Development of new efficient technology for extraction of fine dust impurities from cotton

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Abstract. To date, the problem of creating an effective technology for the extraction of fine dust pollution from cotton has not been solved. This article provides a solution to this problem. The socio-economic significance of the study lies in the fact that the proposed device is associated with significant savings in energy costs for cleaning cotton from dust. After the contaminated cotton enters the threshing floor, under great pressure, fine trash settles firmly inside the cotton. It makes it very difficult to process and clean it in cotton factories. Therefore, the cleaning process of cotton has to be repeated several times. The cost of energy consumed during cleaning increases significantly and the cotton fiber quality is reduced. The device proposed in the article cleans the collected cotton from impurities during machine harvesting. The process of cleaning cotton at this stage is very effective. As a result, the cost of harvested cotton is reduced, which increases the income of cotton farmers and workers employed in cotton factories. In addition, it causes an increase in the quality of textile products. Another socio-economic significance of the device proposed in the article is that it can be installed on a cotton harvester and in other places. In addition, it can be used not only to clean cotton but also to clean other substances from fine dust. As a result of practical research, technology has been developed to extract small contaminants from cotton.

1 Introduction

Today, raw cotton cultivation and processing are among the most important industries. The growing demand for the quality of cotton fiber requires special attention to the re-equipment of factories with new equipment and technologies, which is one of the most pressing problems facing the textile industry, aimed at increasing its competitiveness in the global cotton fiber market, producing modern, technologically reliable, and high-quality products. Particular attention is paid to creating and implementing new technologies with high efficiency in the global ginning industry, improving product quality, and creating

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resource-saving technologies. Based on world experience, research is being conducted to improve the technique and technology of cleaning cotton seeds from fine impurities. In this regard, one of the important tasks is the development of effective technologies and devices for cleaning cottonseeds from fine contaminants, achieving high cleaning efficiency of cottonseeds, and alternating operating modes and parameters. During the years of independence, comprehensive measures have been taken in the country to improve the consumer properties of cotton products and create highly efficient systems for managing the technological processes of primary processing of raw cotton and production. In this regard, significant results are achieved, particularly in producing high-quality cotton products from processed raw materials, depending on the initial characteristics of production, the improvement of equipment, and technology for cleaning cotton from fine impurities [1-4].

President of the Republic of Uzbekistan, Sh.M. Mirziyoyev, signed a decree dated October 17, 2017, UP-3408 "Measures to radically improve the management system in the cotton industry", regarding the cultivation and processing of cottonseeds. It was an important decision to work in a cluster type for the cultivation and processing of raw cotton and to radically modernize the activities of cotton ginning and processing enterprises. The fulfillment of these tasks, including the creation of new technologies for the primary processing of cottonseeds, and the improvement of equipment and technology for the removal of fine contaminants, is one of the important problems in the cotton industry [5-7].

It is known that dust and other impurities (shredded cotton leaves, cotton stalks) and harvested cotton are sucked in by a fan and sent to the hopper by pneumatic transport. Fine dust particles mixed with cotton can contaminate the cotton stored on the threshing floor. In addition, due to the high pressure in the thresher, the force of impurities entering the cotton increases several times. As a result, it takes a lot of energy to clean such cotton in ginneries. Therefore, it is advisable to clean the cotton from fine dust particles during collection.

A device for cleaning cotton from impurities is developed in this article; it is installed on a cotton harvester between the fan and the hopper. Cotton harvesters used in our Republic are shown in Fig. 1.

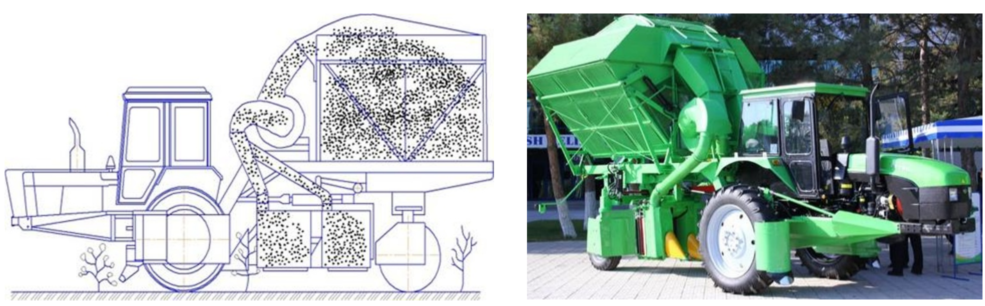

Fig. 1. Cotton harvesters used in our Republic

The technological significance of the article lies in the fact that, for the first time, a device that cleans cotton from impurities at the harvesting stage was studied and developed. This device does not require excessive energy consumption when cleaning cotton from impurities since it is located between the fan and the hopper, and the separation of cotton from impurities is carried out due to the kinetic energy of the cotton fibers obtained in the fan. That is, the process of cleaning from impurities is based on the impact of cotton on the wall and aerodynamic impact. When harvested cotton and impurities move together in a pneumatic conveyor, the bond between them is not strong. Therefore, cleaning harvested cotton from dust during this process can be expected to be very efficient. Another great advantage of the proposed device is that this device allows the cleaning of the cotton. This will prevent the cotton from rotting on the threshing floor or spoiling its quality. In addition, the device proposed in the project aims to save energy costs in the cleaning process carried out in cotton factories. The device is structurally simple and does not require large expenditures. Schematic views of the device are shown in Fig. 2.

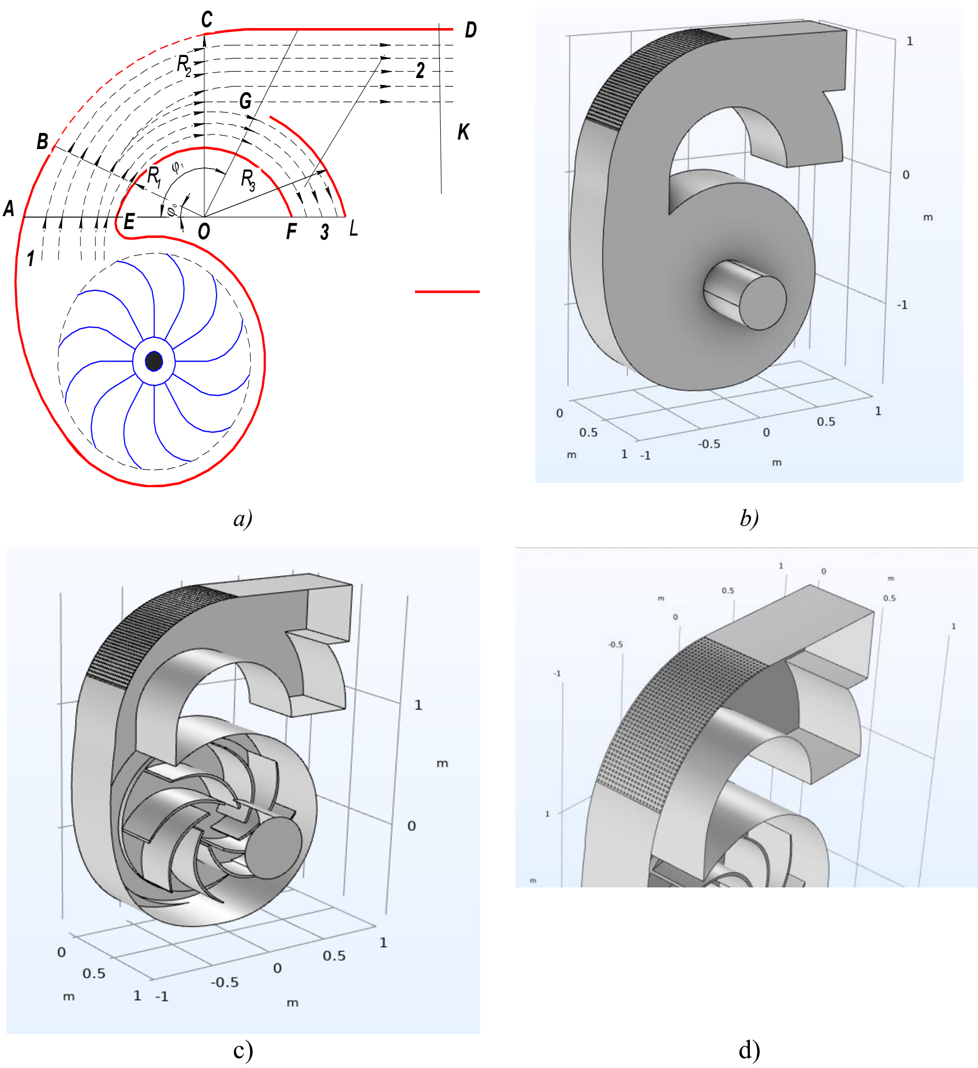

Fig. 2. Schematic view a), outside view b), inside view c), view of grates d)

2 Physical and mathematical statement of the problem

The principle of operation of the device developed by the authors is as follows: a fan sucks in air. Cotton and dust enter the device through channel 1 (A-E) and hit the grate between cotton and dust (B-C) under the action of centrifugal force, and fine dust leaves the grate; through channel 3 (F-L), heavy particles leave the device under the action of gravity; through channel 2 (D-K), the dust-free cotton enters the hopper (Fig. 1a).

For a numerical study of the problem posed, a system of Reynolds-averaged Navier-Stokes equations is used, considering the interaction between the phases [8].

$$\begin{cases} \rho \dfrac{\partial \bar{U}_i}{\partial t} + \rho \bar{U}_j \dfrac{\partial \bar{U}_i}{\partial x_j} + \dfrac{\partial \bar{p}}{\partial x_j} = \mu \dfrac{\partial^2 \bar{U}_i}{\partial x_j \partial x_j} + \dfrac{\partial}{\partial x_j}\left(-\rho \overline{v_i' u_j'}\right) - \sum\limits_{k=1}^{N} \dfrac{\rho_k}{\rho} k_k \left(\bar{U}_i - \left(\bar{U}_{pk}\right)_i\right); \\ \dfrac{\partial \left(\bar{U}_{pk}\right)_i}{\partial t} + \bar{U}_j \dfrac{\partial \left(\bar{U}_{pk}\right)_i}{\partial x_j} = k_k \left(\bar{U}_i - \left(\bar{U}_{pk}\right)_i\right), \\ \dfrac{\partial \rho_k}{\partial t} + \bar{U}_j \dfrac{\partial \rho_k}{\partial x_j} = \dfrac{\partial}{\partial x_j}\left(\dfrac{\partial \rho_k}{\partial x_j}\right), \\ \dfrac{\partial \bar{U}_i}{\partial x_j} = 0. \end{cases} \tag{1}$$

here $\bar{U}_i$ is the air flow velocities; $\left(\bar{U}_{pk}\right)_i$ is similar velocity components for the k-th dust fraction; $\bar{p}$ is the hydrostatic pressure; ρ is the density of the gas; μ is its molecular viscosity; $\overline{v_i' u_j'}$ is the components of the Reynolds stress tensor; ρ_k is the mass density of dust; k_k is the coefficient of interaction between air and k-th fraction of dust; N is the number of dust fractions.

The interaction coefficient between the phases is determined through the Stokes parameter for laminar flow [9]:

$$k_i = \frac{18 \rho v}{\rho_\rho \delta_i^2},$$

where ρ_ρ is the density of the material of dust particles, δ_i is the "effective" particle diameter. The initial and boundary conditions for the system of equations (1) are set in the standard way [10]. The fan blades rotate 20 times per second, which gives an inlet velocity of 22 m/s.

In this study, to determine the turbulent viscosity, we used the SST turbulence models included in the COMSOL Multiphysics software package [11].

SST model. The Menter shear stress transport (SST) model is written as a superposition of the k-ε [12], and k-ω models, based on the fact that k-ε type models better describe the properties of free shear flows, and k-ω models are superior in modeling near-wall flows. A smooth transition from the k-ω model in the near-wall region to the k-ε model far from solid walls is ensured by introducing the empirical weight function F1.

$$\begin{cases} \dfrac{dk}{dt} = \nabla\left[(\mu + \sigma_k \mu_t)\nabla k\right] + P f_{rot} - \beta^* \omega k, \\ \dfrac{d\omega}{dt} = \nabla\left[(\mu + \sigma_\omega \mu_t)\nabla \omega\right] + \dfrac{\gamma}{v_t} P f_{rot} - \beta \omega^2 + 2(1 - F_1)\dfrac{\sigma_{\omega 2}}{\omega}\nabla \omega \nabla k. \end{cases} \tag{2}$$

Turbulent eddy viscosity is calculated from $v_t = \dfrac{ak}{\max(a\omega, Sf)}$.

3 Solution method

In this study, for the difference approximation of initial equations (1–2), the SIMPLE control volume method [13-16] was applied. The integration was conducted with time step Δt<0.001. The simulation started from time t=0 s and was simulated up to t=500 s using a fixed Courant number 1 [17–20].

3.1 Computation grid

1152239 points were used in the computations; the grid was condensed near the wall (Fig. 3).

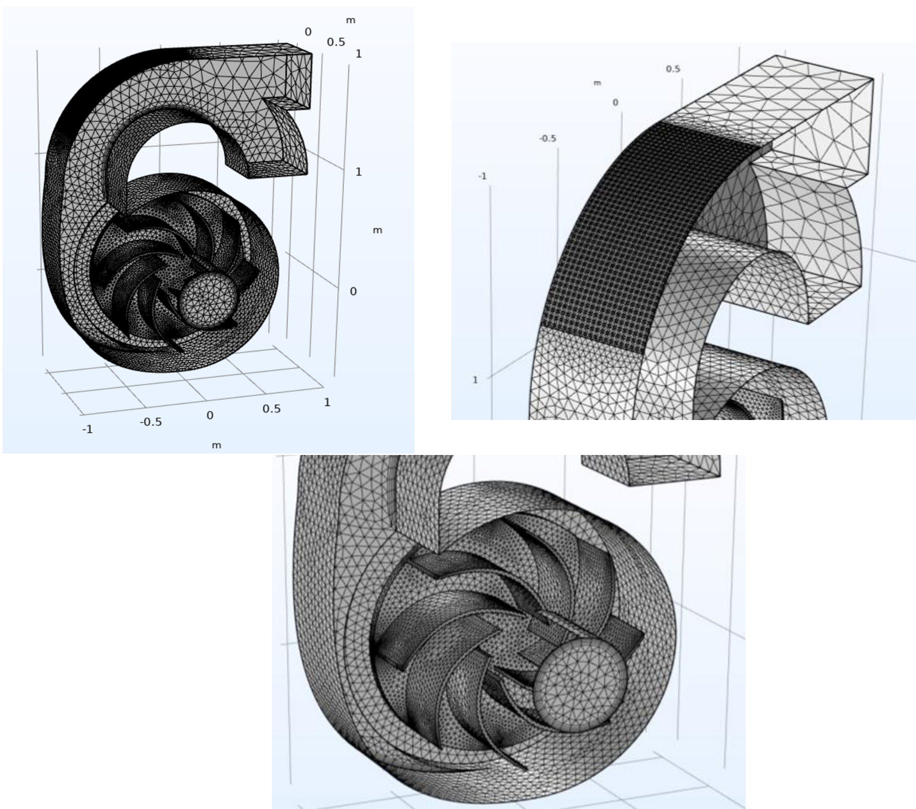

Fig. 3. Calculation grid.

4 Calculation results and their discussion

Figure 4 shows isolines of velocity, pressure, kinetic energy, and flow dissipation. Figure 4 also shows the flow velocity vectors.

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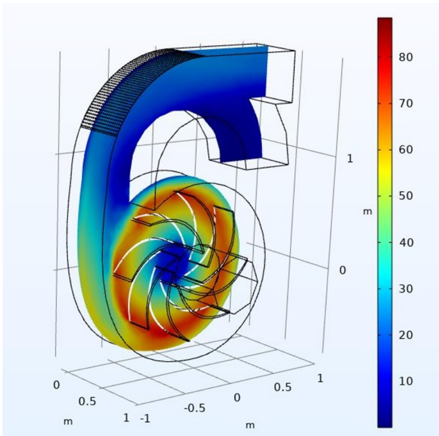
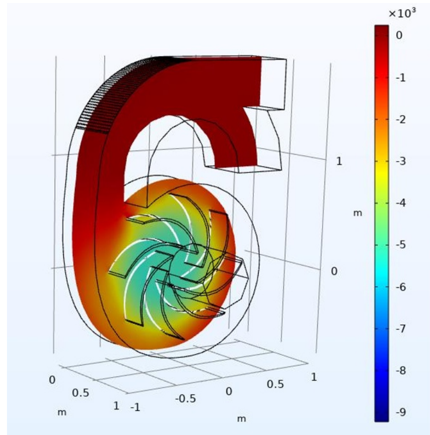


a)



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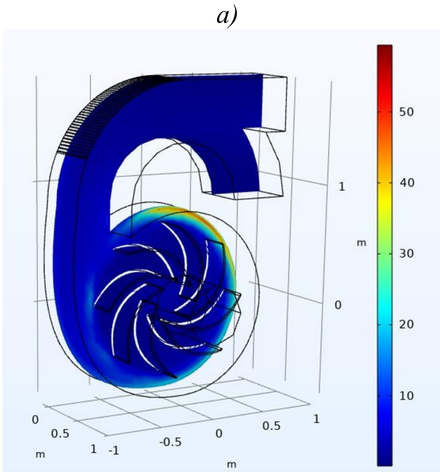
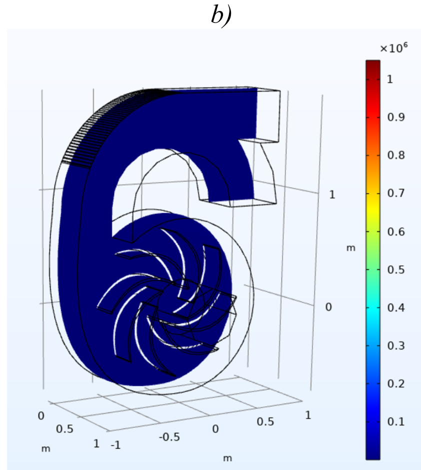
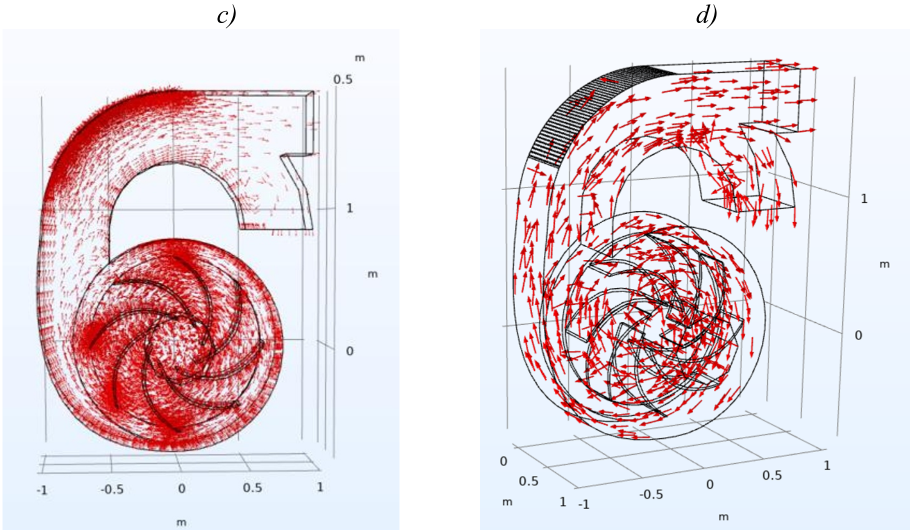


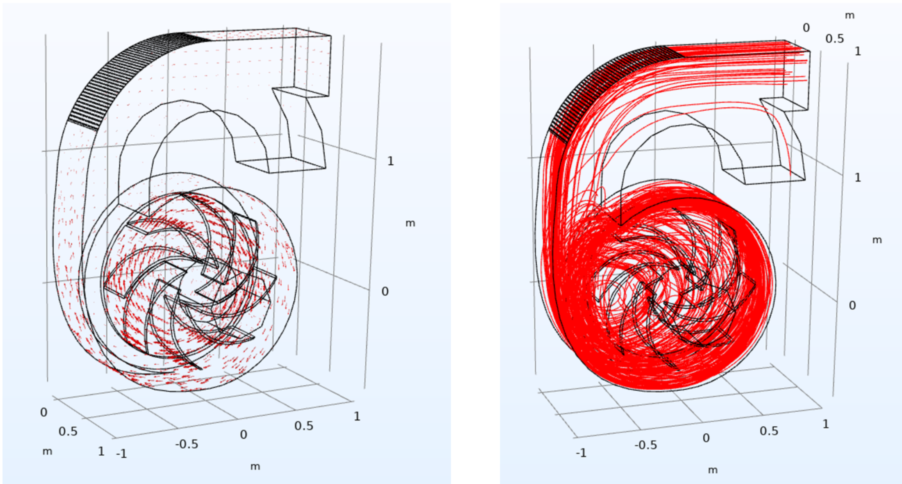
c)



d)



e)



f)

Fig. 4. Velocity isolines a) m/s, pressures b) Pa, kinetic energy c) m^2/s^2, flow dissipation d) m^2/s^3, flow velocity vectors e) and flow isocontours f).

As seen from Figure 4, the fan velocity of rotation can be increased up to 82 m/s. This directs the dust particles toward the device.

Figure 5 shows the trajectory of dust particles of different sizes and over time.

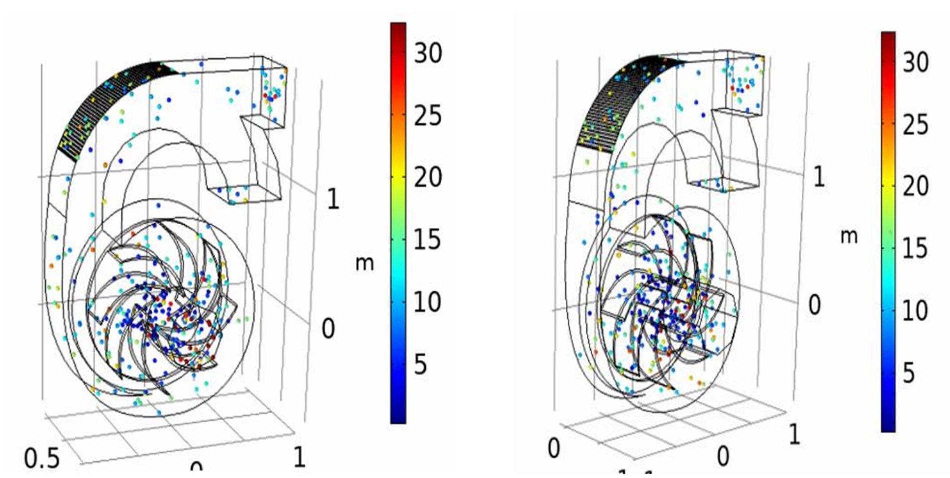


Fig. 5. Trajectory of dust particles of different sizes and over time

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Figure 6 shows the percentage of dust particles.

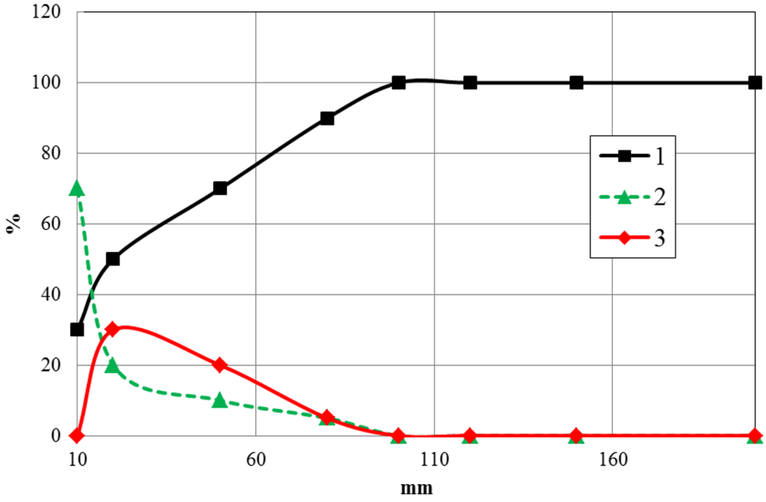

Fig. 6. Percentage of dust particles

Line 1 in Figure 6 shows particles entering and leaving the grate (B-S). Line 2 (D-K) shows the particles leaving the hopper. Line 3 (F-L) depicts dust particles escaping through the channel. As seen from the figure above, 80% of cotton fibers are cleaned of dust.

5 Conclusions

The prospects for commercialization of the device considered in the article are quite wide since this device can be applied to all cotton harvesters manufactured at the factories of the Republic. Implementation of this device will improve the quality of the cotton harvesters being developed and make them more affordable. This, in turn, will increase the rating of cotton harvesters produced in the Republic in the world market and increase the import potential. In addition, the proposed device can be offered to cotton spinning enterprises as additional cotton ginning equipment and can be used in other production areas. Hydrodynamic equations were derived to calculate the optimal parameters of the device, and the results were obtained.

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