

## ENGINEERING & GINNING

### Development of Resource-Effective Equipment for Drying Raw Cotton Material

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#### ABSTRACT

**This study presents the development and analysis of a resource-efficient, small-sized drum dryer with a chain drive, tailored for cotton processing. A chain transmission system was selected with calculations determining the forces on support rollers, torque, and power requirements for drum rotation. The experimental dryer was designed with reduced dimensions, offering enhanced energy efficiency and improved drying performance. Experimental data reveal that the duration of raw cotton in the drum dryer is primarily influenced by rotational speed rather than productivity levels. Increasing rotational speed reduces drying time, enhancing process efficiency without compromising cotton quality. The chain-driven system proved effective, showcasing reliable operation, reduced energy consumption, and minimized environmental impact. The findings contribute to sustainable drying technologies in cotton production, emphasizing the importance of optimized mechanical designs and operational parameters.**

Efficient cotton drying processes are crucial for preserving cotton fiber's integrity (Soloxiddinov et al., 2023), improving processing efficiency, and reducing environmental impact. In this context, researchers have made significant advancements in developing innovative drying technologies tailored for cotton processing. The 2SB-10 drum dryers used in cotton processing plants were designed originally to dry low-grade raw cotton with high moisture content and contamination by forced air extraction, in compliance with technological regulations in

Uzbekistan. Bannikov (1963) was one of the first to determine the specifications of the 2SB-10 cotton drying equipment and drying technology that could be used that did not negatively affect the strength and color of cotton.

Other researchers have conducted research to improve drying technology. Pandey (2004) emphasized the need for advancements in farm equipment tailored for lightweight and small-sized agricultural materials, advocating for the integration of chain-drive mechanisms to enhance energy efficiency. Beyihayo and Mwesigwa (2015) supported this by discussing compact drying systems' roles in decentralized processing units, promoting sustainability and operational simplicity in small-scale farming setups. Heräjärvi and Verkasalo (2017) explored the use of rotary drum dryers in Finland's birch value chains, highlighting the operational stability of chain-drive mechanisms under high rotational loads. Their findings confirmed that these systems ensured uniform moisture distribution and optimized material throughput. Fereres et al. (2024) reviewed mechanization systems, asserting the necessity of compact and energy-efficient designs to meet sustainability demands of agriculture. Uldiyakov (1970) analyzed the technological process of a drum dryer, specifically the drying process in the last 3 m of the drum dryer with local blowing of the raw cotton material transferred to its interior and found that reactive blowing can increase the efficiency of the drying process.

Hamburg (1974) observed that the use of a drying agent with cotton with a high moisture content increased the efficiency of the drying process. The author recommended using a drum dryer with a drying agent added to the flow of cotton raw materials.

Parpiyev et al. (1990) studied cotton drying processes and factors affecting the speed of drying. They analyzed the designs of drying drums and concluded the main reasons for insufficient moisture removal were imperfections in the drying process and hydrodynamic conditions in the drying chambers, as well as insufficient cotton fluffiness. In these dryers,

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the residence time of raw cotton, depending on the consumption of the drying agent, was 6 to 8 min., during which drying was provided for the fiber and seeds, which is necessary when raw cotton has a moisture content of more than 14%, but is impractical when raw cotton has less moisture, as it leads to a decrease in seed weight.

To increase drying intensity, it is necessary to increase the heat exchange between the body and the environment, which can be achieved by increasing the heat exchange coefficient. However, increasing heat transfer is hampered by the boundary layer at the surface of the material, through which heat is transferred to the material because the thermal conductivity of air is low. Therefore, the heat transfer coefficient depends on the thermal conductivity and thickness of the boundary layer. Its thickness is affected by the speed of air movement and the density of the layer.

Baltabaev and Parpiev (1980) and Salmin and Iskanov (1980) reported that during a period of constant drying speed with a drying agent, the moisture content of the air in 2 min. increased from 4.8 to 34.1 g/kg of dry air. Further changes in moisture content proceeded slowly; during the period of falling speed, the drying intensity sharply decreased due to an increase in the partial pressure of water vapor in the air. After 1 min., the partial pressure of water vapor in the air increased from 67.9 to 320 N/m<sup>2</sup>. Thus, as the drying process progressed, the moisture absorption capacity of the agent decreased due to a decrease in temperature and an increase in the partial pressure of water vapor in the air.

The operation of type 2SB-10 dryers and research on their improvement and modernization have shown that they have significant disadvantages. The heat consumption of the drying agent for drying raw cotton was 35 to 40%; the rest of the heat was lost mainly when the spent drying agent was emitted into the atmosphere, which polluted the environment (Uldyakov, 1975). In this case, recirculation of the drying agent was impossible due to its contamination and saturation. Previous attempts to use electric heating elements to heat or preheat the spent drying agent were unsuccessful.

Drying drums of different designs were used for drying various frizzy and lump materials (Agrobook.ru., 2015; MSD Ukraine, n.d.; Sazhin and Sazhin, 1997). All designs used a chain drive to rotate the drum, which was more modern, reliable, and energy-saving than the 2SB-10 drum used in cotton dryers.

There was a reduction in energy consumption, because it increased the traction force transmission arm to the value of the drum radius (in 2SB-10 drum dryers this arm is equal to the distance from the diameter of the central axis of the drum to the axis gearbox). In addition, with a chain drive there is the possibility of uneven rotation of the drum due to the gap between the pitch of the chain and the ring gear. Drum dryers are large and have a bulky design with a heavy gearbox. The drums contain up to 1.5 tons of raw cotton at a time, which complicates the elimination of fires.

The primary objective of this study was to design and evaluate a small-sized drum dryer with a chain drive specifically for cotton processing. By reviewing existing literature, we aim to analyze energy efficiency, drying uniformity, and economic feasibility to develop a sustainable and cost-effective drying solution.

## MATERIALS AND METHODS

Preliminary calculations used a drum diameter of 2000 mm with a length of 6000 mm; accordingly, the parameters of the internal longitudinal and transverse partitions were reduced compared to the existing 2SB-10 drum. Theoretical studies were carried out using the laws of mechanics, hydraulics, mechanics of gas mixtures, algebra, descriptive geometry, and specially developed techniques. A technical diagram of a chain transmission with support rollers for a drum dryer for cotton was developed and an experimental prototype prepared (Karimov, n.d.; Zhu et al., 2023).

The calculation of the load on the sprocket is shown in Fig. 1. The drum dryer is driven by a chain drive with the sprocket on the drum in the middle. The mass of the drum, the coefficient of friction between the supports, and the torque required for rotation are known. The values of the coefficient of rolling friction on the axle can be determined from the Hertz Bilyaev formula:

$$2c = \sqrt[4]{p \frac{1-\mu^2}{\pi} \frac{E_1+E_2}{E_1E_2} \frac{d_r D_w}{2(d_r+D_w)}} \quad (1)$$

where  $p$  = compressive load per unit, (N/m);  $\mu$  = Poisson's ratio;  $E_1, E_2$  = modulus of elasticity of the roller and axle (Pa); and  $d_r D_w$  = radius of the roller and axle (m).

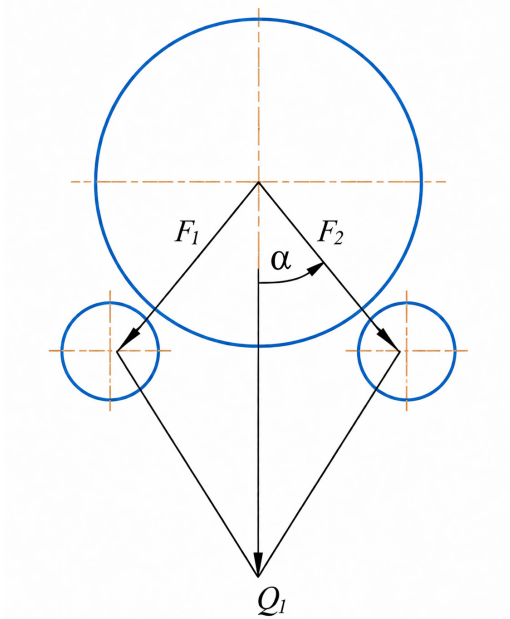


Figure 1. Diagram of the action of forces on the rollers.

Assuming similar materials and deformation, the rolling friction coefficient  $k_1$  can be expressed as:

$$k_1 = \sqrt[2]{p \frac{1-\mu^2}{\pi} \frac{2}{E} \frac{d_r D_w}{2(d_r + D_w)}} \quad (2)$$

Assuming the values from the experiment:  $p = 1.2 \times 10^5$  N/m;  $\mu = 0.3$ ;  $E = 2.1 \times 10^{11}$  Pa;  $d_r = 0.05$  m; and  $D_w = 0.08$  m and substituting into formula 2:

$$k_1 = \sqrt[2]{[1.2 \times 10^5 * (1 - 0.09) / \pi * 2 / (2.1 \times 10^{11}) * (0.05 * 0.08) / (2 * (0.05 + 0.08))]} \\ k_1 \approx 1.57 \times 10^{-4} \text{ m}$$

thus,  $k_1 \approx 0.157$  mm.

The normal force on one support roller ( $N_1$ ) is:

$$F_1 = (m + M)g \cos \alpha \quad (3)$$

Because there are two roller supports, the force is multiplied by 2, and because there were supports on both sides of roller, it is divided

$$N_1 = \frac{F_1}{2} \quad (4)$$

The total rolling friction force from both supports is:

$$F_{friction} = k_1(m + M)g \cos \alpha \quad (5)$$

For example: drum mass  $M = 500$  kg; cotton mass  $m = 300$  kg; inclination  $\alpha = 5^\circ$ ;  $k_1 = 1.57 \times 10^{-4}$  m such that:

$$F_{friction\_rolling} = 1.57 \times 10^{-4} * 800 * 9.81 * \cos 5^\circ \approx 1.23 \text{ N.}$$

The second wrist was in the sliding bearing. Its friction coefficient  $k_2$  was taken from the reference data (e.g.,  $k_2 \approx 0.07$  for lubricated steel-bronze bearings).

The friction force is:

$$F_{friction\ wrist} = k_2 \frac{(m+M)}{2} g. \quad (6)$$

For example,

$$F_{friction\ wrist} = 0.07 * 400 * 9.81 \approx 274.7 \text{ N.}$$

The drum lifts raw cotton. The work done is:

$$A = m_1 g (h - h_0) \quad (7)$$

where  $m_1$  is the mass being lifted (taken as 1/3 of the cotton mass), and  $h_0 = 0$ . The lifting height  $h$  is:

$$h = \frac{D}{2} * (1 + \cos \beta). \quad (8)$$

The lifting time  $t$  for rotation angle  $\beta$  at speed  $n$  (rpm) is (Fig. 2):

$$t = \frac{30\beta}{\pi n} \quad (9)$$

where:  $\beta =$  angle of rotation from the bottom point to the point of incurvation, rad;  $n =$  drum revolutions.

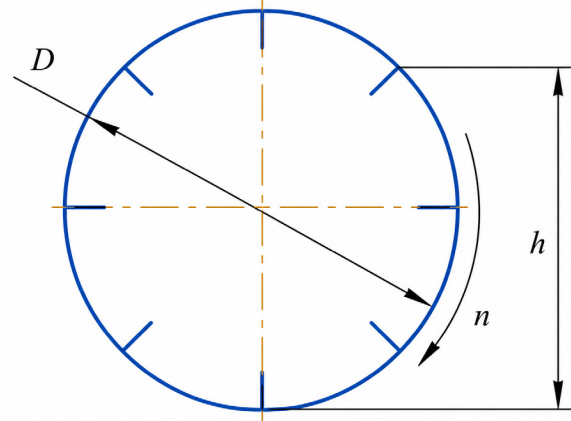


Figure 2. Design diagram of a drum dryer.

Therefore, the power required for lifting is:

$$N_{lift} = \frac{A}{t} = \frac{m_1 * g * h * \pi * n}{30\beta} \quad (10)$$

The corresponding torque for lifting is:

$$M_r = \frac{N_{lift}}{\omega} = \frac{m_1 * g * h}{\beta} = \frac{m * g * D * (1 + \cos \beta)}{6\beta} \quad (11)$$

Example: drum diameter  $D = 1.2$  m; lift angle  $\beta = 120^\circ = 2\pi/3$  rad; speed  $n = 4$  rpm

$$h = 0.6 * (1 + \cos 120^\circ) = 0.6 * 0.5 = 0.3 \text{ m} \\ M_r = (300 * 9.81 * 0.3) / (3 * (2\pi/3)) \approx 140.5 \text{ N} \cdot \text{m.}$$

The total torque  $M_t$  on the drive sprocket is the sum of all resistive torques:

$$M_t = F_{friction\ rolling} * d_r + F_{friction\ wrist} * d_r + M_r. \quad (12)$$

Using  $d_r = 0.05$  m:

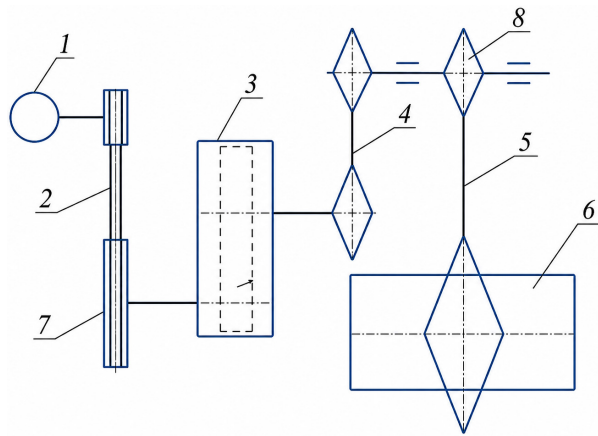
$$M_t = (1.23 * 0.05) + (274.7 * 0.05) + 140.5 \\ M_t \approx 0.06 + 13.74 + 140.5 = 154.3 \text{ N} \cdot \text{m.}$$

Drum power:

$$N_{drum} = M_t * \omega = 154.3 * \left(\pi * \frac{4}{30}\right) \approx 64.6 \text{ W.}$$

Considering losses in the drive system (Fig. 3), the electric motor power is:

$$N_{el} = \frac{N_{drum}}{\eta_{belt} * \eta_{gear} * \eta_{chain1} * \eta_{chain2}} \quad (13)$$



**Figure 3. Kinematic diagram of the chain drive proposed for a small-sized drying drum: (1) electric motor, (2) belt drive, (3) reducer, (4 and 5) chain drive, (6) small dryer drum, (7) pulley, (8) sprocket.**

With efficiencies  $\eta_{belt} = 0.96$ ,  $\eta_{gear} = 0.90$ ,  $\eta_{chain} = 0.96$ :

$$N_{el} = 64.6 / (0.96 * 0.90 * 0.96 * 0.96) \\ \approx 64.6 / 0.796 \approx 81.2 \text{ W.}$$

Applying a safety factor of 1.5:

$$N_{el} \approx 1.5 * 81.2 \approx 121.8 \text{ W.}$$

The pressure on the sprocket bushing is checked with:

$$p = (2 * M_t * K_e) / (d_{sp} * i * b * d_r) \quad (14)$$

where:  $d_{sp}$  = driven sprocket pitch diameter (m);  $b$  = chain width/bushing length (m);  $K_e$  = chain-drive service factor;  $i$  = design coefficient.

Using the results above, a technical solution was proposed for the production of a small-sized drying drum that intensifies the transfer of the drying agent to cotton inside the drum by reducing the overall dimensions of the 2SB-10 cotton drum dryer, reduces heat loss from the drum surface to the external environment by reducing the area of the drum's outer surface, and reduces the consumption of the drying agent by increasing the efficiency of its use.

The proposed drying drum (Fig. 4) consists of a cylindrical body, a drum shell, a drying agent pipe, a chimney, a roller drum rotating mechanism, a frame, a roller guide, and a cotton input tray. The diameter of the experimental cotton drying drum is 2000 mm and its length 6000 mm. The inner surface of the drum has the same longitudinal and transverse blades as in the existing 2SB-10 drum dryer. Only

the dimensions of these blades are reduced accordingly. A chain-roller drive mechanism was used to study the optimal values of the drum dryer's operating modes and a frequency converter powers its electric motor. The experimental drying drum had a maximum productivity of 6 to 7 tons/h. The amount of drying agent and temperature required to obtain a standard moisture content from cotton at such a high efficiency were studied.

The process of drying raw cotton materials in the proposed dryer was as follows. Raw cotton materials enter the drum through an inclined feed chute. The movement of the drum is controlled by a reduction gear and an electric motor. The drying agent is supplied at one end of the drum and dried cotton exits from the other end and the used drying agent is removed. When the drum rotates, its blades catch, mix, and lift the raw cotton materials, in the process it is treated with a drying agent supplied by a gas pipeline. Because the dimensions of the drum are small, it is necessary to study its aerodynamic operating modes to determine the optimal values for the amount of time the cotton is in the drum, the amount of heat that is dissipated to the environment outside the drum body, and other parameters.

The drying drum has a diameter of 2000 mm. Due to manufacturing and logistical constraints associated with this size, the main ring gear (final driven sprocket) was not fabricated as a monolithic component. Instead, it was constructed as a segmented assembly. Each segment had a chord length of 1506 mm, as detailed in Fig. 4.

To meet the required structural strength and engagement width, the sprocket segments were designed with a total width of  $\geq 28$  mm. This was achieved by fabricating each segment from a laminate of three steel plates: two outer plates with a thickness of 8 mm and one central plate with a thickness of 10 mm. Figure 5 illustrates a representative segment during the fabrication and assembly phase, alongside the drive chain transmission.

A functional prototype of the primary drive mechanism was fabricated and assembled according to the engineered kinematic layout. The power transmission system integrates three core elements. The prime mover is a standard industrial three-phase asynchronous electric motor, specified at 7.5 kW with a synchronous speed of 1,430 rpm. This motor is coupled to a single-stage, horizontally mounted helical gearbox providing a fixed reduction ratio of 31.5. However, this ratio results in an intermediate

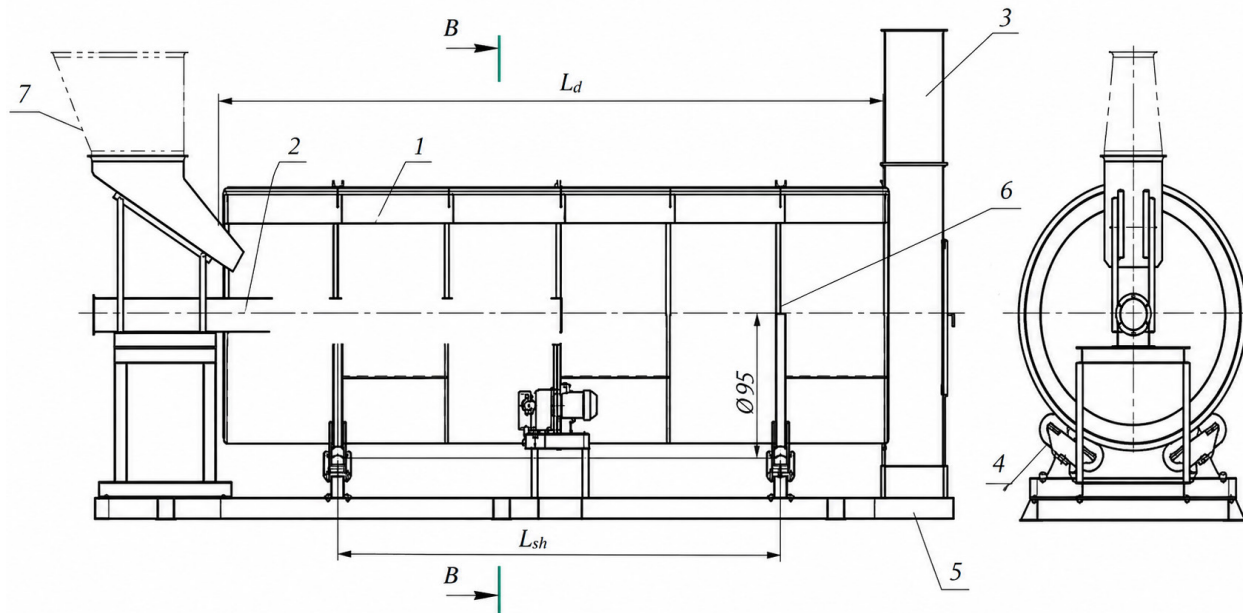


Figure 4. Scheme of a proposed drying drum with reduced dimensions: (1) drum shell, (2) a drying agent pipe, (3) a chimney, (4) a roller drum rotating mechanism, (5) a frame, (6) a roller guide, and (7) a cotton input tray.



Figure 5. Fragment of the manufacturing process of the ring gear and drive chain drive.

output speed that exceeds the required operational range for the drying drum. Based on prior empirical studies and thermodynamic models specific to fibrous material drying, the optimal rotational velocity for the drum was determined to be between 10 and

12 rpm to ensure adequate material tumbling and residence time for efficient moisture removal.

Consequently, a compounded two-stage reduction system was implemented downstream of the gearbox to achieve the final, precise speed reduction. The first stage employs a classical V-belt drive, where the selection of specific driver and driven pulley diameters provides the initial step-down in speed. The output shaft of this belt-drive stage then transmits power to the second and final reduction stage, which uses a heavy-duty roller chain and sprocket assembly. This chain drive directly engages with the segmented ring gear mounted on the drum, thereby imparting the final torque and rotational motion. The pitch diameters for both the belt pulleys and the chain sprockets were calculated through kinematic analysis to cascade the reductions from the gearbox output, ultimately yielding the target drum rotational speed of 10 to 12 rpm. The complete arrangement and spatial configuration of this multi-stage drive train are detailed in the schematic diagram (Fig. 6).

Following the manufacture of all components, the complete drive system, including the motor, gearbox, belt drive, chain drive, bearings, and support structures, was assembled and aligned. Initial commissioning tests were conducted to verify system integrity and operational functionality. A key validation measurement was the rotational speed of the primary drive sprocket (the output sprocket of the chain drive, which engages with the segmented



Figure 6. General view of a drum dryer with a chain drive.

ring gear). This sprocket, with a pitch diameter of 284.6 mm and 16 teeth (matching the tooth profile of the large ring gear), was measured using a calibrated handheld optical tachometer. The measured speed confirmed that the designed reduction ratios successfully provided input conditions to drive the drum within the specified 10 to 12 rpm range.

The successful fabrication and preliminary operation of this prototype established a critical foundation for subsequent empirical investigation. The immediate research focus is to conduct structured experimental studies on the operational prototype. These studies aim to quantitatively substantiate the selected kinematic and dynamic parameters of the drum dryer; characterize the load distribution, efficiency, and durability of the segmented ring gear and chain drive under realistic operating conditions; and validate the theoretical models for torque, power transmission, and sprocket loading. The data acquired from these tests will be essential for final design optimization and the development of reliable operational guidelines for full-scale implementation.

The optimization of drying processes in cotton production is crucial for improving both product quality and energy efficiency. In recent years, the implementation of resource-efficient equipment has become increasingly significant, particularly in drying raw cotton in which thermal parameters and mechanical agitation play vital roles. This section investigates the operational optimization of such equipment using full-factorial experiments within the framework of the Rotatable Central Composite Design (RCCD). The RCCD approach enables ef-

ficient estimation of response surfaces and interaction effects by minimizing experimental runs while maximizing statistical power. Specifically, the effects of drying drum rotational speed and drying agent temperature on drying uniformity and efficiency are examined through replicated trials. This section contributes practical insights into the modeling, replication strategy, and statistical adequacy of drying system parameters under controlled experimental conditions. To determine the optimal parameters of resource-efficient equipment for drying raw cotton, the experiments were designed as full-factorial experiments and conducted in accordance with the established standard, namely the RCCD.

To carry out the optimization process, input and output factors were selected. The following were chosen as input factors:  $X_1$ , rotational speed of the drying drum, rpm; and  $X_2$ , temperature of the drying agent, °C. Output factors were  $Y_1$ , drying uniformity of raw cotton, m; and  $Y_2$ , efficiency of cotton drying, %.

In the rotatable central composite design, the regression coefficients and their dispersions are determined using the following formulae:

$$b_0 = g_1 \sum_{u=1}^N \bar{Y}_u - g_2 \sum_{i=1}^M \sum_{u=1}^N x_{iu}^2 \bar{Y}_u \quad (15)$$

$$b_i = g_3 \sum_{u=1}^N x_{iu} \bar{Y}_u \quad (16)$$

$$b_{ij} = g_4 \sum_{u=1}^N x_{iu} x_{ju} \bar{Y}_u \quad (17)$$

$$b_{ii} = g_5 \sum_{u=1}^N x_{iu}^2 \bar{Y}_u - g_6 \sum_{i=1}^M \sum_{u=1}^N x_{iu}^2 \bar{Y}_u - g_7 \sum_{u=1}^N \bar{Y}_u \quad (18)$$

$$\begin{aligned} S^2\{b_0\} &= g_1 S^2\{\bar{Y}\} & S^2\{b_i\} &= g_3 S^2\{\bar{Y}\} \\ S^2\{b_{ij}\} &= g_4 S^2\{\bar{Y}\} & S^2\{b_{ij}\} &= g_7 S^2\{\bar{Y}\} \end{aligned} \quad (19)$$

Based on the experimental results, we derived a second-order multiple regression mathematical model and a general-form regression model obtained:

$$Y_R = b_0 + \sum_{i=1}^M b_i x_i + \sum_{j=1}^n b_{ij} x_i x_j + \sum_{i=1}^M b_{ii} x_i^2 \quad (20)$$

Because two factors are involved in our experiment, the above expression takes the form:

$$Y_R = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 + b_{11} x_1^2 + b_{22} x_2^2 \quad (21)$$

In the equations,  $b_0, b_1, \dots$ , are the regression coefficients; and  $x_1, x_2, x_3, \dots$ , are the coded values of the factors.

Using preliminary trial experiments, the base level and variation ranges of the factors are determined (Table 1). To derive a regression model that represents the stationary level, an RCCD was conducted using the matrix in Table 2. Each experiment in the matrix was repeated three times to determine

the uniformity of raw cotton drying, and the results were entered into the Table 2. Based on the matrix in Table 2, the following values are calculated using the above formulae:

$$\begin{aligned} \sum x_{1u}Y_u &= 0.66242; & \sum x_{2u}Y_u &= 0.44968; \\ \sum x_{1u}^2 Y_u &= 36.36; & \sum x_{1u}x_{2u}Y_u &= 0.08; \\ \sum x_{2u}^2 Y_u &= 35.94; & \sum Y_u &= 60.35; \\ \sum_{u=1}^{NM} (Y_{uM} - \bar{Y}_M)^2 &= 0.012 & \bar{Y}_M &= 4.84; \\ \sum_{u=1}^N (Y_u - \bar{Y}_{Ru})^2 &= 0.057. \end{aligned}$$

Then we determined the regression coefficients:

$$\begin{aligned} b_0 &= 0.2 * 60.35 - 0.1 * 72.3 = 4.84; \\ b_1 &= 0.125 * 0.66242 = 0.08; \\ b_2 &= 0.125 * 0.44968 = 0.06; \\ b_{12} &= 0.25 * 0.08 = 0.02; \\ b_{11} &= 0.125 * 36.36 + 0.0187 * 72.3 - 0.1 * 60.35 = -0.14; \\ b_{22} &= 0.125 * 35.94 + 0.0187 * 72.3 - 0.1 * 60.35 = -0.19. \end{aligned}$$

Table 1. Baseline and range values of factors

Factors	Change levels					<i>I<sub>i</sub></i>
	-1.414	-1	0	1	1.414	
X <sub>1</sub>	3	4	6	8	9	2
X <sub>2</sub>	106	110	120	130	134	10

Table 2. Rotatable Center Combinational Experience Working Matrix

Working Matrix					<i>Y<sub>1</sub></i> – cotton raw material drying constant, m			<i>Y<sub>2</sub></i> – cotton drying efficiency, %		
<i>x<sub>1</sub></i>	<i>x<sub>2</sub></i>	<i>x<sub>1</sub><sup>2</sup></i>	<i>x<sub>1</sub> x<sub>2</sub></i>	<i>x<sub>2</sub><sup>2</sup></i>	<i>Y<sub>1u</sub></i>	<i>Y<sub>1Ru</sub></i>	<i>(Y<sub>u</sub> - Y<sub>Ru</sub>)<sup>2</sup></i>	<i>Y<sub>u</sub></i>	<i>Y<sub>Ru</sub></i>	<i>(Y<sub>u</sub> - Y<sub>Ru</sub>)<sup>2</sup></i>
-1	-1	1	1	1	4.3	4.39	0.01	4.5	3.82	0.47
1	-1	1	-1	1	4.57	4.52	0.00	5	4.43	0.32
-1	1	1	-1	1	4.4	4.46	0.00	3.6	3.48	0.01
1	1	1	1	1	4.75	4.67	0.01	3.5	3.49	0.00
-1.414	0	2	0	0	4.57	4.45	0.02	3.1	3.51	0.17
1.414	0	2	0	0	4.6	4.68	0.01	3.7	3.95	0.06
0	-1.414	0	0	2	4.42	4.38	0.00	3.6	4.33	0.53
0	1.414	0	0	2	4.54	4.54	0.00	3.5	3.43	0.00
0	0	0	0	0	4.87	4.84	0.00	3.8	3.72	0.01
0	0	0	0	0	4.75	4.84	0.01	3.9	3.72	0.03
0	0	0	0	0	4.85	4.84	0.00	3.7	3.72	0.00
0	0	0	0	0	4.84	4.84	0.00	3.6	3.72	0.01
0	0	0	0	0	4.89	4.84	0.00	3.6	3.72	0.01

We calculated the variance of the output parameter using the following formula:

$$S^2 = \{Y\} = S_M^2\{Y\} = \frac{0.012}{5-1} = 0.003.$$

Using formula 19, the variances of the regression coefficients are determined:

$$\begin{aligned} S^2\{b_0\} &= 0.2 * 0.003 = 0.0006 & S &= \{b_0\} = 0.02 \\ S^2\{b_i\} &= 0.125 * 0.003 = 0.000375 & S &= \{b_0\} = 0.2 \\ S^2\{b_{ij}\} &= 0.25 * 0.000375 = 0.00009375 & S &= \{b_0\} = 0.1 \\ S^2\{b_{ij}\} &= 0.1438 * 0.00009375 = 0.00001348125 & S &= \{b_0\} = 0.0 \end{aligned}$$

We determine the estimated values of the Student criterion for the calculated coefficients:

$$\begin{aligned} t_R\{b_0\} &= 4. \frac{84}{0} . 0.02 = 200.97; & t_R\{b_1\} &= 0.08/0.02 = 4; \\ t_R\{b_2\} &= 0.06/0.02 = 3; & t_R\{b_{12}\} &= 0.02/0.01 = 2.10; \\ t_R\{b_{11}\} &= 38.22; & t_R\{b_{22}\} &= 52.77. \end{aligned}$$

The calculated value of the Student criterion is compared with the normative value of this criterion.

$$t_{nor} = [R] = 0.95; \quad f\{S_M^2\} = [5 - 1 = 4] = 2.776.$$

The comparisons show that all coefficients are statistically significant except for  $b_{11}$ .

Therefore, a relationship is established between the rotational speed of the drying drum, the temperature of the drying agent, and the uniformity of raw cotton drying, as follows:

$$Y_R = 4.84 + 0.08x_1 + 0.06x_2 - 0.14x_1^2 - 0.19x_2^2.$$

Next, the adequacy of the second-order multiple regression model obtained through RCCD is tested. For this, the calculated value of the Fisher criterion is determined using the following formula:

$$S_{adeq}^2\{Y\} = \frac{0.057 - 0.012}{13 - 5 - (5 - 1)} = 0.0075$$

$$F_R = \frac{S_{adeq}^2\{Y\}}{S_M^2\{Y\}} = \frac{0.0075}{0.012} = 0.649$$

The standard value of this criterion for the experiment is equal to:

$$F_{nor}[P_r] = 0.95; \quad fS_{adeq}^2\{Y\} = 13 - 5 - (5 - 1) = 4;$$

$$f\{S_M^2\} = [5 - 1 = 4] = 6.39$$

If  $F_R < F_{standard}$  the standard is considered adequate. In the case under study

$$F_R = 0.649 < 6.39 = F_{nor}$$

hence, the obtained regression mathematical model adequately represented the studied process with sufficient accuracy.

The planning matrix, into which the research results are entered, is presented in Table 2. Again, the adequacy of the second-order multiple regression model obtained through RCCD is tested. For this, the calculated value of the Fisher criterion is determined using the following formula:

$$S_{adeq}^2\{Y\} = \frac{0.057 - 0.012}{13 - 5 - (5 - 1)} = 0.0075$$

$$F_R = \frac{S_{adeq}^2\{Y\}}{S_M^2\{Y\}} = \frac{0.0075}{0.012} = 0.649$$

The standard value of this criterion for the experiment was the same as the above value. If  $F_R < F_{standard}$  the standard is considered adequate. In the second case under study

$$F_R = 5.788 < 6.39 = F_{nor}.$$

Therefore, the obtained regression mathematical model adequately represents the studied process with sufficient accuracy.

The experiments successfully demonstrate that the drying performance of raw cotton is significantly influenced by both the drum's rotational speed and

the drying agent's temperature. Using a second-order polynomial regression model, the study establishes quantifiable relationships between these input parameters and the output responses: drying uniformity and efficiency. Each experimental point in the RCCD matrix was replicated three times to ensure reliability and reduce the impact of experimental variability. Statistical tests, including Student criterion and Fisher's F-test, confirmed the significance and adequacy of the derived models. These findings offer a robust foundation for the design and optimization of industrial-scale cotton drying systems, enabling improvements in resource efficiency and product consistency.

A two-way factorial experiment was designed and conducted to investigate the effects of the drum's rotational speed and the system's throughput, or productivity, on the total drying time of cotton. The study incorporated three levels for each operational factor. Rotational speed (Factor A) was tested at 4, 6, and 8 rpm. Productivity (Factor B), defined as the mass feed rate, was tested at 4000, 5000, and 6000 kg/h. This full factorial design resulted in nine distinct experimental conditions (Fig. 7). The primary response variable measured for each condition was the total drying time, recorded in minutes. Each combination of speed and productivity was observed, as detailed in Table 3, to allow for a comprehensive analysis of main effects and potential interaction effects.

The primary objective of the statistical analysis was to test two central hypotheses. The null hypothesis ( $H_0$ ) stated that neither rotational speed nor productivity level has a statistically significant effect on the drying time. Conversely, the alterna-

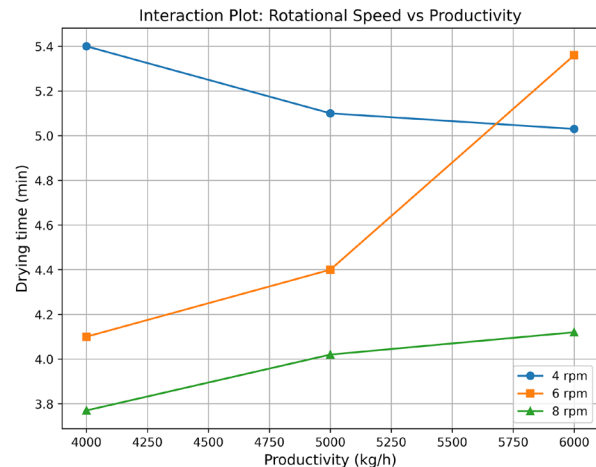


Figure 7. The interaction plot of the results.

Table 3. ANOVA results

Parameters	df	sum_sq	mean_sq	F	PR(>F)
C(Productivity)	2.0	0.667029	0.333514	38.134599	3.373838e-07
C(Speed)	2.0	6.641520	3.320760	379.701410	1.912659e-15
C(Productivity):C(Speed)	4.0	2.169154	0.542288	62.006192	2.791691e-10
Residual	18.0	0.157423	0.008746	NaN	NaN

tive hypothesis ( $H_a$ ) posited that at least one level of either factor, or their interaction, exerts a significant influence on the drying time. To evaluate these hypotheses, the experimental data were subjected to a two-way analysis of variance (ANOVA) with an alpha level ( $\alpha$ ) of 0.05 set as the threshold for statistical significance.

The ANOVA results provided strong evidence against the null hypothesis. The main effect of productivity was found to be statistically significant ( $F = 38.13, p < 0.001$ ), indicating that the mass feed rate is a determinant of drying duration. Furthermore, the main effect of rotational speed was highly significant ( $F = 379.70, p < 0.001$ ), demonstrating that the drum's speed profoundly influences the drying process kinetics. Crucially, the analysis also revealed a statistically significant interaction effect between productivity and speed ( $F = 62.01, p < 0.001$ ). This interaction signifies that the magnitude and direction of the rotational speed's effect on drying time are not constant but are contingent upon the specific productivity level at which the system is operating. Consequently, the optimal operational parameters cannot be determined by considering each factor in isolation; their interdependence must be accounted for.

## RESULTS AND DISCUSSION

The results of this ANOVA analysis underscored the critical influence of both rotational speed and productivity levels on drying time during the cotton drying process in drum dryers. The significant effects observed in both individual factors and their interaction revealed the complex interplay between operational parameters.

Specifically, rotational speed exhibits a highly significant impact, as does productivity, whereas the interaction effect highlights the necessity of a holistic approach when optimizing drying processes. These findings suggest that achieving optimal drying efficiency requires a careful balance of speed and productivity tailored to specific operational goals.

The results of the experiments are shown in Table 3. From the experimental results in Table 3, it can be observed that the productivity of the drum dryer for raw cotton has no significant effect on the drying duration of the cotton. With a constant drying agent supply, an increase in the rotational speed of the drum dryer reduces the residence time of raw cotton within the drum body, or in other words, shortens the drying duration. For instance, when the drum dryer's productivity for raw cotton is 4000 kg/h and its rotational speed is 4 rpm, the drying duration for raw cotton is 5.4 min. However, when the rotational speed of the drum dryer is increased to 8 rpm, the drying duration decreases to 2.96 min. Similar results were observed in smaller drum dryers designed for productivity levels of 5000 kg/h and 6000 kg/h, as shown in Table 4.

Thus, based on the data presented in Table 4, it can be concluded that in all three variants studied for the productivity of raw cotton, the drying duration of the cotton depends on the rotational speed of the drum dryer and does not change relative to the productivity of the cotton. This phenomenon can be explained as follows: at the minimum rotational speed of 4 rpm studied, the maximum drying duration is observed because the impact on the drying raw cotton inside the drum reduces its movement along the axis of the drum. As the rotational speed increases, the effect on the movement of raw cotton intensifies, thereby decreasing the drying duration. At the same time, it is essential to consider that an excessive increase in the drying duration of raw cotton negatively affects its quality parameters. Therefore, the required drying mode should be selected based on the initial moisture content of the cotton.

## CONCLUSIONS

The duration of drying raw cotton in a drum dryer recommended for cotton processing was studied. By examining the drying duration of cotton, it becomes possible to plan the amount of moisture removed from the cotton. Theoretical analyses de-

**Table 4. Results of experiments to determine the drying time of cotton raw materials**

Cotton drum dryer productivity, kg/h	Drying time of cotton raw material (min) versus rotation speed of drum dryer (rpm)		
	4	6	8
4000	5.3	3.8	3.8
	5.7	4.3	3.7
	5.2	4.2	3.8
average	5.4	4.1	3.77
5000	5.3	4.7	4.01
	5.1	4.2	3.99
	4.9	4.3	4.06
average	5.1	4.4	4.02
6000	5.2	5.2	4.2
	5.1	5.3	4.0
	4.8	5.6	4.16
average	5.03	5.36	4.12

termined that the amount of drying agent introduced into the drum body should be 6000 m<sup>3</sup>/h. For this study the drying agent supplied into the drum body through a pipe was set at 6000 m<sup>3</sup>/h.

From the analysis of the experiments performed at the JCS Cotton Research Center of Uzbekistan, a chain transmission scheme for a cotton dryer with reduced dimensions was selected for further research work. Theoretical studies have determined the forces on the drum support rollers, the total moment coming to the drive sprocket, and the required power spent on lifting the drum dryer. Based on the design specifications, the main components were manufactured and a drum dryer with a chain drive was assembled. The results of the experiment indicate that the drying duration of raw cotton in drum dryers does not depend on its productivity level. However, if the rotational speed of the drum dryer increases in the studied variants, the drying duration of raw cotton decreases.

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