

Optimization of Technology for the Use of Spinning Waste in Yarn Production

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Abstract – The paper considers issues related to the development of technology for the use of spinning waste in the production of cotton yarn. The process of forming a column of cotton fibers with included waste in an improved feeder-hopper of a loosening-scutching unit designed for cleaning from foreign impurities and dust is theoretically analysed. The optimal design parameters of an improved hopper-feeder with perforated walls have been determined depending on the performance of the loosening-scutching unit. The approximate distribution of the concentration of foreign impurities and dust is determined depending on the technological and design features of the improved hopper-feeder with perforated walls. The optimal technological parameters of the post-treatment of the formed fibrous layer of cotton after the hopper-feeder have been determined.

Keywords – Axial cleaner; cleaning and loosening machine; horizontal loosening machine; inclined cleaner; loosening-scutching unit; mathematical description of the process; production waste, secondary material resources

1. INTRODUCTION

Environmental problems of the textile industry of the Republic of Kazakhstan are mainly related to the utilization and regeneration of production waste, wastewater treatment, the creation of a recycling water supply system, cleaning the air of the working area from dust, etc. [1]. Production of yarn from low-grade cotton and production waste is one of the current problems of the industry, affecting the economic efficiency of textile enterprises. The use of spinning production waste and low-grade raw materials in the production of yarn of high linear density using the pneumomechanical spinning method allows to reduce the cost of a unit of production. Yarn produced with the investment of spinning production waste and low-grade raw materials is used in the manufacture of household, a number of technical, raincoat and clothing fabrics, where significant mechanical loads on the fabric are not required, as well as cotton wool and batting for the furniture and shoe industry.

The primary processing of cotton entering the spinning units, i.e. the separation of cotton shreds into smaller fractions and its dedusting from foreign impurities, dust and fluff have a decisive influence on the quality indicators of the final product of spinning and the course of the technological process [2], [3]. Optimization of the operation of loosening-scutching and

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cleaning units leads to a reduction in the consumption of energy resources, raw materials and an increase in equipment productivity. For the efficient use of waste from spinning production and low-grade cotton in the production of yarn of high linear density, various options for primary loosening, cleaning and dedusting of cotton have been developed and used.

In the scientific literature, the issues of efficient use of spinning production waste are very insignificant and they are mainly devoted to the use of low-grade cotton raw materials. The works of Russian scientists are devoted to this problem: Baev K.V., Gordeichuk G. S., Kabanov S. M., Pavlov O. V., Lebedev N. A. etc. However, these works did not completely solve the problems associated with the use of spinning production waste in the production of cotton yarn with simultaneous cleaning of fiber from foreign impurities and dust [4]–[6]. Therefore, the development of technology for the use of spinning production waste in the production of cotton yarn and the determination of the optimal technological and design parameters of the proposed design, which improves the technological and environmental-economic characteristics of the semi-finished product at the stage of preparation of the cotton mixture, is relevant.

2. MATERIALS AND METHODS

To ensure a significant reduction in the contamination of the fibrous layer and improve its uniformity in the feeders-hoppers loosening-scutching unit it is proposed to use perforated walls with individual suction of the air flow from the main zone of formation of the fibrous base of the web [7].

The results of the analysis of experimental data on the study of the technology and aerodynamics of the formation of a column of fibres in a feeder-hopper with perforated walls in practically important ranges of changes in their geometric and regime characteristics allow us to note the following features of the fibre mixture flow [4]:

- The fibre column flow is axisymmetric;
- Along the OY and OZ axis, the concentration of the mixture practically does not change, i.e., foreign impurities and dust are removed through both perforated walls in the direction of the OX axis;
- The mass transfer coefficient (β) remains constant during the cleaning process;

In accordance with the above features and when placing the origin at a point on the axis of the hopper, the differential equation of mass transfer for determining the mass flow in relation to the feeder-hopper according to [4] has the form:

$$\frac{dC}{d\tau} = \frac{\beta}{m \cdot \gamma} \left(\frac{d^2C}{dx^2} + \frac{d^2C}{dy^2} + \frac{d^2C}{dz^2} \right), \quad (1)$$

where

- C Current concentration of the mixture in the hopper;
- β Mass transfer coefficient, m/s; m is the amount of fibre and air particles in the flow that have lost energy;
- γ Specific gravity of air;
- τ Time.

Considering the first two conditions and entering $a = \frac{\beta}{m \cdot \gamma}$, Eq. (1) is rewritten in the following form (Eq. 2):

$$\frac{dC}{d\tau} = \frac{\beta}{m \cdot \gamma} \frac{d^2C}{dx^2}, \tag{2}$$

where

$$\frac{d^2C}{dy^2} = 0; \frac{d^2C}{dz^2} = 0.$$

Boundary and time conditions are introduced:

$$C = C_H \text{ at } \tau = 0 \text{ and } x = 0; \pm L; C = C_k \text{ at } \tau = \tau_k \text{ and } x = 0; \pm L,$$

where C_H, C_k accordingly, the concentration of the mixture at the beginning and at the end of the process; τ_k time of the process.

Introducing a dimensionless variable change in concentration (G) and a dimensionless coordinate (X) (Eq. 3):

$$G = \frac{C - C_k}{C_H - C_k}, X = \frac{x}{L}. \tag{3}$$

Then Eq. (2) takes the form:

$$\frac{dG}{d\tau} = a \frac{d^2G}{dX^2}. \tag{4}$$

In this case, the boundary conditions for Eq. (3) have the form: $G = 1$ at $\tau = 0$ and $X = 0; \pm 1$; $G = 0$ at $\tau = \tau_k$ and $X = 0; \pm 1$. The derivation of the equations for calculating the distribution of the concentration of foreign impurities and dust is shown in Fig. 1.

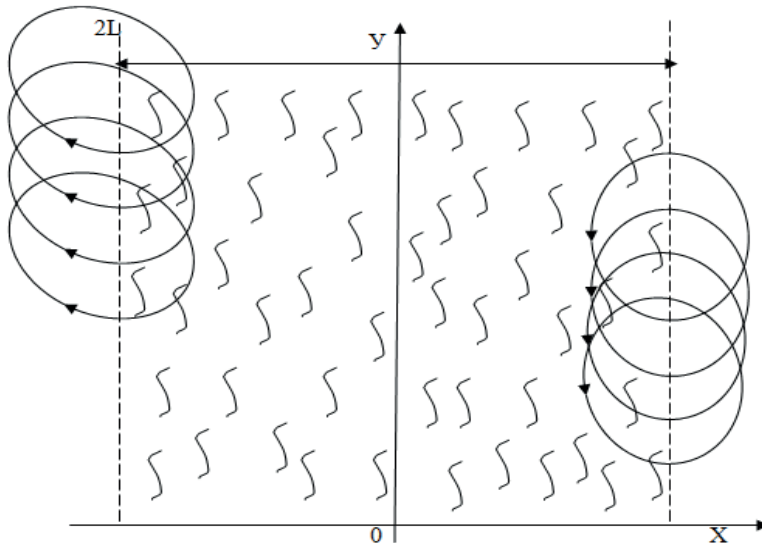


Fig. 1. Derivation of equations for calculating the distribution of the concentration of foreign impurities and dust.

The simplified mass transfer Eq. (3) is solved by the method of separation of variables, i.e. we introduce functions:

$$G = \varphi(X) \cdot F(\tau). \tag{5}$$

Now we will rewrite Eq. (3) in the form:

$$\frac{1}{\varphi} \frac{d^2\varphi}{dX^2} = \frac{1}{a} \frac{1}{F} \frac{dF}{d\tau}. \tag{6}$$

In this case, the left and right sides of Eq. (7) are equal to a constant value. The final solution of the equation will have the form:

$$G = 4\pi^{-1} \exp(\pm a\pi^2 \cdot \tau) \cdot \cos\left(\frac{\pi}{2nX}\right) + \frac{4}{3}\pi^{-1} \exp(\pm 9a\pi^2 \cdot \tau) \cdot \cos\left(\frac{3}{2\pi X}\right) + \dots \tag{7}$$

Now, denoting $a\tau = \theta$ and for fixed values (θ), we plot the dependence of G on X (Fig. 2).

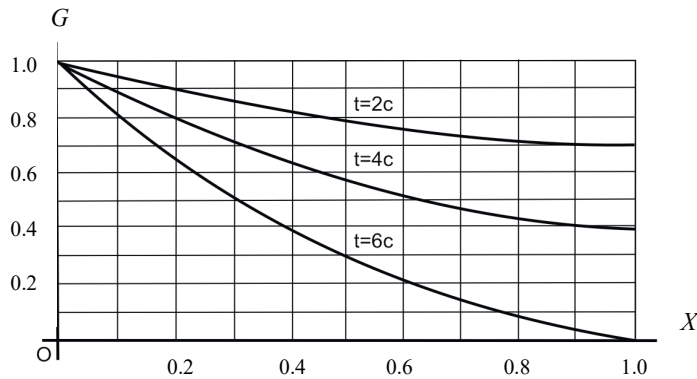


Fig. 2. Approximate distribution of the concentration of trash impurities and dust in the feeder-hopper.

Fig. 2 shows an approximate distribution of the concentration of foreign impurities and dust, depending on the technological and design features of the location of the perforated walls in the feeder hopper in a dimensionless form. To determine the optimal cleaning time of the mixture during its passage through the perforated hopper, the equations of concentration change along the height of the hopper were used in the form:

$$\frac{dC}{d\tau} = k \cdot C(\tau, y), \tag{8}$$

where

- $C(\tau, y)$ Function of changing the concentration of foreign impurities and dust in the section I – to the perforated wall of the hopper, depending on the time and the current height of the wall;
- τ Current cleaning time;
- k Proportionality coefficient, and experimental data of authors and works S.M. Kabanov, Saprynin D. N. and Frolov V. D. [8].

Provided that approximately 82 % of foreign impurities and dust are removed in the hopper feeder, the optimal cleaning time is 1.35 minutes.

To determine the optimal area of the perforated wall of the hopper-feeder, the material balance equations compiled for the upper and lower parts of the hopper, the Bernoulli's equations and the experimental data of the above authors were used [8], [9]. Provided that the concentration of foreign impurities in the hopper-feeder varies from 100 % to 40 %, the required surface area of the perforated wall is 2.82 m².

Equations were derived to calculate the optimal size of the perforation step and the diameter of the holes. Assuming the velocity of the sucked air through the hole is equal to $w_0 = 10$ m/s, define the design parameters of the perforation. The holes are staggered. It follows from the continuity equation of the flow that the ratio of the free cross-sectional area of the perforation S_0 to the total cross-sectional area S will be:

$$\frac{S_0}{S} = \frac{w}{w_0 \cdot Z}, \tag{9}$$

where

- Z Coefficient that considers 5 % of the free cross-section area, $Z = 0.95$;
- w Air velocity to the opening.

With a staggered arrangement of holes with a step t , the area is equal to:

$$S_w = t \cdot x = 2t\sqrt{t^2 - t^2 4} = 1.73t^2. \tag{10}$$

Then the area of the two holes $S_2 = 2 \cdot 0.785d_0^2 = 1.57d_0^2$.

The ratio (8) is rewritten as:

$$\frac{1.57d_0^2}{1.73t^2} = \frac{w}{w_0 \cdot Z}. \tag{11}$$

Hence the perforation step:

$$t = \alpha \sqrt{\frac{1.57 \cdot d_0 \cdot w_0 \cdot Z}{1.73 \cdot w}}. \tag{12}$$

Equation for calculating the hydraulic diameter of the entire perforation:

$$w_0 = \frac{\varphi \cdot \varepsilon}{\sqrt{1 - \varepsilon^2 \left(\frac{d_0}{d_1}\right)^4}} \cdot \sqrt{2g \frac{\Delta p}{\gamma}}, \tag{13}$$

where

- d_0 Hydraulic diameter of the entire perforation;
- d_1 Hydraulic diameter before perforation at a fiber flow column variable in height;
- w, w_0 According to the air speed before and in the hole;
- Z Coefficient that considers 5 % of the free cross-section area, $Z = 0.95$;
- Δp Pressure difference in the perforated wall;
- γ Air specific gravity;

- ε Jet compression ratio;
- φ Coefficient that considers the loss of mechanical energy.

3. RESULTS

Using these equations and experimental data, the changes in the concentration of foreign impurities and dust along the height of the hopper-feeder were calculated. The calculation results are summarized in Table 1, where:

- C – Current concentration of foreign impurities and dust contained in the fibrous layer of 100 %;
- c – Current concentration of foreign impurities and dust removed through the perforated walls of 40 %;
- $C - c$ – Respectively, the concentration of foreign impurities and dust contained in the fibrous layer in the upper and lower parts of the perforated hopper-feeder;
- k – The proportionality coefficient.

In order to determine the distribution of the concentration of weed impurities and dust in the fibrous layer along the height of the perforated wall of the hopper-feeder, it is necessary to plot its graph depending on $\frac{1}{k(C-c)} = f(C)$.

TABLE 1. CHANGE IN THE CONCENTRATION OF FOREIGN IMPURITIES AND DUST BY THE HEIGHT OF THE HOPPER-FEEDER

C	c	$C - c$	k	$\frac{1}{k(C-c)}$
100	40	60	320.67	$0.69 \cdot 10^{-4}$
80	35	45	315.2	$0.83 \cdot 10^{-4}$
60	30	30	290.3	$1.22 \cdot 10^{-4}$
40	25	15	255.1	$2.62 \cdot 10^{-4}$

According to Table 1, we plot the distribution of the removed concentrations of foreign impurities and dust along the height of the perforated wall of the hopper-feeder (Fig. 3).

When integrating, we obtain that the surface area of the perforated wall is 2625 mm² and for the accepted scale is:

$$\int_{C_1}^{C_2} \frac{dl}{k(C-c)} = \frac{2625}{40} \cdot 10^{-4} = 70.5 \cdot 10^{-4}. \tag{14}$$

From where, the required surface area of the perforated wall:

$$S_n = m_b \cdot C_b \int_{C_1}^C \frac{dG}{k(C-c)} = \frac{800}{n} \cdot 70.5 \cdot 10^{-4} = 2.82 \text{ m}^2, \tag{15}$$

where $n = 2$ is the number of perforated walls in the hopper-feeder.

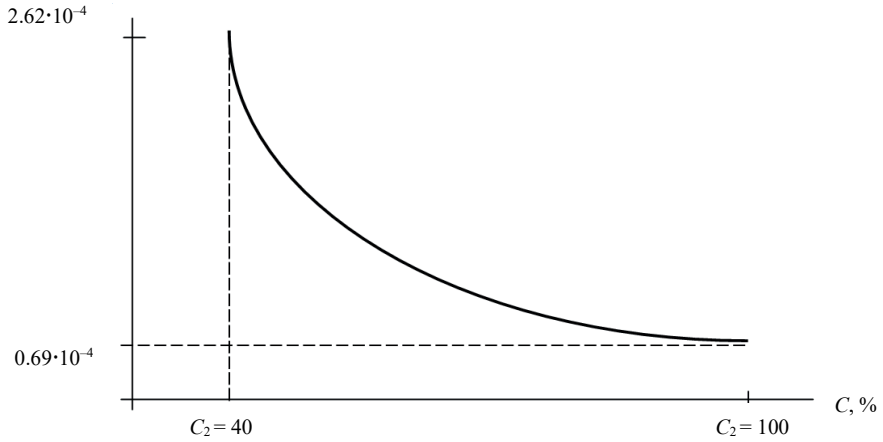


Fig. 3. Graph of the distribution of the removed foreign impurities and dust along the height of the perforated wall of the hopper-feeder.

To determine the optimal parameters of the post-treatment of the formed fibrous layer of cotton, consider the model of the movement of a speck. According to the principle of D'Alembert, the forces of inertia, gravity and resistance act on the mote when moving, i.e.

$$\vec{F}_i = \vec{F}_g + \vec{F}_r, \tag{16}$$

where $\vec{F}_i, \vec{F}_g, \vec{F}_r$ accordingly, the forces of inertia, gravity and resistance.

Using the d'Alembert method for a moving dust particle, the optimal parameters of the post-treatment of the formed fibrous layer of cotton after the hopper-feeder were theoretically calculated, i.e., the time of passage of the foreign impurity through the fibre layer with a thickness of $S = 0.12$ cm is equal to $\tau = 0.013$ s.

4. DISCUSSION

In the proposed layout scheme of the loosening-scutching unit instead of the usual horizontal loosening machine installed loosening-scutching unit cleaning and loosening machine. The layout diagram is shown in Fig. 4. As a result, the resulting pneumomechanical yarn of linear density 36 and 72 tex, it was developed from the composition of sorting (Table 2 and Table 3). The efficiency of cleaning machines included in the loosening-scutching unit was determined by the well-known method of Zarubin M., Zarubina V. [10], [11] (Table 3).

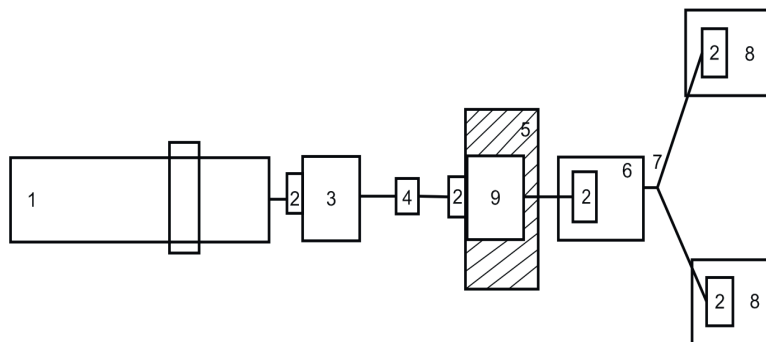


Fig. 4. Scheme of the loosening-scutching unit: 1 – Automatic stack-loosening; 2 – high-speed condenser; 3 – inclined cleaner; 4 – axial cleaner; 5 – horizontal loosening machine; 6 – mixer; 7 – serrate scutching; 8 – dedusting machine; 9 – cleaning and loosening machine.

TABLE 2. SORTING COMPOSITION

A breeding variety of cotton	Fiber length, m	Staple length, m	Linear fiber density, tex	Endurance, cH	Humidity, %	Sum of defects, %
Kir-3	31/32	31.7	0.170	24.7	5.4	2.0
3010	31/32	31.5	0.122	21.3	6.7	8.5
Kir-31	33/34	33.3	0.144	20.4	6.5	10.5
T-16	35/36	35.7	0.125	26.4	5.5	6.0
Fer-3	31/32	31.7	0.163	25.5	5.0	2.0
waste	31/32	31.9	0.169	24.1	5.6	2.1
Average	31/32	32.2	0.15	20.88	5.7	8.66

TABLE 3. CLEANING EFFICIENCY

Equipment	Existing	Proposed
Inclined cleaner	41.00	40.90
Axial cleaner	8.10	8.11
Horizontal loosening machine	16.00	–
Cleaning and loosening machine	–	23.40
Total	65.10	72.41

As follows from Table 4, as a result of the replacement of the machine horizontal loosening machine with cleaning and loosening machine, the total cleaning capacity of the unit increased by 10.2 %.

The looseness of cotton fibre, the quantity and quality of the waste released on the loosening-scutching unit machines are shown in Tables 4–6.

TABLE 4. LOOSENING OF COTTON FIBRE

Name of the equipment	Existing version	The proposed option
Inclined cleaner	0.34	0.34
Axial cleaner	0.29	0.30
Horizontal loosening machine	0.21	–
Cleaning and loosening machine	–	0.26
Mixer	0.21	0.20

TABLE 5. AMOUNT OF SEPARABLE DEBRIS

Name of the equipment	Existing version	The proposed option
Inclined cleaner	3.58	3.60
Axial cleaner	0.46	0.46
Horizontal loosening machine	1.60	–
Cleaning and loosening machine	–	1.87
Total	5.64	5.93

TABLE 6. QUALITATIVE COMPOSITION OF WASTE

Composition of the suspension	Inclined cleaner	Axial cleaner	Horizontal loosening machine	Cleaning and loosening machine
Pure fibre content, %	52.8	59.6	67.2	48.8
The content of defects including, %	47.2	40.4	32.8	51.2
Large litter and broken seed	32.1	26.2	20.6	32.8
Skin with fibre	5.9	7.2	6.6	8.0
Small rubbish	9.2	7.0	5.6	10.4
Fluff and dust from the filter of the machine, g	17.0	11.0	9.0	22.0

As can be seen from Tables 4–6, the looseness of cotton fibre increased from 0.21 (for horizontal loosening machines) to 0.26. The amount of separated garbage increased from 1.6 % to 1.93 %; the content of spun fibre in the waste on the cleaning and loosening machine is 30.2 % less.

The physico-mechanical parameters and irregularities of yarn produced using a machine of the cleaning and loosening machine type and without it are investigated [12], [13]. As the results of the experiment showed, the specific breaking load for yarn of linear density 36 and 72 tex, respectively, increased by 7.1 % and 4.3 %, the breakage decreased by 12.2 % and 32.1 %.

The unevenness of the yarn was evaluated using spectral analysis [11]. To determine the efficiency of the proposed and existing units on the BD-200-SN pneumatic spinning machines, yarn of linear density 36 and 72 tex was produced. The analysis of spectrograms

gives reason to believe that the yarn produced using the cleaning and loosening machine is better. When using a cleaning and loosening machine, pronounced peaks are smoothed out on spectrograms [14]–[16]. The coefficient of variation and defects of yarn 36 and 72 tex are shown in Fig. 5 and Fig. 6.

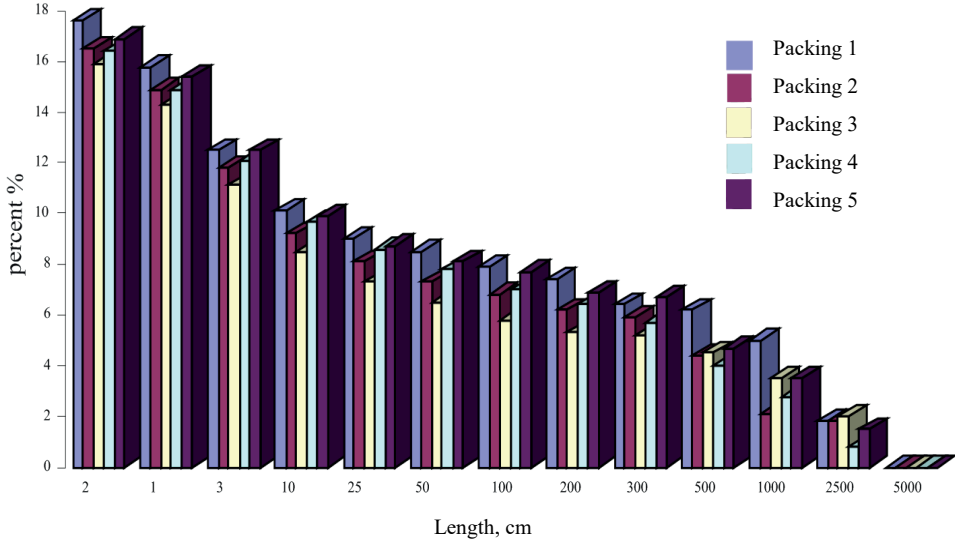


Fig. 5. Spectrum 1. Machine No. 3, material: T-36 tex (No. 28).

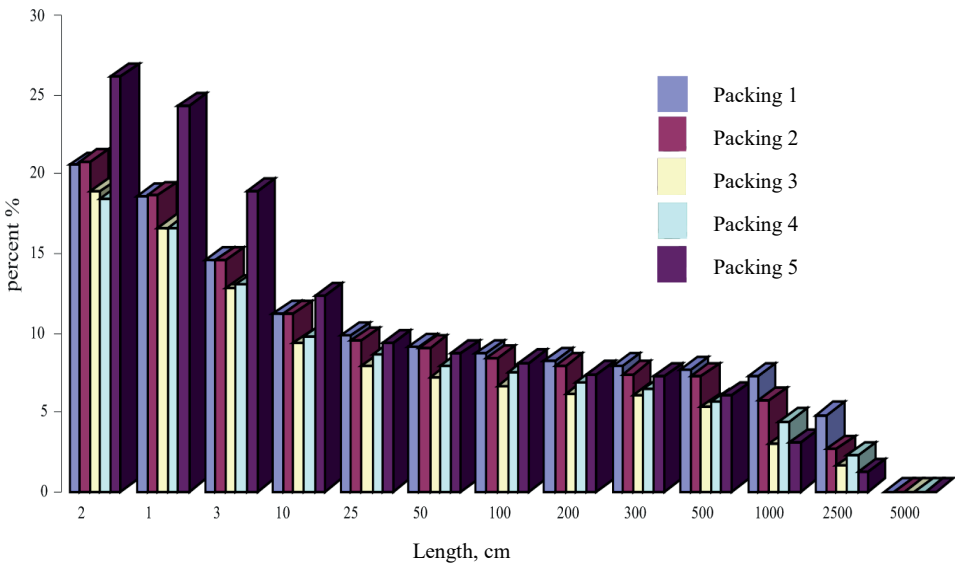


Fig. 6. Spectrum 2. Machine No. 4, material: T-72 tex (No. 14).

As the results of the study showed, the coefficient of variation of yarn with a linear density of 36 tex decreased from 8.8 % to 40 % depending on the length of the implementation, and the number of thickenings and thinnings decreased by 58.4 % and 78.2 %, respectively.

For yarn with a linear density of 72 tex, the coefficient of variation decreased from 14.7 % to 24.1 %, depending on the length of the implementation, and the number of thickenings and thinnings in the yarn by 85.1 % and 36.1 %, respectively.

5. CONCLUSION

The process of forming a column of cotton fibers with included waste in an improved hopper-feeder loosening-scutching unit designed for cleaning from foreign impurities and dust is theoretically analysed [17].

The optimal design parameters of the improved hopper feeder with perforated walls are determined depending on the performance loosening-scutching unit. The diameter of the perforation hole is 3.92 mm, and the optimal area of the perforated walls of the hopper feeder is 2.98 m². The approximate distribution of the concentration of foreign impurities and dust is determined depending on the technological and design features of the improved hopper feeder with perforated walls. The level of cleaning of the column of cotton fibers from foreign impurities and dust in the hopper feeder is from 30 % to 40 %. The optimal technological parameters of the post-treatment of the formed fibrous layer of cotton after the hopper-feeder have been determined.

As a result of the replacement of the machine horizontal loosening machine with an improved machine cleaning and loosening machine, the total cleaning capacity of the developed variant loosening-scutching unit increased by 11.2 %, the content of pure fibre in carbon monoxide decreased by 30.3 %. The specific breaking load of yarn of linear density 36 tex, produced from cotton fibre with waste included, increased by 7.6 %, and yarn 72 tex – by 4.3 %. The value of breakage in the production of yarn of linear density 36 tex decreased by 12.3 %, and yarn of linear density 72 tex – by 12.9 %.

As a result of the introduction of the developed technology, the indicator of the closed use of waste in comparison with the existing mode of operation of production increased by 24 %.

For the specific use of the research results, the following is proposed: an improved hopper feeder with perforated walls with a dedusting, loosening-scutching machine of the type cleaning and loosening machine, which allows you to reduce the cost of producing a unit of yarn with improved qualities. The research results can be used in the calculation and design of resource-saving spinning equipment, in the educational process. The initial data for the use of research results is a database for the implementation of resource-saving technology in cotton spinning [18], [19].

The introduction of research results into practice will reduce the cost of producing a unit of yarn and improve the environmental situation of spinning production.

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