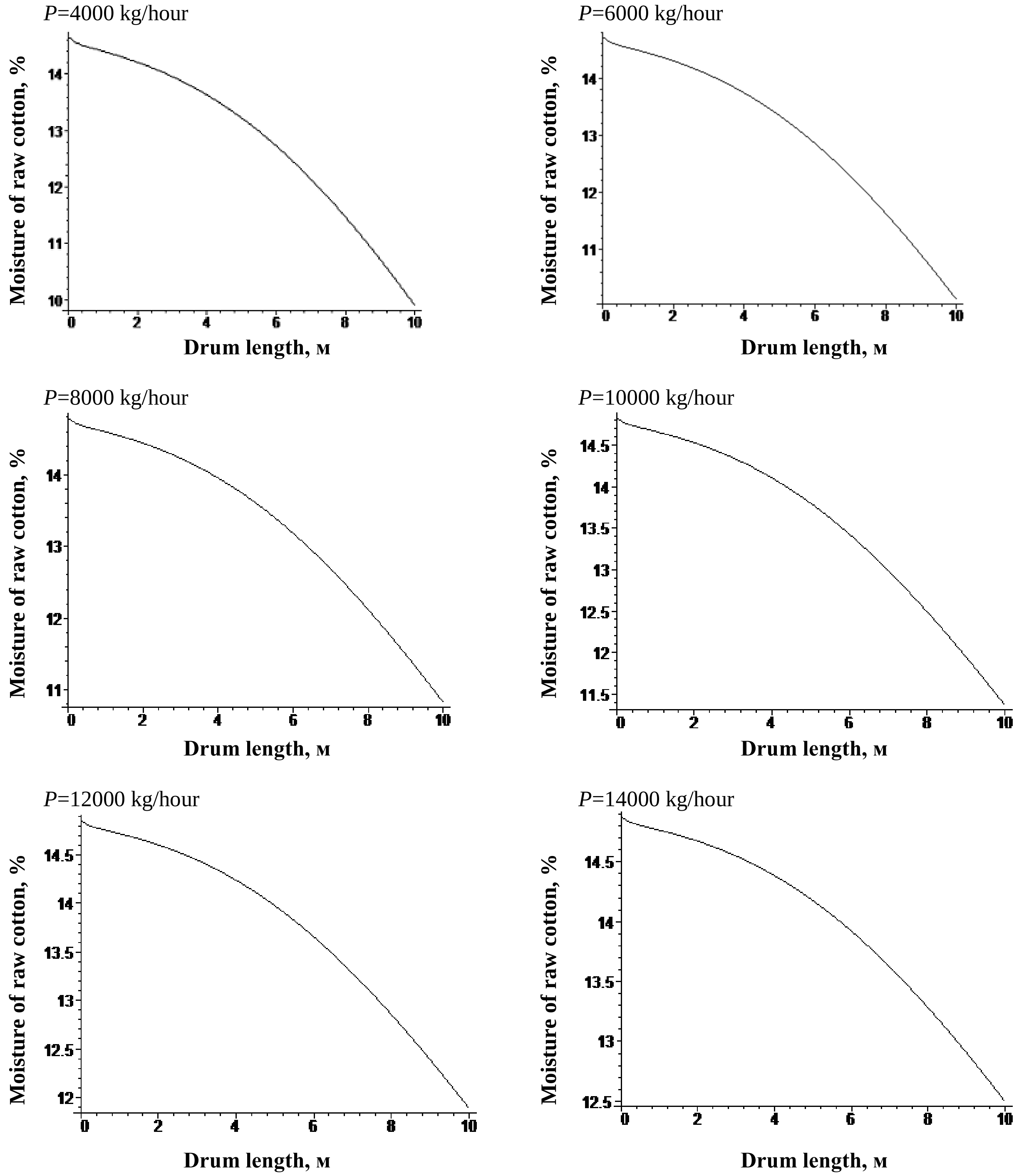

Fig.3. Changes in the moisture content of raw cotton along the length of the drying drum

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Analogous curves for the moisture content of raw cotton along the length of the drum are shown in Fig.3. It can be seen that with the increase in drum productivity, the amount of moisture extraction decreases. So, for example, at P = 4000 kg / h , moisture extraction is about 5%, at P = 14000 kg / hour – 2,5%.

V. CONCLUSION AND FUTURE WORK

The regularities of the change in the volume coefficient of heat exchange, the temperature of the drying agent and raw cotton, as well as the humidity of raw cotton along the length of the drum are determined for different capacities of the drying drum for wet cotton.

For effective use of the drying drum by volume, it is recommended to operate the drying drum at capacities of 8-12 t/h on wet cotton. This also contributes to an increase in the uniformity of drying of raw cotton components at such productivity [8].

It is established that the recommended drying regimes based on the temperature of heating of raw cotton at the exit of the drying drum is erroneous, since the analysis of the temperature of heating of raw cotton along the length of the drying drum showed that this index exceeds by 28°C than at the output, which leads to a sharp deterioration in the quality parameters of the fiber .

Moisture removal along the length of the drying drum describes a convex curve, which means that in the initial sections of the installation the heat is expended on heating the raw cotton, and then a gradual decrease in humidity begins.
The analysis of the curves shows that with a decrease in drum capacity, the final moisture content decreases and can accelerate the process of moisture extraction from the drum.

The obtained results can be used in the development of optimal drying regimes in existing plants, depending on the initial moisture content of raw cotton, the productivity of the dryer on wet cotton, and in the development of new technology and technology for drying plants for raw cotton

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