Development of a resource-saving technology allowing to increase the environmental sustainability of drying cotton raw materials

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Abstract. The article covers the principle of operation, as well as the results of theoretical research of the improved technology of the screw mixer-feeder unit of a new construction for the drying drum that allows the initial mixing of cotton raw materials with hot air and improves the ecological stability of the environment. The forces acting on the cotton pieces during the drying process have been determined. The graphs of the dependence of the amount of moisture release on the speed and density of hot air at different temperatures during the drying of cotton raw materials have been obtained. The laws of movement of cotton pieces in the screw conveyor along the surface of the screw have been theoretically substantiated.

1 Introduction

In the world, scientific-research and experimental construction work is being carried out aimed at creating new technologies for drying cotton raw materials that have a positive effect on the technological processes of primary processing of cotton and have a positive effect on environmental ecology.

In this regard, special attention is paid to creating the scientific basis of the laws of changing the thermo physical properties of cotton and its components, establishing the speed and uniformity of non-stationary processes of heat and mass exchange of seed and cotton fiber. In order to ensure the production of fiber with competitive quality indicators, it is a demand of the time to carry out large-scale scientific research work on the development of new techniques and technologies of drying cotton raw materials based on energy saving [1, 2].

2 Materials and methods

It can be seen in the work of cotton ginning enterprises in the conditions of agricultural accounting and market economy that increasing the competitiveness of cotton products in the domestic and foreign markets is considered one of the important issues. To solve this problem, it is necessary to improve the quality of cotton fiber, which is the main product of

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the cotton industry. Taking into account the influence of the external environment, scientists have theoretically studied the drying process of raw cotton at 20 and 35 ^{0}C external atmospheric temperature and 130 ^{0}C hot air, and the obtained results have been sufficiently improved [3, 4].

Analyzes show that increasing the quality of fiber depends on the efficient operation of drying and cleaning shops, currently the drying-cleaning shops of the existing cotton ginning enterprises do not use the available opportunities sufficiently as a result, this affects the quality of fiber and seed. In recent years, SXL-1.5M, 2SBS counter-moving convective-drum dryers (in which the drying agent and material move in opposite directions) and the same direction SXB-1.5M, 2SB-10, brand SBO (in which the cotton raw material and the drying drum move in the same direction) were used. In counter-flow dryers, the temperature of the drying agent acting on the cotton raw material is constantly rising, where the heat affects the fiber more than the husk and core, and overheating occurs. In such dryers, the drying of components does not proceed evenly compared to dryers of the same direction. There are also other advantages of unidirectional drum type dryers. Currently, the drying-cleaning shops of cotton factories are equipped with 2SB-10, SBO and SBT drum dryers [5, 6].

During drying, cotton raw material falls into the drum under the influence of the drying agent through the supply device. Cotton raw material falls on the blades, rises up and is saturated with heat during the descent. At the same time, the drying agent transmits its heat to the wet material and releases the moisture to the environment through the pipes. And the cotton raw material leaves the drum after drying to a certain extent as a result of many ups and downs. To transfer the dried cotton raw material to the next process, it is done with the help of paddles attached to the spokes at the end of the drum. The 2SB-10 drying drum is distinguished by its simple construction and ease of use [7, 8]. But 2SB-10 type, unidirectional drum dryers have the following disadvantages:

1. Drying of cotton raw materials is not evenly distributed along the length and width. Empty zones remain, where heat is wasted.
2. Heat transfer is not uniformly distributed along the length and width of the drum. The average speed of heat at the entrance is 7-8 m/s, and at the exit it drops to 0.1-0.4 m/s.
3. The system of supplying cotton to the dryer drum has a sufficient influence on the speed and direction of heat flow.

The theoretical and experimental study and analysis of the laws of movement in the cotton raw material transmission network, as well as other operations in the processing of seed cotton were experimentally summarized. The obtained results show that according to the results of the analytical and experimental research of technological parameters, it is necessary to create new constructions of cotton drying equipment and cotton transfer equipment [9-13].

As a working hypothesis for solving the existing problems, there is no possibility to effectively use the hot air flow moving in the proposed construction channel to dry the falling cotton raw materials and accelerate the drying process in the initial part of the drum. In order to eliminate these shortcomings, many technical solutions and researches were conducted to create a new power transmission network that can positively solve environmental problems, and as a result, new structural solutions were found.

An operating scheme proposed structure is shown in Figure 1. The studied device consists of a drying drum 1, a flange 5 mounted on rotating rollers and a support 7 that ensures smooth rotation of the flange and holds the drum firmly. The entrance part of the heat transfer network to the drum is made conical, and in the upper part there is a collector 3, a supply roller 4, and a screw drum 9 with piles at the bottom for the purpose of crushing and mixing cotton raw materials with hot air [14-17].

The screw mixer-feeder works in the following scheme.

Cotton raw material is transferred to the right and left screw drum 9, which rotates through the supply rollers 4. Because of the rotation of the right and left screws 9, the cotton raw material is rotated with a uniform distribution inside the feeder and is mixed with hot air and transferred to the initial zone of the drying drum and is affected by the flow of hot air inside the drum.

The drying process in the proposed device increases the intensity of drying due to the formation of a mixture of hot air with raw cotton and the reduction of its density due to the division of cotton into small pieces, the consumption of fuel decreases, the consumption of electricity decreases due to the efficient use of hot air flow, and the quality of fiber improves.

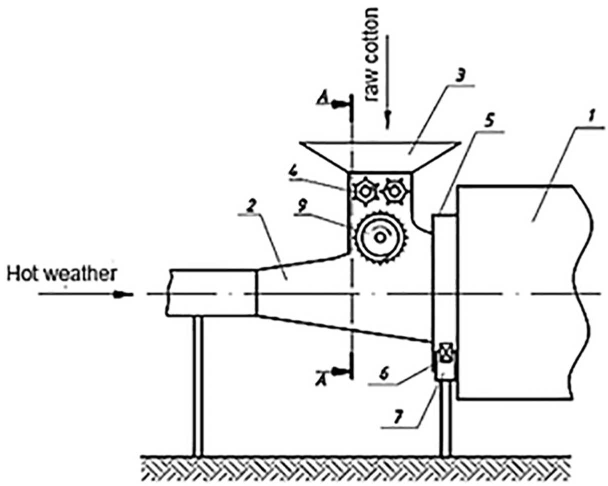


Fig. 1. Scheme of the feeder.

In the recommended screw feeder, the cotton material falls from the middle. Then the screw moves the pieces of cotton in two opposite directions.

In addition, under the influence of hot air flow, cotton raw materials partially dry and their movement in the direction of the screw is accelerated. It is important to determine the effect supplier parameters on the law of movement of cotton raw materials [18-20].

3 Results and discussion

The performance of the proposed drying drum supply device is determined using the following formulas:

$$P = 47 D_S^2 \cdot S_P \cdot n \cdot \rho_S \cdot \psi \cdot \varphi$$

Where D_S is the diameter of the auger screw, m;

S_P is the screw pitch, m;

n is the number of rotations of the screw, min^{-1};

ρ_S is the density of cotton in screw auger, kg/m^3.

$$\rho_S = \rho_\omega \cdot k_d$$

where p_ω is bulk weight of cotton with taking into account moisture content;

$k_d = 1.20$ is the coefficient that takes into account the density of cotton raw material when it moves in the screw;

ψ = 0.4 is filling factor of the auger;

φ is the influence coefficient of the angle of inclination in the installation of the auger, $\varphi=(1\pm\sin\alpha)$;

α is the angle of inclination when installing the auger, if the cotton moves up, then the (-) sign is taken, if it moves down, the (+) sign is taken.

The diameter of the screw auger is determined as follows, given the productivity:

$$D_S = K\sqrt{\frac{U}{47 S_P n \rho_S \psi \varphi}}$$

where *K* is the coefficient taking into account the uneven transfer of cotton from the separator to the auger, *K*=1.20.

The power of the motor driving the auger is determined as follows:

$$N = \frac{K_r}{\eta}\left[\frac{D\cdot L}{360\cdot S_v}(2D_v\cdot\mu_1 + D_v\cdot\mu_2 + S_v\cdot\mu_1) + 0.5n\cdot D_k^2\cdot(K_v^2\cdot D_v\cdot L\right]\cdot$$

$$\cdot(1\pm\sin\alpha); kVt$$

where K_r = 1.3÷1.4 is coefficient of resistance not taken into account;

η is coefficient of efficiency;

L is the working length of the auger, m;

D_k is the diameter of the screw shaft;

$\mu_1=\mu_2=1.3$ is coefficient of friction of wet cotton on screw and rod;

$K_v=0.05\div0.06$ is an empirical factor that takes into account the weight of the screw.

The power required to operate the screw feeder can be briefly calculated by the following formula:

$$N = K_r\frac{R\cdot V}{\eta}$$

where $K_r = 1.15\div1.25$ is power reserve coefficient;

P is tractive force of the screw shaft.

If the auger is located horizontally,

$$P = 10\cdot q\cdot L\cdot\omega = \Pi\cdot L\cdot\omega/0.36\cdot V$$

where $q = P/3.6\ V$ is the mass of cotton in one meter of screw duct;

V is the speed of cotton in screw duct;

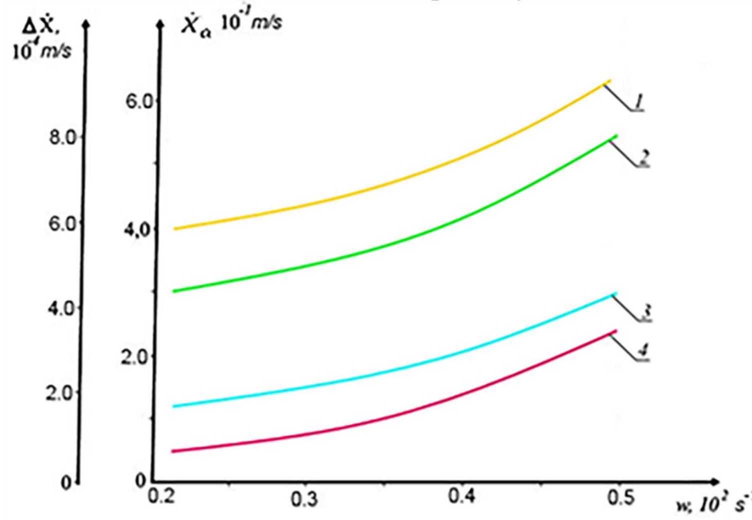
ω is experimentally determined resistance coefficient affecting the movement of cotton.

For the moist cotton $\omega=15\div20$, then the power

$$N = K_r\frac{2.78D\cdot L\cdot\omega}{10^3\cdot\eta}$$

Laws of change of thermal conductivity and heat capacity of cotton and seed that allows choosing the optimal energy-saving drying mode of the proposed dryer, taking into account the differences in thermal-physical properties of cotton components, dependence on humidity, volume density and temperature have been developed, which ensure the creation of the necessary conditions for the acceleration and uniformity of the process during the drying process based on the optimization of the air flow, and the uniform distribution of cotton on the cross-sectional surface of the drum is ensured [21, 22].

It is known that, according to experimental results, the masses of cotton pieces after the feeder are in the range of $(0.45\div1.1)\cdot10^{-3}$ kg [23]. Figure 2 shows graphs of the dependence of the average speed of cotton raw material on the surface of the screw and its coverage on the angular speed of the screw. Analysis of graphs showed that when the angular speed of the screw increased from $0.23\cdot10^2$ to $0.51\cdot10^2 s^{-1}$, the average speed of cotton raw material with a mass of $0.22\cdot10^{-3}$ kg increases from 0.39 m/s to 0.62 m/s in a nonlinear pattern, respectively, respectively, the average speed increases from 0.265 m/s to 0.526 m/s when a piece of cotton weighs $0.45 \cdot 10^{-3}$ kg. This is because when the mass of cotton raw material increases, more force is needed to move it at sufficient speed. Moreover, when the mass of raw cotton is $0.22 \cdot 10^{-3}$ kg, the value $\Delta\dot{X}$ increases nonlinearly from $2.1 \cdot 10^{-4}$ m/s to $3.21 \cdot 10^{-4}$ m/s, when the mass is $0.45 \cdot 10^{-3}$ kg, respectively, the values of $\Delta X^{\cdot}$ increases from $0.85 \cdot 10^{-4}$ m/s to $2.36 \cdot 10^{-4}$ m/s, respectively.



where: $1{,}2 - \dot{X}_a = f(\omega)$; $3{,}4 = \Delta\dot{X} = f(\omega)$;
$1{,}3 - m = 0.22 \cdot 10^{-3}\ kg$; $2{,}4 - m = 0.45 \cdot 10^{-3}\ kg$;

Fig. 2. Graphs of the dependence of the average speed of the cotton raw material on the surface of the screw and its coverage on the angular speed of the screw.

Therefore, it is recommended to select angular speed of the screw between $(38 \div 43)s^{-1}$ in order to ensure the movement of cotton pieces from the screw surface at a sufficient speed, and to further accelerate the threading. It should be noted that in the recommended construction, it is important not only to move cotton pieces, but also to dry them with hot air. In this case, the hot air does not dry the cotton pieces, but also makes them move faster. Therefore, the effect of the coefficient K_m, which represents the airflow speed and movement, on the movement of cotton pieces was studied [24]. The laws of motion representing the effect of hot air flow on the speed of movement of cotton raw material along the surface of the screw are shown (Figure 3). Based on the analysis of the received laws, it can be noted that the speed of movement of cotton pieces of different masses along the surface of the screw and its oscillation amplitude increase significantly with increasing air flow speed (Figure 3. a, b). In this case, the larger the mass of the piece of cotton, the smaller its average speed and oscillation amplitude (see graphs 3 in Figure 3, a, b).

Graphs of the dependence based on the obtained laws representing the effect of airflow on the movement of cotton particles have been plotted. Graphs of the dependence of the average speed of cotton raw material (see Figure 4) on the surface of the screw and the extent of its change on the speed of the hot airflow are shown. It should be noted that the screw is made symmetrically. For this, pieces of cotton falling on the surface of the screw from the middle move the surface of the screw to both sides.

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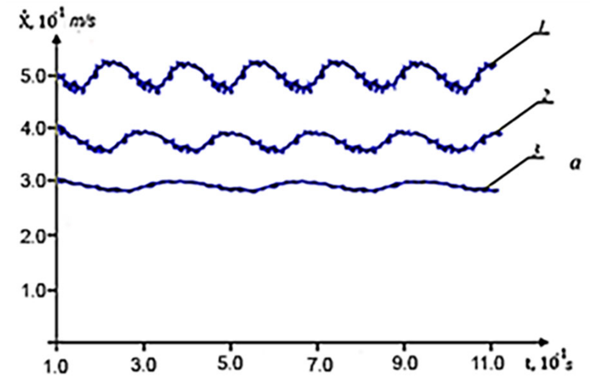
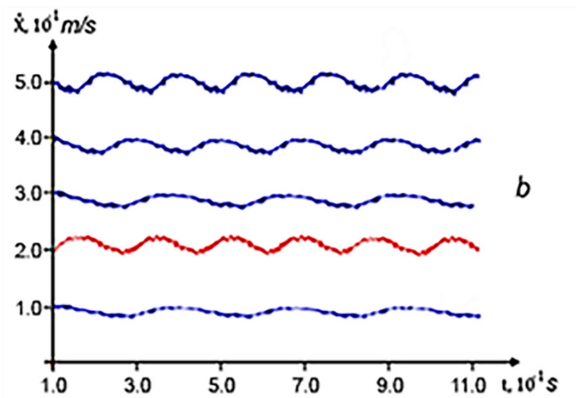


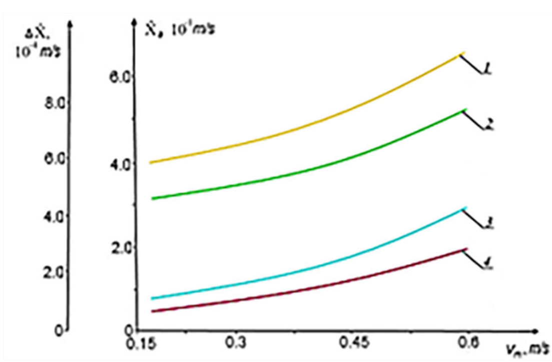
where: $1 - m - 2 \cdot 3; \omega = 36.03s^{-1}$; $K = 1.5\ kg/m$



where: $\omega = 36.63\ s^{-1}$; $K = 3.5\ kg/m$; $v_x = 0.55\ m/s$

Fig. 3. The effect of hot airflow on the speed of movement of cotton raw material along the surface of the screw.

The direction of screw blade is symmetrically directed in the opposite direction from its center.



where: $1.2 - \dot{X}_a = f(V_m)$; $3.4 - \Delta\dot{X} = f(V_m)$;

$1.3 - K = 4.0\frac{kg}{m}$; $2.4 - K = 1.5\ kg/m$

Fig. 4. Graphs of the dependence of the average speed of the cotton raw material on the surface of the screw and its range of change on the speed of the hot airflow.

Based on the analysis of the graphs of the dependences, shown in Figure 4, it can be noted that when the speed of the hot air increases from 0.2 m/s to 0.6 m/s, the average movement speed of cotton raw material increases nonlinearly from $4.0 \cdot 10^{-1}$ m/s to $6.1 \cdot 10^{-1}$ m/s. In addition to the speed of the airflow, the coefficient representing its temperature also plays an important role in this. Accordingly, when this coefficient is set to K_a=4.0, the oscillation range of the displacement speed of cotton raw material with a mass of $0.22 \cdot 10^{-3}$ kg increases nonlinearly from $1.41 \cdot 10^{-4}$ m/s to $2.83 \cdot 10^{-4}$ m/s. Therefore, in order to ensure the movement speeds of cotton pieces and their oscillation amplitudes are high, it is recommended that the speed of the hot airflow be (0.5÷0.7) m/s and the coefficient K≥4.0. It is known that frictional forces with relevant surfaces are very important in the transportation of cotton pieces [25, 26].

At the same time, the interaction and friction of cotton pieces is also important. In the considered case, the force of the interaction of the cotton pieces and the effect of the friction of the cotton pieces with the surface of the screw on the law of motion were also considered.

4 Conclusions

Therefore, with the creation of a new energy-efficient design of the cotton raw material transfer device to the drying drum, the cotton raw material transferred from above in the drum pipe does not accumulate in one place and the hot airflow is effectively used. It is important to apply this to production.

The new construction the cotton raw material supplier-mixer device has been developed, and theoretical and experimental research on the supplier-mixer device of the new proposed scheme has been carried out, and the working parameters of this construction has been established.

The laws of changing the moisture content of raw cotton at different values of the hot air speed have been obtained and it has established that changing the relative speed of the drying agent from 0.2 to 0.6 m/s has a significant effect on the rate of moisture release at different temperatures of the drying agent.

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