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Theoretical Issues of Development an Innovative Technology of Cleaning Raw Cotton

Mardonov B.M., Usmanov Kh.S., Sirojiddinov F.N., Tangirov A. Karimov A.

ABSTRACT: A mathematical model for the separation of weed impurities from the composition of the stationary mass flow of cotton in the cleaning zone is presented. The one-dimensional Euler equation is compiled with respect to pressure, the velocity and the density of a moving stream of raw cotton, where the law of conservation of mass flow and the equation of state, representing the relationship between the density and pressure, are used. After determining the density distribution field of raw cotton in each section of the cleaning zone, the model of A.G. Sevostyanov was used, which describes the separation of weed impurities from the raw cotton mass under the impact of spikes. Graphic dependences of the distribution of the amount of weed impurities from a cotton stream along an arc are obtained.

KEYWORDS: weed impurities in cotton, raw cotton mass, Euler equation, mesh surface, pin, pin drum sections, law of conservation, equation of state.

I. INTRODUCTION

An analysis of the scientific and practical work carried out to improve the processes of cleaning raw cotton from weed impurities showed [1] that as a result of research conducted in the world, a number of major scientific results in this direction were obtained, including: modern automation systems for technological processes of cleaning equipment were developed (Lummus, USA), an effective technology for cleaning cotton from large and small weed impurities was created (Lummus, USA, Cotton research and development corporation, Australia).

The results of theoretical and experimental research conducted in Uzbekistan were the development of new machines for cleaning cotton from weed impurities (Tashkent Institute of Textile and Light Industry, Paxtasanoat ilmiy markazi JSC, Republic of Uzbekistan). When creating devices and technologies for cleaning raw cotton, research is carried out in a number of priority areas, including: the creation of a regulated system of cleaning ratio; increasing the profitability of enterprises through the introduction of new resource-saving cleaners; the creation of a flexible automated system for cleaning raw cotton, the creation of an effective technology for cleaning raw cotton from weed impurities and rational designs of working bodies of cleaners.

In recent years, given the preferential transition to machine cleaning of raw cotton, special attention is paid in the technology of primary cotton processing to the cleaning of the indicated raw materials. In this direction, in general the work was carried out in two directions: the improvement of technological processes and the creation of new designs of machines and mechanisms. As a result of these studies, a universal cotton complex (UHK) was created at the end of the last century. (Fig. 1).

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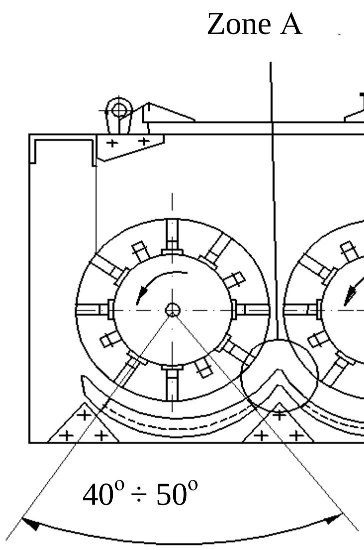

Fig.1. Diagram of the cleaning section from small weed impurities of the unit UHK

Owing to the counter-rotation of adjacent drums in zone A, there is a significant damage to the raw cotton (especially when processing low grades) due to a sharp change in the direction of movement of the raw cotton in the next cleaning section during the process. In the existing design of the raw cotton cleaner from small weed impurities, the process of transporting raw cotton is carried out by unidirectional movement of the spike drums, where in zone A between two adjacent drums that are moving towards each other are particles of raw cotton that are exposed to significant impacts from the adjacent spike drums. adjacent drums. During transportation, the linear speed of the spike drums is V_1= 9 m/sec, while oncoming movement a particle of raw cotton is subjected to shock impact with a speed of V_2 =18 m/sec (the speed of the opposite adjacent drum is added). This results in significant damage to the fiber and seeds.

In continuation of the previous studies [2], we propose an improved scheme of vertical cleaner of cotton from small litter, which allows to eliminate the above disadvantages by sequential movement of the spike drums, where it becomes possible to increase the angle of coverage of the drum mesh surface. The proposed scheme is shown in Figure 2, where its transverse section is shown. The unidirectional rotational speed of the spike drums allows to eliminate clogging situations in the machine. An application No. FAP 20170134 dated November 27, 2017 for this line-up of the construction of a cleaner from small litter has been filed to the Agency for Intellectual Property of the Republic of Uzbekistan [3]. At the same time, the wrap angle of the spike drum with the mesh surface is more than 180^o. The given layout of the cleaning sections and the consistent transportation of seed cotton through the adjacent cleaning sections (Fig. 2) can significantly increase the cleaning effect, as well as preserving the natural quality indicators of raw cotton and its components, will keep fiber and seeds from damage during transportation through the drums, which is the basis for the development of technology for vertical cleaning of seed cotton at cotton plants. Of particular importance is the installation of the cleaning section of large impurities after the cleaning section of small litter, which allows, compared with the UHK unit, to reduce the metal structure with a complete set from 20.0 to 8.8 tons, the energy intensity decreases from 98 to 39 kW.

Due to the complexity of the distribution and the connection of weed impurities with the fibers in the composition of the fibrous medium, there is practically no theoretical description of the process of isolating them from the composition of raw cotton. There are simple technological methods for calculating the amount of impurities after passing through the cleaning zone, based on the balance of raw materials before and after processing it in cleaners [4-5]. Simple models have been proposed for describing the mechanism for removing individual particles of impurities from raw cotton. These models are based on an elementary representation of the presence of motes and their connection with fibers raw cotton. At the same time, there are no serious theoretical studies for the further development of the concept of the mixture of "impurities-fibrous mass" and the development of a model of the nature of the movement of weed impurities.

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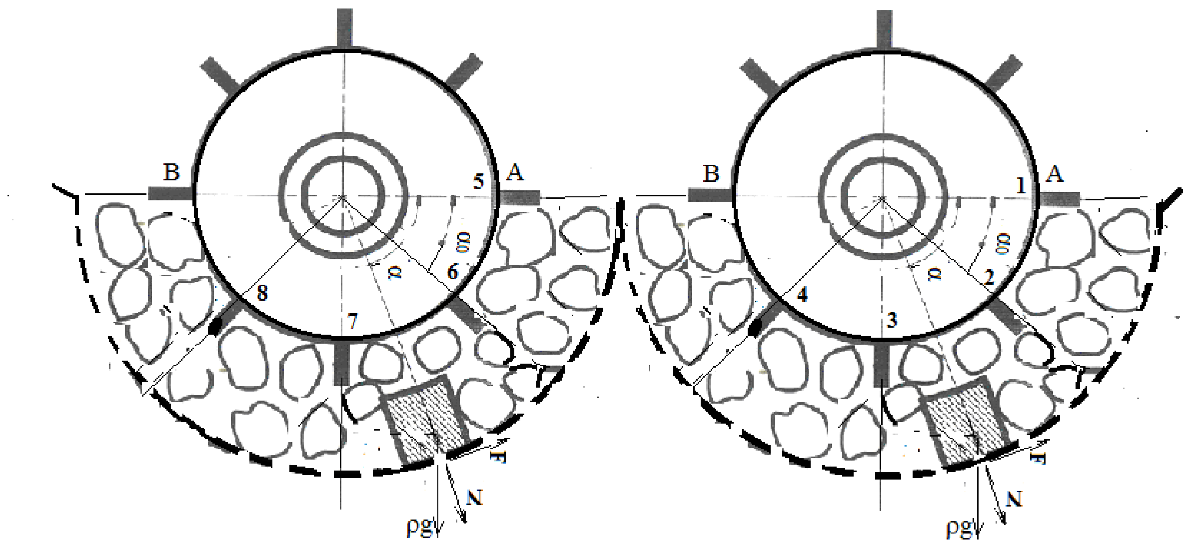
II. FORMULATION OF THE PROBLEM.

We model the process of cleaning raw cotton stream from weed impurities by horizontally placed sections, where the flow comes from the feeder zone, with constant performance Q_0. We assume that the flow is one-dimensional and its speed changes along a horizontal arc in each section of the spike drum. When the flow in the cleaning zone occurs, the raw cotton particles come into contact with the mesh surface, as a result of which the weed particles are separated from the stream composition. We study separately the flow in each section of the drum. The first section is determined by the value of the angle α in the interval $\alpha_0 < \alpha < 2\alpha_0$ (Fig. 1. a). We consider the medium to be compressible, select from this section an element from the raw cotton stream ds (Fig. 1.b) and make up the equation of motion in the form of Euler [7]. The flow is considered stationary.

a)



b)

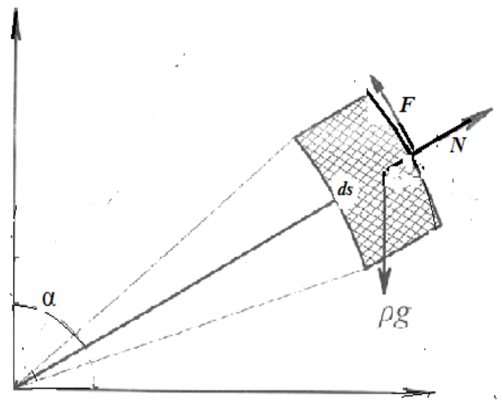


Fig. 1. Scheme of flow of raw cotton in sections along the drum under the action of four spikes.

III. SOLUTION METHOD

We make up the equations of flow for two sections of the cleaning zone, where we assume that in this zone the raw cotton is cleaned of weed impurities as it moves over the mesh surface for angle values, $0 < \alpha < 3\alpha_0$ i.e. in each section of the strike is made with three spikes.

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The Euler equation for a layer of raw cotton in the case of a flow in the horizontal direction along the grid of the first section is written as:

$$v\rho\frac{dv}{ds} = -\frac{dp}{ds} + \rho g\sin\alpha - Nf \quad . \quad N = \rho\frac{v^2}{R} + \rho g\cos\alpha \qquad (1)$$

where s - the length of the arc of contact of the raw cotton with the mesh, measured from point A, v – current speed of cotton particles, p , ρ - pressure and density, R- drum radius, N- normal specific force, *f*- coefficient of friction between the surface of the mesh and raw cotton.

After eliminating the force N from (1) we obtain the equation for the pressure $p(s)$, $\rho(s)$ and speeds $v(s)$:

$$v\rho\frac{dv}{ds} = -\frac{dp}{ds} + \rho g(\sin\alpha - f\cos\alpha) - \rho\frac{v^2}{R}f \qquad (2)$$

Equations (2) contains 3 unknowns: p , ρ and v . To close it, we use the equation of state of a compressible medium, which establishes a relationship between pressure p and density ρ :

$$\rho = \rho_c[1 + A(p - p_c)] \qquad (3)$$

and the condition of mass conservation for stationary flow

$$\rho v S_0 = Q_0 \qquad (4)$$

There $S_0 = k_0 Lh$ – cross sectional area of the flow layer, *h*- layer thickness, *L*- drum length, k_0 - coefficient characterizing the reduction of the area of contact of raw materials with the surfaces of the spikes. Q_0 – cleaner performance, ρ_c p_c - density and pressure upon receipt of raw materials on the contact surface, *A*- a constant characterizing compressibility of raw cotton. With $A << 1$ (4) determine the speed

$$v = v_c[1 - A(p - p_c)] \qquad (5)$$

With the shock impact of spike on raw cotton the particles of the flow gains speed $v_c = \beta v_k$, where v_k - linear speed of the spike, $\beta < 1$- the coefficient of speed reduction, determined experimentally, in [1], the average flow rate in the cleaning zone is taken $v_{cp} = 0.5v_k$. Putting in the formula (5) $v = v_c$, find the density of the raw material on the surface $\rho_c = \dfrac{Q_0}{S_0 v_c}$

To determine the pressure p_c, it is assumed that pressure p_0 and raw material density ρ_0 in the feed zone are known. Then assuming $p = p_0$ and $\rho = \rho_0$ in the formula (3), we find

$$p_c = p_0 - (\rho_0 / \rho_c - 1)/A \qquad (6)$$

From the requirement of the absence of separation of raw materials from the surface of the spike it results that $p_c > 0$, which means $\dfrac{\rho_0}{\rho_c} < 1 + p_0 A$.

On the other hand, the condition of depression of raw materials in the cleaning zone $p_c < p_0$ should be fulfilled, which gives $\dfrac{\rho_0}{\rho_c} > 1$.

Thus, to implement the process of depression of raw materials without disturbing the contact with the spike it is necessary that the ratio of densities $\dfrac{\rho_0}{\rho_c}$ satisfies an inequality $1 < \dfrac{\rho_0}{\rho_c} < 1 + p_0 A$.

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We assume that the pressure p_0 does not damage the seeds during the shock interaction of the spike with the raw material.

If denote the ultimate impact force by P_k at which the seeds are damaged, then assume $p_c < P_k / S_0$ in the formula (7), we get

$p_0 < P_k / S_0 + (\rho_0 / \rho_c - 1) / A$.

We introduce a new variable according to the formula (6) $\alpha = s / R$ (α - central angle, R - drum radius). In view of (4) and (6), we write equation (2) with respect to pressure p.

$$a\frac{dp}{d\alpha} = R\rho g(\sin\alpha - f\cos\alpha)[1 + A(p - p_c)] - \overline{Q_0} f[1 - A(p - p_c)]$$

The last equation we bring to:

$$\frac{dp}{d\alpha} = F_1(\alpha)p + F_2(\alpha) \qquad (7)$$

where $F_2(\alpha) = \dfrac{A[R\rho_0 g F_1(\alpha) + \overline{Q_0} f v_0]}{a}$, $F_4(\alpha) = \dfrac{(1 - Ap_c)F_1(\alpha)R\rho_0 g - \overline{Q_0} v_0 f(1 + p_c A)}{a}$

$$F_1(\alpha) = \sin\alpha - f\cos\alpha,\ a = 1 - \overline{Q_0} v_c A,\ \overline{Q_0} = \frac{Q_0}{S_0}$$

Solution of equation (7) satisfying the condition $p(0) = p_c$ represented in quadratures

$$p = F_3(\alpha)[\frac{p_{0c}}{F_3(0)} + \int_0^\alpha \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \qquad (8)$$

where $F_3(\alpha) = \exp[\int F_2(\alpha)d\alpha]$

Formula (8) is used to determine the pressure in each section.

The contact of the flow of raw cotton in the first section with a mesh surface occurs in four areas $0 < \alpha < \alpha_0$ $\alpha_0 < \alpha < 2\alpha_0$, $2\alpha_0 \le \alpha < 3\alpha_0$ и $3\alpha_0 \le \alpha < 4\alpha_0$. The solution (8) at each area, taking into account the change in contact pressure by the formula (6), due to the impact of each spike, is written in the form:

$$p = p_1 = F_3(\alpha)[\frac{p_c}{F_3(0)} + \int_0^\alpha \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } 0 < \alpha < \alpha_0 \qquad (9)$$

$$p = p_2 = F_3(\alpha)[\frac{p_{1c})}{F_3(\alpha_0)} + \int_{\alpha_0}^\alpha \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } \alpha_0 < \alpha < 2\alpha_0 \qquad (10)$$

$$p = p_3 = F_3(\alpha)[\frac{p_{2c}}{F_3(2\alpha_0)} + \int_{2\alpha_0}^\alpha \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } 2\alpha_0 < \alpha < 3\alpha_0 \qquad (11)$$

$$p = p_4 = F_3(\alpha)[\frac{p_{3c}}{F_3(3\alpha_0)} + \int_{3\alpha_0}^\alpha \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } 3\alpha_0 < \alpha < 4\alpha_0 \qquad (12)$$

Similarly for the second section we have

$$p = p_5 = F_3(\alpha)[\frac{p_{4c}}{F_3(0)} + \int_0^\alpha \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } 0 < \alpha < \alpha_0 \qquad (13)$$

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$$p = p_6 = F_3(\alpha)[\frac{p_{5c}}{F_3(\alpha_0)} + \int_{\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } \alpha_0 < \alpha < 2\alpha_0 \quad (14)$$

$$p = p_7 = F_3(\alpha)[\frac{p_{6c}}{F_3(2\alpha_0)} + \int_{2\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } 2\alpha_0 < \alpha < 3\alpha_0 \quad (15)$$

$$p = p_8 = F_3(\alpha)[\frac{p_{7c}}{F_3(3\alpha_0)} + \int_{3\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)} d\alpha] \text{ with } 3\alpha_0 < \alpha < 4\alpha_0 \quad (16)$$

where

$$p_{1c} = p_1(\alpha_0) - [\frac{\rho_1(\alpha_0)}{v_c} - 1]/A \quad , \quad p_{2c} = p_2(2\alpha_0) - [\frac{\rho_2(2\alpha_0)}{v_c} - 1]/A \quad ,$$

$$p_{3c} = p_3(3\alpha_0) - [\frac{\rho_3(3\alpha_0)}{v_c} - 1]/A \quad , \quad p_{4c} = p_4(4\alpha_0) - [\frac{\rho_4(4\alpha_0)}{v_c} - 1]/A \quad ,$$

$$p_{5c} = p_5(\alpha_0) - [\frac{\rho_5(\alpha_0)}{v_c} - 1]/A \quad , \quad p_{6c} = p_{26}(2\alpha_0) - [\frac{\rho_6(2\alpha_0)}{v_c} - 1]/A \quad ,$$

$$p_{7c} = p_7(3\alpha_0) - [\frac{\rho_7(3\alpha_0)}{v_c} - 1]/A$$

For the calculation, the reduced coefficient of friction between the mesh and raw cotton is used according to the formula $f = f_0(1-n)$, where $n = S/S_0$, S - mesh area occupied by open sections, S_0 - total mesh area.

We consider the process of separating weed impurities from the composition of raw cotton when moving it over a mesh surface. Following the work [6], we present the relationship between the mass m of raw cotton entering the cleaning zone and its density ρ in the form:

$$\frac{dm}{m} = \lambda \frac{d\rho}{\rho}$$

where $\lambda = 1/(1+a)$, $a > 0$ - coefficient of proportionality.

Integrating the last equation satisfying the conditions $m = m_9$ (m_0 - the mass of raw cotton entering the zone between the first and second spikes of the raw cotton cleaning zone per unit of time) , $\rho = \rho_c$ with $\alpha = 0$ for the cleaning zone between the first and second spikes, we get

$$\frac{m_1}{m_0} = \left(\frac{\rho_1}{\rho_c}\right)^{\lambda}$$

Given the dependence (3), we have

$$\frac{m_1}{m_0} = [1 + A(p_1 - p_c]^{\lambda} \text{ with } 0 < \alpha < \alpha_0$$

The mass of the selected impurities related to the mass m_0, between the first and second, second and third, third and fourth spikes and after the impact of the fourth one is determined by the formula

$$\varepsilon_1 = \frac{m_0 - m_1}{m_0} = 1 - [1 + A(p_1 - p_{0c}]^{\lambda} \text{ with } 0 < \alpha < \alpha_0$$

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$$\varepsilon_2 = \varepsilon_1(\alpha_0)\left(\frac{\rho_2}{\rho_c}\right)^{\lambda} = \varepsilon_1(\alpha_0)[1 + A(p_2 - p_{1c})]^{\lambda} \text{ with } \alpha_0 < \alpha < 2\alpha_0$$

$$\varepsilon_3 = \varepsilon_2(2\alpha_0)[1 + A(p_3 - p_{2c}]^{\lambda} \text{ with } 2\alpha_0 < \alpha < 3\alpha_0,$$

$$\varepsilon_4 = \varepsilon_3(3\alpha_0)[1 + A(p_4 - p_{3c}]^{\lambda} \text{ with } 3\alpha_0 < \alpha < 4\alpha_0$$

Similarly, for the second cleaning zone, we have

$$\varepsilon_5 = \varepsilon_4(4\alpha_0)[1 + A(p_5 - p_{4c}]^{\lambda} \text{ with } 0 < \alpha < \alpha_0,$$

$$\varepsilon_6 = \varepsilon_5(\alpha_0)[1 + A(p_6 - p_{5c}]^{\lambda} \text{ with } \alpha_0 < \alpha < 2\alpha_0$$

$$\varepsilon_7 = \varepsilon_6(2\alpha_0)[1 + A(p_7 - p_{6c}]^{\lambda} \text{ with } 2\alpha_0 < \alpha < 3\alpha_0,$$

$$\varepsilon_8 = \varepsilon_7(3\alpha_0)[1 + A(p_8 - p_{7c}]^{\lambda} \text{ with } 3\alpha_0 < \alpha < 4\alpha_0,$$

where the pressure p_i $(i = 1,2,3..8)$ is determined using formulas (9)-(16). The total mass of weed impurities (referred to the total mass of raw cotton on the mesh surface) of the two cleaning zones is presented as a sum

$$M = \sum_{i=1}^{4} \int_{(i-1)\alpha_0}^{i\alpha_0} \varepsilon_i d\alpha + \sum_{i=1}^{4} \int_{(i-1)\alpha_0}^{i\alpha_0} \varepsilon_{4+i} d\alpha .$$

IV. ANALYSIS OF THE RESULTS

Figures 2-4 show the graphs of the distribution of density, velocity and mass of emitted impurities (referred to the uncleaned mass of raw cotton) in the arc of contact of raw cotton with the mesh surface of the first cleaning zone at two values of the productivity of the cleaning machine. In the calculations the following numbers are taken: R=0.2m, ω=50s−1 vc=3.8m/sec; $h = 0.018$м; L=1.7 m, $\alpha_0 = 45^0$, $k_0 = 0.8$, $S_0 = k_0 hL = 0.02448$ м^2, $f = 0.1$, ρ0=40kg/m^3, p0=2500Pa, A=7·10−41/Pa. From the analysis of the graphs, it follows that as a result of the impact of spikes, the density and speed in sections of the flow layer at the places of impact change abruptly, while the density at the transitions to the sections between the spikes practically does not change, and the speed increases significantly, it is noticeable when the machine productivity is high (fig.3).

Q_0=8 ton/hour Q_0=10 ton/hour

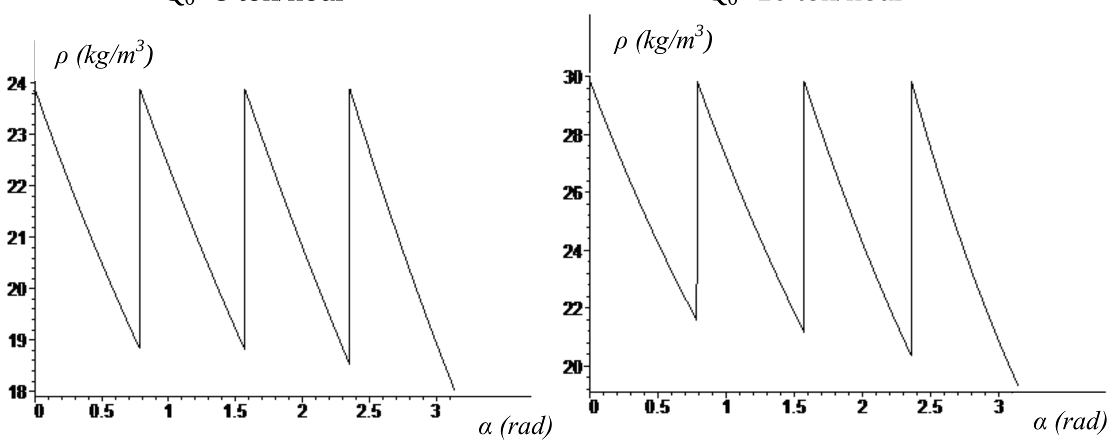

Fig.2 Density distribution ρ(kg/m^3) of raw cotton in the area of the first cleaning section for two productivity values Q_0.

Q_0=8 ton/hour Q_0=10 ton/hour

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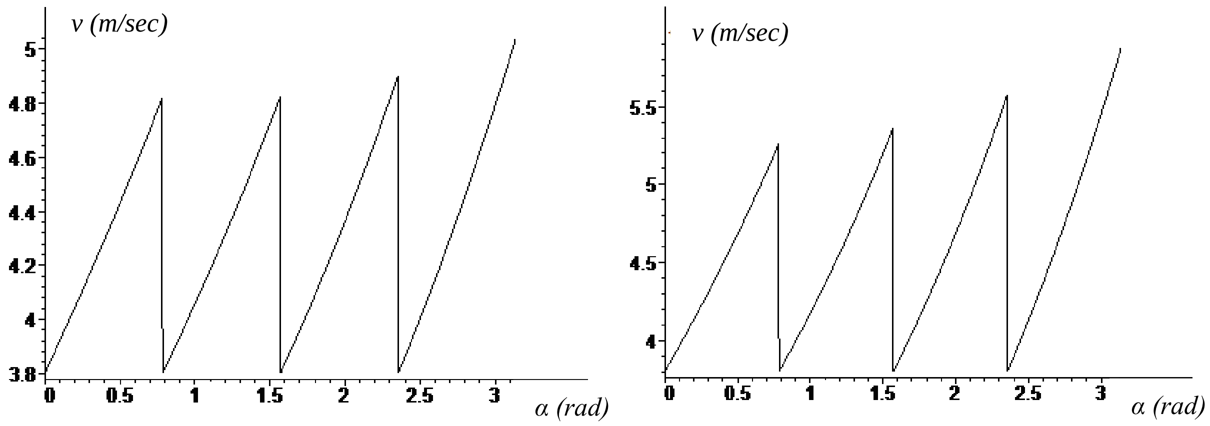

Fig 3 Raw cotton flow rate distribution v(м/с) in the area of the first cleaning section for two productivity values Q_0.

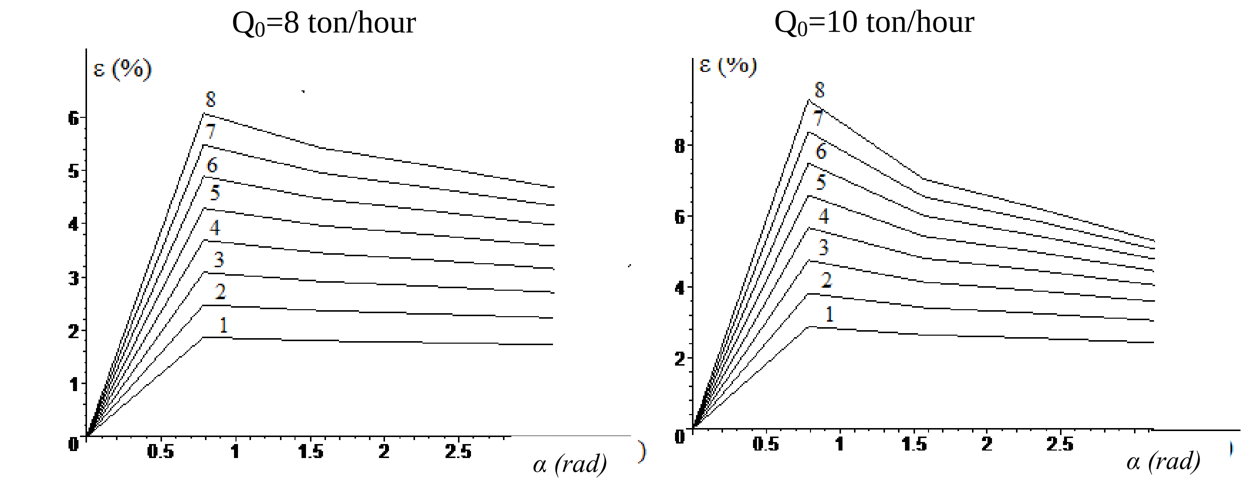

Fig.4. Distribution of emitted weed impurities (related to the mass of uncleaned raw cotton) ε (in percent) in the first cleaning section with two productivity values Q_0 and different parameter values $\lambda : 1-\lambda = 0.06$, $2-\lambda = 0.08, 3-\lambda = 0.1, 4-\lambda = 0.12, 5-\lambda = 0.14, 6-\lambda = 0.16, 7-\lambda = 0.18, 8-\lambda = 0.2$

The table shows the amounts of emitted weed impurities in the areas between the spikes and their total mass (related to the mass of uncleaned raw cotton). The calculations were performed for different values of the parameter λ and two performance values Q_0. From the analysis of tabular data it follows that the total mass of emitted impurities can increase significantly with large values of the parameter λ. In this case, an intensive selection of weed impurities occurs in the areas between the first and second grate.

Values of the mass of emitted weed impurities between the spikes and their total mass (referred to the mass of uncleaned raw cotton,%) in the first section of the cleaning zone when Q_0=20/9 kg/hour and various parameter values λ.

Table 1.

λ	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.2	0.24
$0 < \alpha \le \alpha_0$	0.731	0.972	1.211	1.448	1.685	1.920	2.153	2.385	2.615	2.844
$\alpha_0 < \alpha \le 2\alpha_0$	1.438	1.901	2.356	2.803	3.242	3.674	4.098	4.515	4.925	5.328
$2\alpha_0 < \alpha \le 3\alpha_0$	1.400	1.833	2.251	2.653	3.041	3.415	3.775	4.120	4.453	4.772
$3\alpha_0 < \alpha \le 4\alpha_0$	1.369	1.780	2.169	2.239	2.888	3.219	3.532	3.828	4.107	4.369
$M_k = \sum_{i=1}^{4} M_{ik} (\%)$ $k = 1,2,3\ldots10$	4.937	6.485	7.987	9.444	11.29	12.23	13.56	14.85	16.10	17.31

V. CONCLUSION

It is proposed to use the Euler equations to describe the motion of a stationary flow in cleaning zones, which allows to determine the laws of pressure, density and velocity distribution along the arc of contact of a moving raw cotton layer with a mesh surface in the process of impacting with spikes along the fiber mass. It has been established that the pressure, densities and flow rates along the cleaning arc as a result of shocks of spikes change intermittently, with a decrease in pressure and density and an increase in the flow velocity along this arc. This indicates the process of significant loosening of the flow when moving from the cleaning section to the second one and there is a slight change in their values in other cleaning sections. It is proposed to use the model of A.G.Sevostyanov to describe the process of cleaning raw cotton from weed impurities Equations have been compiled for determining the amount of isolated impurities both in the areas between the jars and between the sections of the cleaning zones. It has been established that the greatest amount of impurities is released in the areas between the first and third spikes, then there is a slight drop in the areas between the next spikes. This fact should be taken into account when choosing the length of the zones of contact of the raw material with a mesh surface.

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Based on the results of the analysis of the research carried out to improve the process of cleaning raw cotton from small weed impurities, we can draw the following conclusions:

1. It is necessary to develop theoretical and practical research to increase the useful area of the mesh surface to 180° and more by creating an optimal composition of the sections for cleaning raw cotton from small impurities.
2. In order to eliminate the dangerous zones and transitions between the spike drums, it is necessary to develop a model of the unstressed movement of raw cotton when cleaning it from fine litter by switching to a vertical scheme for cleaning cotton from fine litter and arranging the module for cleaning from large litter.

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