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Mathematical model for drying raw cotton in solar-dryer installations

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ABSTRACT:. In this paper we developed a mathematical model which considers the cotton and involved with it the air as a continuum. In particular, the mass of cotton can be represented as a continuous elastic system of interconnected flying detachment cotton committing motion under gravity and air flow.The interaction between the phases is determined by empirical laws, to include the effect of viscous forces influence heterogeneity of the velocity field, the inertial forces associated with attached masses rapidly moving continuum. Based on these considerations, the aim of the article is to provide a theoretical dependence characterizing the process of movement "Cotton - air flow."

KEYWORDS: Cotton, drying, fiber quality, energy consumption, dryers, the volume of the law of deformation, load, elastic-plastic nature, cotton - air flow, phase mass, flying detachment.

I. INTRODUCTION.

Currently, among the major economic problems facing the Republic of Uzbekistan, are the problems associated with the solution of problems arising from the development of the energy sector and environmental problems. These tasks that require immediate solutions, helps to increase the use of renewable energy.
The use of solar energy in a rational combination with other energy sources in many cases can save a considerable amount of fuel and energy resources. The effect of the use of solar energy is especially noticeable in the implementation of the most energy intensive processes in the heat, solar thermal system. These include processes, helio drying technologies of raw cotton. Implementation helio processes is of great national economic significance.
Given the increasing demand for fiber quality one of the main objectives of the cotton industry is currently developing more sophisticated and cost-effective technology for processing raw harvested and development of new technology, which provides higher production efficiency and product quality.

In this regard, the primary processing of cotton makes high demands on the organization of the drying operation, the quality of which depends largely on the quality of manufactured fibers ginneries.
In recent years, the development and improvement of the drying equipment took place on ways to improve the performance and alignment processes of drying and cleaning of raw cotton in one device. This solution has been used in the dryer drum type 2SB-10 and SDO (Social and domestic orientation) based on convective drying method, which is widely used in drying and cleaning and cleaning shops cotton plants that do not meet modern requirements of the market economy.

Now, one of the most promising directions in securing cotton fiber loss which in some cases exceeds 25 percent / 1 /, is to improve the technology of processing industry, including the development of new process units for drying and storage of raw cotton. At the present stage of development of further growth in agricultural production and processing enterprises is closely related to the degree of power supply industrial consumers. The use of solar energy is an important reserve in the improvement of power supply processing equipment and technology.

More energy drying processes and drying trend in the development of engineering and technology in recent years, demand, along with the improvement of their design, the search for alternative solutions to the problem of energy sources.
Favorable climatic conditions for the implementation of the Central Asian region helio processes due to the abundant amount of solar energy, low relative humidity and high ambient temperatures, allow a period of mass maturation of agricultural products almost completely to save fossil fuel it takes to heat the drying agent.

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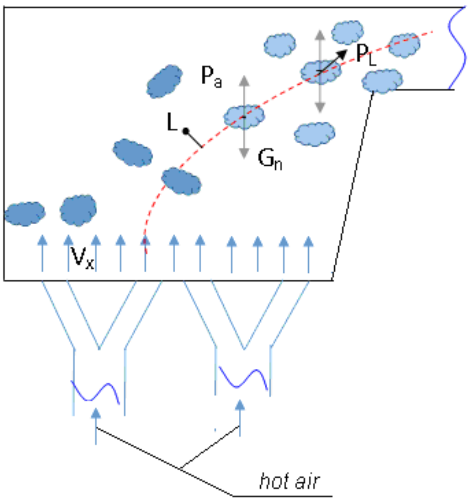
Development of new efficient solar dryers, introduction of energy-efficient drying technology Helio will significantly reduce the loss of cotton fiber, consumption of energy resources, preventing pollution of the surrounding air with the exhaust gases. This shows the relevance of research related to the development of scientific and technical bases helio drying technology and drying systems for upland cotton varieties of raw grades I and II.
Initial processing of cotton, is important to the process of cleaning cotton various impurities, and drying them. Since the quality of cotton fiber depends on the humidity of the cotton that is achieved when pre-drying process using a heated air stream.

The movement of raw cotton in the working drum is complicated by how much raw cotton from the perspective of a mechanical object represents both air and pulp. A mathematical model describing the state and the motion of such a medium in general is not yet available.
As shown, the experimental pilot study in a closed volume drying because of heating the air raw cotton is deformed by a nonlinear law with virtually reversible deformation.
In the "open volume" is shifted from the beginning pulp and then with increasing compression force irreversible deformation occurs fibers. Hence the law of deformation for small loads is reversible linear with increasing load of elastic-plastic nature.

II. PURPOSE AND MATHEMATICAL MODEL OF THE PROBLEM.

Considered raw cotton and involved with it the air as a continuum. In particular, the mass of cotton can be represented as a continuous elastic system of interconnected leafjet committing motion under gravity and air flow.
For the space-time description of the motion blend "Cotton - air flow" will be treated to a solid two-phase medium, described by the theory of interpenetrating continua. Each phase is moving continuous medium, subject to the general law of mechanics environments with its rheological law. The air stream has a predetermined temperature.
The interaction between the phases is determined by empirical laws, to include the effect of viscous forces influence heterogeneity of the velocity field, the inertial forces associated with attached masses rapidly moving continuum. Based on these considerations, the aim of the article is to provide a theoretical dependence characterizing the process of movement "Cotton - air flow."**The main part"Cotton - air" under the action of heated air**

Consider the motion of two-phase media under the action of the heated air flow. The general equations of the dynamics of each of the phases will be considered to express a three laws of continuum mechanics: conservation of mass, momentum change, change of angular momentum. The first two laws of continuum mechanics are described by the following equations:



G_n –theweightofcottonslice. P_a – the aerodynamic power of hot air current in vertical line.P_L – Totalpowerofcottonslice.V_x – Thespeedofthecurrentofhotair.L – Trajectoryofcottonslice.
Fig. 1.Themotionfigureofthesliceofcottonfiberintheworkingchamber.

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$$\frac{\partial\rho_k}{\partial t}+di\vartheta\left(\rho_k\vartheta^{(k)}\right)=0 \quad \left.\begin{aligned}&\frac{\partial\rho_k}{\partial t}+di\vartheta\left(\rho_k\vartheta^{(k)}\right)=0\\&\rho_k\frac{\partial\vec{\vartheta}^{(k)}}{\partial t}=di\vartheta(\xi^{(k)})+\vec{F}_k+\rho_k\vec{g}\end{aligned}\right\} \quad (1)$$

There $\rho_k=\rho_k(t,x)=\rho_k{}^0\vec{g}*\varepsilon_k$ - density; k = 1 air, k = 2, raw cotton;

$\rho_k{}^0$ – the real density of the medium; $\varepsilon_k=\varepsilon_k(t,x,y)$ - the volume density of the medium;

$\vec{\vartheta}^{(k)}=\vec{\vartheta}^{(k)}(t,x,y)$ - The speed of movement; $\hat{\xi}^{(k)}=\hat{\xi}^{(k)}(t,x,y)$ - the tensor arrayed the medium

$\hat{\xi}^{(k)}=\left\|\xi_{ij}{}^{(k)}\right\|^3$ - Symmetric tensor of rank dressed the medium, i, j = 1;

$\frac{d\vec{\vartheta}}{dt}=\frac{\partial\vec{\vartheta}}{\partial t}+(\vec{\vartheta}^{(k)}*\nabla)*\vec{\vartheta}^{(k)}$,for a total differential phase;

$\vec{F}_k=\vec{F}_k(t,x,y)$ - The volume density of power, taking into account the interacting forces in phase with other phases; (Stokes);

$$\vec{F}_1=\vec{F}_{12};\ \vec{F}_2=\vec{F}_{12}; \quad (2)$$

$$\vec{F}_{12}=\frac{1}{2}n_2*C_{\mu12}*\pi*r_1{}^2\left|\vec{\vartheta}^{(1)}-\vec{\vartheta}^{(2)}\right|*\vec{\vartheta}^{(1)}-\vec{\vartheta}^{(2)} \quad (3)$$

$F_{j,k}$ - force that acts, j- phase on the k-phase

$C_{\mu12}$ - coefficient of resistance of the medium in the movement of raw cotton; $C_{\mu12}=0{,}44$;

$n_2=3\varepsilon_2/(4\pi r_2{}^3)$ - numberflying detachment cotton;

The rheological properties of materials component environment are reflected in the proportions determined by the following stress tensor:

$$\sigma_{ij}{}^{(k)}=(-P^{(k)}+\lambda_k di\vartheta\vec{V}^{(k)})\sigma_{ij}+2\mu_{12}V_{ij}{}^{(k)} \quad (4)$$

Where: $P^{(k)}$ - is the pressure determined by the thermal equation of state; λ_k,μ_k - k- dynamic coefficients of bulk and connected viscosities;

For pressure $P^{(1)}$ - dependence on other parameters of the equation of state is established according to the law of thermodynamics:

$$\left\{\begin{aligned}&P^{(1)}=P^{(1)}(\rho_1) && (5)\\&P^{(2)}=k_pF(\varepsilon_2)\left[V^{(1)}\right]^2 && (6)\\&K_p=\frac{107(\rho_1{}^0)^2}{1-K_{AXK}\rho_2{}^0} && (7)\end{aligned}\right.$$

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$$F_{(\varepsilon_2)} \leq \varepsilon_2 \frac{\sqrt[3]{\varepsilon_2{}^0/\varepsilon_2} - 1}{(1-\varepsilon_2)^2} \qquad (8)$$

$$\varepsilon_2{}^0 = 100\,кг/м^3; \qquad K_{AXK}(0{,}47) \cong 0{,}1$$

If we assume that the air flow is steady movement then the system (1) takes the following form:

$$\frac{\partial \varepsilon_1 V_x^{(1)}}{\partial x} + \frac{\partial \varepsilon_1 V_y^{(1)}}{\partial y} = 0 \qquad (9)$$

$$V_x^{(1)} \frac{\partial V_x^{(1)}}{\partial x} + V_y^{(1)} \frac{\partial V_x^{(1)}}{\partial y} = -\frac{1}{\rho_1^0 \varepsilon_1} \cdot \frac{\partial \rho^{(1)}}{\partial x} + \frac{1}{\rho_1^0 \varepsilon_1} \left\{ \frac{\partial}{\partial x} \left[(\lambda_1 - \frac{2}{3}\mu_1) \left(\frac{\partial V_x^{(1)}}{\partial x} + \frac{\partial V_y^{(1)}}{\partial y} \right) \right] + \right.$$

$$\left. + \frac{\partial}{\partial x}(\mu_1 \frac{\partial V_x^{(1)}}{\partial x}) + \frac{\partial}{\partial y}(\mu_1 \frac{\partial V_y^{(1)}}{\partial y}) + \frac{\partial}{\partial x}(\mu_1 \frac{\partial V_y^{(1)}}{\partial x}) + \frac{\partial}{\partial y}(\mu_1 \frac{\partial V_y^{(1)}}{\partial y}) \right\} - \qquad (10)$$

$$-\frac{3}{8} C_{\mu_{12}} \frac{\varepsilon_2}{\rho_1^0 r_2 \varepsilon_1} \sqrt{(V_x^1 - V_x^2) + (V_y^1 - V_y^2)^2} \cdot (V_x^1 - V_x^2) + g$$

$$\partial V_y^{(1)} \frac{\partial V_y^{(1)}}{\partial x} + V_y^{(1)} \frac{\partial V_y^{(1)}}{\partial y} = -\frac{1}{\rho_1^0 \varepsilon_1} \cdot \frac{\partial \rho^{(1)}}{\partial y} + \frac{1}{\rho_1^0 \varepsilon_1} \left\{ \frac{\partial}{\partial y} \left[(\lambda_1 - \frac{2}{3}\mu_1)(\varepsilon_2(y)) \right] + \right.$$

$$\left. + \frac{\partial}{\partial x}(\mu_1 \frac{\partial V_y^{(1)}}{\partial x}) + \frac{\partial}{\partial y}(\mu_1 \frac{\partial V_y^{(1)}}{\partial y}) + \frac{\partial}{\partial x}(\mu_1 \frac{\partial V_x^{(1)}}{\partial y}) + \frac{\partial}{\partial y}(\mu_1 \frac{\partial V_y^{(1)}}{\partial y}) \right\} - \qquad (11)$$

$$-\frac{3}{8} C_{\mu_{12}} \frac{\varepsilon_2}{\rho_1^0 r_2 \varepsilon_1} \sqrt{(V_x^1 - V_x^2) + (V_y^1 - V_y^2)^2} \cdot (V_y^1 - V_y^2) - g$$

$$\rho^{(1)} = \rho^{(1)}(\varepsilon_1) \qquad (12)$$

$$\rho_2(t,y) = \rho_2{}^0 (1 + \alpha e^{-T_0 t}) \varepsilon_2(y) \qquad (13)$$

$$\frac{\partial P_2}{\partial t} + di\vartheta(\rho_2 \vec{V}^{(2)}) = 0 \qquad (14)$$

$$P_2 \frac{d^2 \vec{V}^{(2)}}{dt} = di\vartheta(\hat{\xi}^{(2)}) + \vec{F}_2 + \rho_2 \vec{g}$$

From here:

$$\left. \begin{aligned} &\frac{\partial P_2}{\partial t} = (-T_0 \rho_2{}^0 \alpha * e^{-T_0 t}) \varepsilon_2(y) \\ &di\vartheta(P_2 \vec{V}^{(2)}) = \varepsilon_2 \left(\frac{\partial \vartheta_x^{(2)}}{\partial x} + \frac{\partial \vartheta_y^{(2)}}{\partial y} \right) \end{aligned} \right\} \qquad (15)$$

if (15) is substituted into (14) we obtain:

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$$(-T_0\rho_2^0\alpha\cdot e^{-T_0t})^{\varepsilon_2(y)}+\varepsilon_2\left(\frac{\partial V_x^{(2)}}{\partial x}+\frac{\partial V_y^{(2)}}{\partial y}\right)=0 \quad (16)$$

$$V_x^{(2)}\frac{\partial V_x^{(2)}}{\partial x}+V_н^{(2)}\frac{\partial V_ч^{(2)}}{\partial y}=-\frac{1}{\rho_2^0\varepsilon_2}\cdot\frac{\partial\rho^{(2)}}{\partial x}+\frac{1}{\rho_2^0\varepsilon_2}\left\{\frac{\partial}{\partial x}\left[(\lambda_2-\frac{2}{3}\mu_2)\left(\frac{\partial V_ч^{(2)}}{\partial x}+\frac{\partial V_y^{(2)}}{\partial y}\right)\right]+\right.$$
$$\left.+\frac{\partial}{\partial x}(\mu_2\frac{\partial V_ч^{(2)}}{\partial x})+\frac{\partial}{\partial y}(\mu_2\frac{\partial V_ч^{(2)}}{\partial y})+\frac{\partial}{\partial x}(\mu_2\frac{\partial V_н^{(2)}}{\partial x})+\frac{\partial}{\partial y}(\mu_2\frac{\partial V_н^{(2)}}{\partial x})\right\}+ \quad (17)$$
$$+\frac{3}{8}C_{\mu_2}\frac{1}{\rho_2^0r_2}\sqrt{(V_x^1-V_x^2)+(V_y^1-V_y^2)^2}\cdot(V_x^1-V_x^2)+g$$

$$V_x^{(2)}\frac{\partial V_x^{(2)}}{\partial x}+V_x^{(2)}\frac{\partial V_y^{(2)}}{\partial y}=-\frac{1}{\rho_2^0\varepsilon_2}\cdot\frac{\partial\rho^{(2)}}{\partial y}+\frac{\partial V_y^{(2)}}{\partial y}\left\{\frac{\partial}{\partial y}\left[(\lambda_2-\frac{2}{3}\mu_2)\left(\frac{\partial V_x^{(2)}}{\partial x}+\frac{\partial V_y^{(2)}}{\partial y}\right)\right]+\right.$$
$$\left.+\frac{\partial}{\partial x}(\mu_2\frac{\partial V_y^{(2)}}{\partial x})+\frac{\partial}{\partial y}(\mu_2\frac{\partial V_y^{(2)}}{\partial y})+\frac{\partial}{\partial x}(\mu_2\frac{\partial V_x^{(2)}}{\partial y})+\frac{\partial}{\partial y}(\mu_2\frac{\partial V_y^{(2)}}{\partial y})\right\}+ \quad (18)$$
$$+\frac{3}{8}C_{\mu_2}\frac{1}{\rho_2^0r_2}\sqrt{(V_x^1-V_x^2)+(V_y^1-V_y^2)^2}\cdot(V_y^1-V_y^2)-g$$

$$\rho^2=K_pF(\varepsilon_2)(V^{(1)})^2 \quad (19)$$

For two-phase media, we have the following equation: $\varepsilon_1+\varepsilon_2=1$ (20)

Stated above relationships constitute a system of nonlinear partial differential equations. To highlight a clear solution to this system of equations is necessary to set a sufficient number of boundary conditions. From the point of view of mathematical physics such a curve problem refers to the section of complex mathematical problems. According to this hypothesis put forward further having at a theoretical and experimental basis and to simplify the task. Then additionally assume the following:

1. To take the airflow rate and the volumetric flow of the medium: $\lambda_1\approx\mu_1=0$.
2. For the beam flying detachment cotton: $\lambda_1\approx\mu_1=0$

Then a mixture of "cotton-to-air" to get a simplified system of equations:

a) The boundary conditions for air flow:

$$\left.\begin{array}{l}\vartheta_x^{(1)}(0;y)=0\\ \varepsilon_1(0;y)\vartheta_y^{(1)}(0;y)=0\end{array}\right\} \quad (21)$$

$$\vec{V}^{(1)}=\vec{V}(y)=(V_x^{(1)},V_y^{(1)})=\left(0,\frac{V}{\varepsilon_1(y)}\right)=\left(0;\frac{V}{1-\varepsilon_2(y)}\right) \quad (22)$$

V - Const air velocity.

For flying detachment cotton equations of motion (16) and (17) obtained in the form:

$$(-T_0\rho_2^0\cdot\alpha\cdot e^{-T_0t})\cdot\varepsilon_2\left(\frac{\partial V_y^{(2)}}{\partial y}\right)=0\ |:\varepsilon_2(y)$$

$$V_y^2=T_0\rho_2^0\cdot\alpha\cdot e^{-T_0t}\cdot y \quad (23)$$

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$$\left(V_y^2 = V_y^2(t,y)\right) V_y^2 \frac{\partial V_y^{(2)}}{\partial y} = -\frac{1}{\rho_2^0 \varepsilon_2(y)} \quad ;$$

$$\frac{d\rho^2}{dy} + \frac{3}{8} C_{\mu_{12}} \frac{1}{\rho_2^0 r_2} \cdot \left| V_y^{(1)} - V_y^{(2)} \right| \cdot (V_y^{(1)} - V_y^{(2)}) - g \quad (24)$$

Using equation (6) we calculate $\frac{d\rho^2}{dy}$:

$$\frac{d\rho^2}{dy} = \frac{d}{dy}\left(K_p \cdot F(\varepsilon_2)\left[V^1\right]^2\right) = K_p\left[V^1\right]^2 \frac{dF(\varepsilon_2)}{d\varepsilon_2} \cdot \frac{d\varepsilon_2}{dy} \quad (25)$$

Here: $$\frac{dF(\varepsilon_2)}{d\varepsilon_2} = \frac{d}{d\varepsilon_2}\left(\varepsilon_2 \cdot \sqrt[3]{\frac{\varepsilon_2^0}{\varepsilon_2}} / (1-\varepsilon_2)\right) \quad (26)$$

(25) put in (24) we obtain:

$$V_y^2 \cdot (T_0 \cdot \rho_2^0 \alpha \cdot e^{-T_0 t}) = -\frac{1}{\rho_2^0 \varepsilon_2} \cdot K_p \left[V^{(1)}\right]^2 \cdot \frac{dF_2}{d\varepsilon_2} \cdot \frac{d\varepsilon_2}{dy} + \frac{3C_{\mu_{12}}}{8\rho_2^0 r_2} \cdot \left|V_y^{(1)} - V_y^{(2)}\right| \cdot (V_y^{(1)} - V_y^{(2)}) - g \quad (27)$$

Or

$$\frac{d\varepsilon_2}{dy} = \left[\frac{3 \cdot C\mu_{12}}{8\rho_2^0 r_2}\left|V_y^{(1)} - V_y^{(2)}\right| \cdot (V_y^{(1)} - V_y^{(2)}) - V_y^{(2)} \cdot (T_0 \rho_2^0 \alpha e^{-T_= t}) - g\right] \cdot \left[\frac{K_p \cdot \left(V_y^{(1)}\right)^2}{\rho_2^0 \varepsilon_2^{(y)}} \cdot \frac{dF_2(\varepsilon_2)}{d\varepsilon_2}\right]^{-1} \quad (28)$$

The boundary conditions for this equation: $\varepsilon_2(0) = \varepsilon_2^0 \qquad y \in [0;h]$

Equation (28) represents a change in the bulk density of the cotton flying detachment during vertical movement. Mathematical analysis of the dynamics of the movement of cotton based on the change in density over time. If we consider the change in the mass of cotton, then this task is simplified.

For vertical movement of cotton under the influence of the heated air flow using the motion equations of equilibrium in the working chamber.

$$m\frac{d^2 y}{dt^2} = mg + \frac{1}{2} C_{\mu_0} \pi r^2 \left|\vec{V}_{havo}\right| V_{havo} ; \quad (29)$$

Here $m_0 = \frac{4}{3}\pi r^3 \rho_3^0$ - the actual mass of flying detachment cotton.

$m = m_0(1 + \alpha e^{-T_{0=} t})$ - The reduced mass of cotton with the humidity, temperature

$C_{\mu 0}$ - the resistance coefficient

g - acceleration of free fall.

V_{air}– velocity heated air.

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Due to the mass flow drying cotton decreases. Let the initial mass of cotton $m = m_0(1+\alpha)$ α-humidity value of cotton, m_0- mass concentration cotton.
Let the mass change over time is written as following:

$$m = m_0\left(1+\alpha e^{-T_0 t}\right) \qquad (30)$$

Which T_0 - air temperature;

Boundary and initial conditions:
$$y = y(t)$$
$$\dot{y} = \vartheta(t)$$
$$\ddot{y} = a(t)$$

$$\begin{cases} t = 0; m = m_0(1+\alpha) \\ y(0) = 0; \end{cases}$$

$V^{(1)}$ - the velocity of the air; r - radius of flying detachment of cotton; ρ^0 - the real density of cotton;

The actual mass of flying detachment cotton determined by the formula $m_0 = \frac{4}{3}\pi r^3 \rho_p$

ρ_p the density of the flying detachment.
To determine the solutions (29) takes into account the following inputs
r = 2 cm; ρ_p = 0,15 kg / cm3; $C_{\mu 0}$ = 0.44; α=0,2; T_0= 50-100 C°; V_{air} = 8-12 m / s.
The initial conditions for t=0:y(0)=0; y`(0)=0;
The results of solving differential equations shown in the graph (Fig. 2).

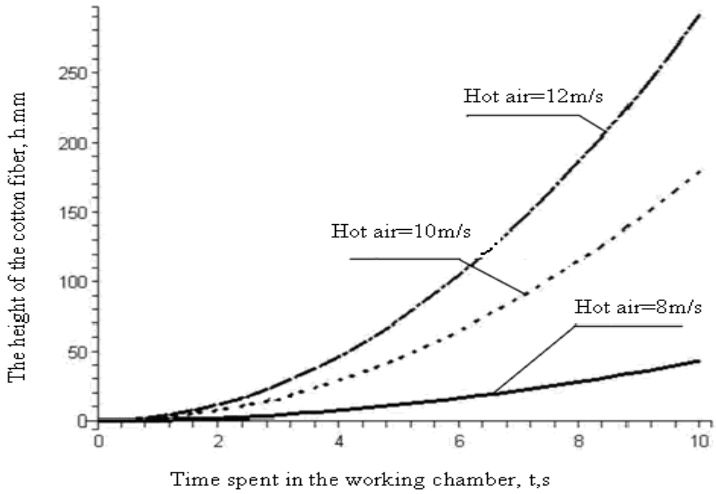

Fig. 2. The trajectory of flying detachment - cotton on time at various air velocities.

Analysis of the results.
The graph shows that the vertical drop flying cotton with airflow 1-12m / s moves from 5-30sm. When the velocity of the heated air is less than 8 m / s along -cotton drop flying detachment vertical direction does not occur i.e. drying the cotton is not sufficient. Required for drying must cotton (h = 30 cm) air speed of about 12m / s.
From (30) t=0, $m=m_0(1+\alpha)$, α=0.2, m_0=5 r.T0=50-100 C°;
The graph (Figure3) shows the variation in mass of cotton depending on the temperature of the air stream.

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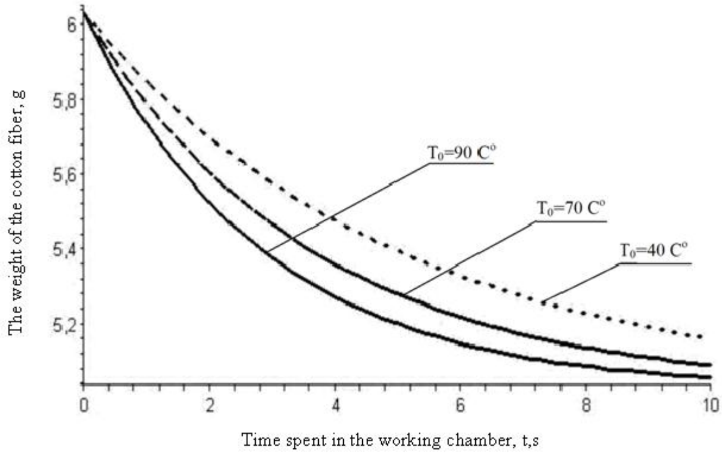

Fig.3. The dependence of the mass in dependence of the cotton over time for different temperatures of the air stream.

As can be seen from the graphs (Figure 3) drying cotton for the time t = 0-10c. Depends on the temperature of the heated air flow at T <40 C^o cotton with no time to dried, and does not meet the requirement for T> 100 C^o on the contrary that the fibers can not lose their natural qualities. It turns out when the temperature T = 70-90 C^o Over-drying cotton meets optimal requirements.

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