Improvement of the design of the unit for cleaning the air stream from dust at a cotton ginnery

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Abstract. The article covers research on the design of a dust-cleaning unit using a cyclone and additional water that cleans the air from cotton factories with high efficiency. The history of cyclones for dust air cleaning from cotton ginneries has been studied and deeply analyzed. The composition of the dusty air stream coming out of the cotton ginneries has been studied, and a new improved unit to the cyclone separator according to the dusty air composition has been designed. A new unit design has been developed and positive results has been obtained by simulation using the most modern programs.

1 Introduction

Cyclone separators are widely used in all existing ginneries of our republic to clean the dust particles coming out of various machines during the initial cotton processing. Cyclone separators (hereinafter "cyclones") were developed at the turn of the 19th century. Although these cyclone separators are obsolete, they are considered the most popular cleaners today and have very few analogues. In fact, cyclones in ginneries are copies of cyclones designed to separate solids from process gas flows, i.e., cyclones invented to separate solid particles from air [1].

During the initial cotton processing, a significant amount of dust is released into the atmosphere from machines and technological processes. Dusting pollutes the buildings and the factory area, creating unfavorable conditions for the work of people and equipment. The norm of dust in the air in the production buildings of the ginneries is 10 mg/m^3, and the amount of waste air released into the atmosphere is 150 mg/m^3. In order to create normal sanitary-hygienic conditions, production facilities and separate dust emitting devices are cleaned of dust. Before releasing the air to the atmosphere, it is iteratively cleaned of dust [2].

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2 Theoretical research

The dust from the ginneries is transported by the air stream, which contains short fibers, small mineral and organic waste, and is sucked together with the air by a fan and delivered to the dust collectors, i.e. the cyclone, for cleaning the dusty air (Figure 1) [3].

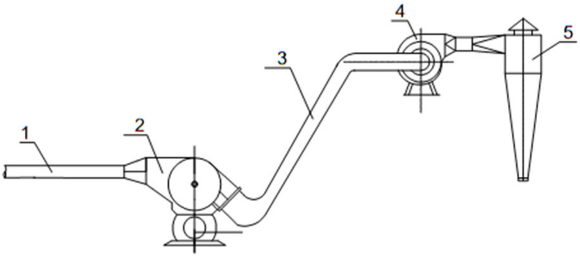


Fig. 1. Scheme of the technological process of the dust cleaning system. 1,3 – pneumatic transport pipeline; 2 – separator; 4 – fan; 5 – dust holding cyclone.

At present, SS-15A and SX separators are widely used in ginneries to deliver cotton raw materials from the gin or from one machine to another machine [4].

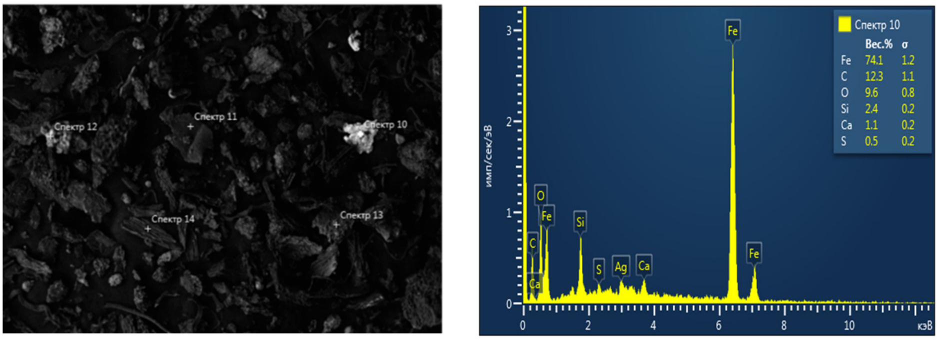
Unfortunately, the mineral, organic wastes, seed husk, and short fiber debris in the seeded cotton or fiber entering the SS-15A or SX separators passes through the mesh surface and collects in the dust traps.

In order to control this, first, it is necessary to find out the amount of waste coming out of the pneumatic transport system and aspiration system installed in the shops of ginneries.

At the beginning of the technological process of cotton transportation, drying and cleaning in pneumatic machines, up to 80% of fine mineral dust and 20% of large organic dust are separated. Large dispersed dust larger than 50 micron can make up 70% of the total mass. In the process of ginning and lintering, the share of dust mineral fractions decreases, and dust organic particles increase up to 80-90%. In this case, the size of dust particles is smaller than 50 microns. The dust level of used air in the system of technological equipment varies from 800 to 2000 mg/m^3. High level of dustiness is 3000-4000 mg/m^3. All of the above results were obtained using the most modern SEM EVO MA (10) Zeiss scanning electron microscope with an X-ray detector (Oxford Instrument Nano Analysis) available in our country [5].

Fig. 2. SEM EVO MA (10) Zeiss scanning electron microscope. 1 – test bench with automatic high/low vacuum system and electronic control systems; 2 – chambers for samples; 3 – electron-optical system (handle); 4 –x-act energy dispersive X-ray spectrometer (Oxford Instrument NanoAnalysys); 5 – secondary electronic detector (SE), 6 – monitor (3 pcs), 7 – keyboard and joystick; control computers (3 pcs); 8 – electronic blocks of the X-ray spectrometer; 9 – processors (3 pcs).

Fig. 3 and graph 1 below show the elemental analysis of the elements in the dust. Spectra from different points of the dust particle were determined (10 spectrum analysis was given) and it has been determined what mineral substances are contained in the particle. In the Figure, the number of particles in relation to the weight of the dust determined at the 10th spectral point, i.e. C(carbon), O(oxygen), Si(silicon), S(sulfur), Ag(silver), Ca(calcium), Fe(iron) correlation graph is given, and Table 1 shows the full details of the scanning microscope results.



a b

Fig. 3. Elemental analysis of the dust particle at the 10th spectral point. a – the 10th spectral point; b – graph of the 10th spectral point dependence on the spectral composition per unit volume of the particle.

Table 1 shows data on the 10th spectral point of the dust results determined by the scanning microscope according to Figure 3.

Table 1. shows the types of elements found in the dust under a scanning microscope

Element	**Lines type**	**Conditional concentration**	**Ratio, k**	**Weight, %**	**Sigma weight, %**	**Standard name**	**Preset referenc**	**Target calibration date**
C	K series	0.16	0.00161	12.34	1.06	C Vit	Yes	
O	K series	0.56	0.00189	9.55	0.78	SiO_2	Yes	
Si	K series	0.11	0.00087	2.40	0.23	SiO_2	Yes	
S	K series	0.03	0.00023	0.50	0.16	FeS_2	Yes	
Ca	K series	0.07	0.00060	1.09	0.23	Wollastonite	Yes	
Fe	K series	3.77	0.03767	74.12	1.19	Fe	Yes	
Sum:				100.00				

Considering the obtained analysis, first, we need to mention the shortcomings of dust collectors in order to catch the fibrous waste coming out of the technological processes of ginneries with dusty air and to clean the concentration of dust coming into the atmosphere at a moderate level. Because the consumption of electricity in dust collectors is very high, the reduction of cylindrical type dust collectors and creation of efficient design of cyclones is the urgent problem of today.

Cyclones are mainly separators working based on centrifugal force, that is, a device that separates dust minerals from air (Figure 4). They simply convert the inertial force of the dust particle into centrifugal force through the vortex created in the cyclone body. Air containing particles enters tangentially from the top and rotates in the inner body of the cyclone, forming a vortex. Particles hit the walls with centrifugal forces, lose momentum and fall to the cyclone support. In the lower part, the air begins to flow inwards towards the axis, and the air turns upwards towards the exit channel.

$$F = \frac{\rho_p d_p^3 v_{\tau p}^3}{r} \tag{1}$$

where; ρ_p is particle density, (kg/m^3); d_p is particle diameter (mcm); $v_{\tau p}$ is tangential speed of the particle (m/s); r is the radius of the circular path (m) [6].

Fig. 4. The general view of the TS-6 cyclone separator in operation at ginnery.

It can be seen that the cyclone separators shown in Figure 4 are available in all ginneries of our republic. In order to reduce stated shortcomings, we have designed an effective dusty air-cleaning device in the pre-cyclone process that cleans the dusty air coming out of the ginneries (Figure 5).

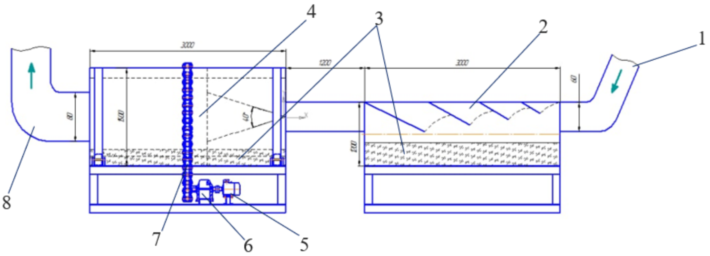


Fig. 5. Design scheme of the proposed dust air cleaning device in the pre-cyclone process. 1 – dusty air intake pipe; 2 – dusty air flow changing screens; 3 – water; 4 – rotating water drum; 5 – engine; 6 – reducer; 7 – chain drive; 8 – supply pipe of partially purified dust air to the cyclone.

We know that physical-chemical processes are always taking place in the apparatus. In the structure shown in Figure 5, a physical process also occurs, where the dusty air hits the screen 2 through the pipe 1 and continues its movement through the water surface inside the rectangular prism-shaped bath, changing its direction. At first, the partially purified dust air in the prism-shaped bath passes through the tube to the drum, which is partially filled with water, at its own speed. The drum 5 is rotating with the help of a motor, and the inner walls of the drum are constantly wet. The dusty air coming through the pipe and partially cleaned is again cleaned due to its own speed hitting the inner surfaces of the drum and delivered to the existing or simulated new cyclone.

Advantage of this design is that, using the speed and temperature of the hot dust air moving in the pipe, it is initially cleaned mainly by water through two water baths, the first prismatic with a rectangular base and the second cylindrical drums, which in turn allows the dust air to be cleaned up to 35-40 percent before the cyclone (Figure 6).

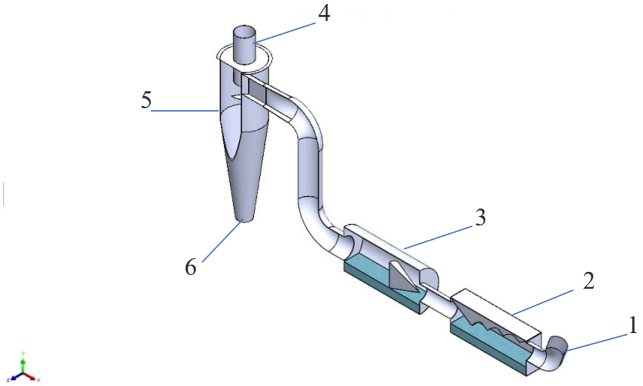


Fig. 6. Half cut 3D view of an effective additional structure to cyclones for cleaning the dust in ginneries. 1 – dusty air intake pipe; 2 – rectangular prismatic bath; 3 – rotating water drum; 4 – purified air outlet pipe; 5 – cyclone separator; 6 – bottom of the cyclone from which the waste come out.

The improved design shows that the waste accumulated in the water are periodically cleaned and replaced. The cheapest artisanal or irrigation waters can also be used in baths. We will cover the cycle of cleaning processes in our next scientific works.

As the dust from cotton pre-treatment machines and units in ginneries are delivered to cyclones through pipes, we conducted a study of dust air temperature in the pipe in January 2023 through practical research. This, in turn, results in an initial temperature of 68°F from the machines, and 35.5°÷50°F near and within the cyclone. So even when the natural air temperature is below 32°F, additional dust added to cyclones for cotton gins means that the water inside the air-cleaning unit will theoretically not freeze, meaning the structure will continue to operate.

The composition of the purified dust separated from the air is fully described above, and it is recommended to process and use the waste as well. Currently, wastes are widely used and processed for local fertilizer, greenhouses, chicken production factories, pulp and paperboard production [7].

3 Analysis of results

Numerical simulation of dusty air transported through pipes to cyclones, average speed of dust particles was analyzed through theoretical and practical research. Until now, the above cases have been studied the least. The characteristics of the flow field inside the dusty air transport pipe, the speed fluctuation can only be accurately predicted if there is a complete unsteady unit simulation. In the ducts, the fan draws in constant air, but the drawn air stream does not contain completely dusty air. The most dust is generated during cotton cleaning and fiber separation from seed [8].

Because of the research, we studied the history of cotton ginning factories in our republic and the history of the origin of the existing machine units. Cyclone separators are widely used in all existing ginneries of our republic to clean the dust particles coming out of various machines during the initial processing of cotton. These cyclones were copied by the USSR in 1932 from the cyclones created by US scientists and were widely used in the construction of cotton factories in Central Asia, and these cyclone separators are still in use today [9].

To date, modern computers and their programs are used to solve problems and provide a great help in improving machines and aggregates, creating new structures. Among them, we can point “SOLIDWORKS Flow Simulation”, “CFD”, “Ansys CFX”, RSTM programs [10].

The long period, as well as unavailability of these programs have been a major obstacle to the unsteady simulation of cyclones and dust-carrying pipelines. Nowadays, due to the increase in the performance of relatively inexpensive simple computers, it is possible to simulate cyclones and air ducts using non-stationary models. For example, the simulation results and graphics of the new unit we just created using the SOLIDWORKS Flow Simulation program on personal laptop.

Very little is known about the effect of dust speed variation modeling on cyclone and dust duct performance. The change in speed of a dust particle in a cyclone and dust air duct is usually expressed as its root mean square speed (RMS). Nevertheless, experimental studies using the most modern devices showed that the pulsation speed in the pipe carrying dust air is 35-40 m/s, and the average speed in the internal parts of cyclones is 15-20 m/s [11, 12].

The main topic of our ongoing theoretical and practical research is the improvement of the design of the airflow dust-cleaning unit in ginneries by studying and analyzing the movement of harmful compounds in the air flow.

Research in order to increase the cleaning efficiency of the cyclone and the airflow dust-cleaning unit has been conducted, that is, the main purpose of these researches are twofold. The first part is devoted to the modeling of average and variable speed. The second one consists of developing a design of a cyclone turbulence reduction and airflow dust-cleaning unit through the Stairmand program, simulating and obtaining results through the SOLIDWORKS Flow Simulation program, and analyzing the results obtained from the modeled areas of variable speed. The simulation results of the dust collection efficiency are compared with the measurements presented by Zhao [13].

In theoretical and experimental studies of the movement of dust particles, a numerical method is used, i.e. a mathematical model of Reynolds Navier–Stokes equations in the vector form [14]:

$$\frac{\partial \vec{v}}{\partial t} = -(\vec{v} \cdot \nabla)\vec{v} + v\Delta\vec{v} - \frac{1}{\rho}\nabla p + \vec{f} \tag{2}$$

The enhanced airflow in dust-cleaning unit can be considered as an unsteady, isothermal and incompressible turbulent flow.

$$u_i = U_i + u_i^{'}, \tag{3}$$

$$\frac{\partial U_i}{\partial X_i} = 0 \tag{4}$$

$$\rho\frac{\partial U_i}{\partial t} + \rho U_j\frac{\partial U_i}{\partial X_j} = -\frac{\partial U_i}{\partial X_i} + \frac{\partial}{\partial X_j}\left[2\mu S_{ij} - \overline{\rho u_i^{'} u_j^{'}}\right] \tag{5}$$

It can be expressed by Reynolds averaged mass conservation equations and Navier–Stokes equations. As shown in the (4) and (5) formulas, when the instantaneous speed u_i becomes the average value U_i and the fluctuation u_0 *i* is expressed by equation (2).

where $\tau = -\overline{\rho u_i^{'} u_j^{'}}$, x_i is position, *t* is time, *q* is constant dust density, *P* is average static pressure, *l* is dust molecular viscosity, *j* is Reynolds stress tensor, ва S_{ij} is average stress tensor.

In this study, the RSTM method was used to calculate Reynolds stress values [15, 16].

$$S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial X_j} + \frac{\partial U_j}{\partial X_i}\right) \tag{6}$$

From all six independent components of the Reynolds stress tensor derived from the Navier–Stokes equations, the Reynolds stress Model (RSTM) equation can be written as:

$$\frac{\partial \tau_{ij}}{\partial t} + U_k\frac{\partial \tau_{ij}}{\partial X_k} = -\tau_{ik}\frac{\partial U_j}{\partial X_k} - \tau_{jk}\frac{\partial U_i}{\partial X_k} + \in_{ij} - \prod_{ij} + \frac{\partial}{\partial X_k}\left[\nu\frac{\partial \tau_{ij}}{\partial X_k} + C_{ijk}\right] \tag{7}$$

The stress tensor is important for strong rotating flows in dust cyclones [17].

Turbulent transfer was modeled in a simplified form and gradient transfer was used by Lien and Leschziner. Numerical solutions of the problem are solved on a modern computers and the results are obtained. The diffusion tensor is modeled using the Kolmogorov method [18]:

$$\epsilon_{ij} = \frac{2}{3}\rho\epsilon\delta_{ij} \tag{8}$$

where a model like scalar propagation speed is obtained from the transfer equation:

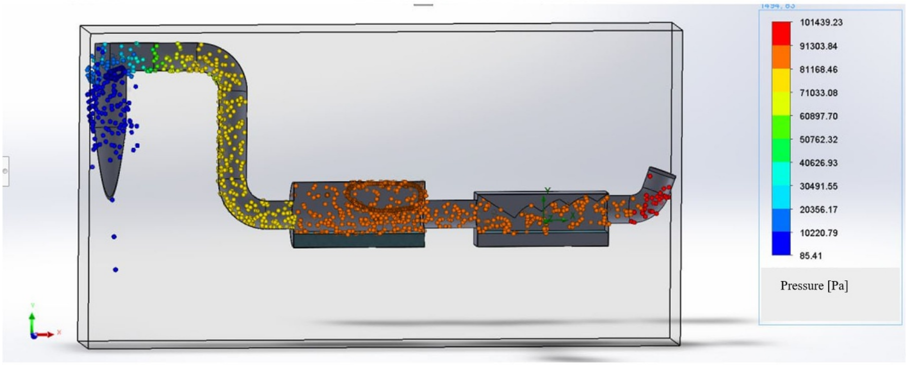
$$\rho\frac{\partial \in}{\partial t} + \rho U_j\frac{\partial \in}{\partial X_j} = C_{\epsilon 1}\frac{\epsilon}{k}\tau_{ij}\frac{\partial U_i}{\partial X_j} - C_{\in 2}\rho\frac{\epsilon^2}{k} + \frac{\partial}{\partial X_j}\left[\left(\mu + \frac{\mu_T}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial X_j}\right] \tag{9}$$

where m_T=rC_m k^2/e viscosity and, k=1/2 ¯(u_i^' u_j^') turbulent kinetic energy. However, if there is a value of turbulent kinetics k, a threshold energy is required, which is determined from the transfer equation as follows [19. 20]:

where $\mu_T = \rho C_\mu k^2/\epsilon$ is viscosity and $k = \frac{1}{2}\overline{u_i' u_j'}$ is turbulent kinetic energy. However, if there is a value of turbulent kinetics k, a boundary energy is required, which is determined from the transfer equation as follows [19, 20]:

$$\rho\frac{\partial k}{\partial t} + \rho U_j\frac{\partial k}{\partial X_j} = \tau_{ij}\frac{\partial U_i}{\partial X_j} - \rho \in + \frac{\partial}{\partial X_j}\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\frac{\partial k}{\partial X_j}\right] \tag{10}$$

The model coefficients in these equations are equal to $C_{\epsilon 1} = 1.44. C_{\epsilon 2} = 1.92. \sigma_r = 1.0.$ $C_\mu = 0.09$ and $\sigma_k = 0.82$.



Pressure contour values in (Pa) and turbulent kinetic energy change (K) values in J.

Fig. 7. The correlation of dust air and aggregate inner surface in an optimized variant of the modeled high-performance improved unit.

A large vortex unit simulation is modeled using SOLIDWORKS Flow Simulation software. The basis of unit modeling is that large obstacles are largely problem-specific, defined by boundary conditions and geometry, as can be seen in the figures above. Small scales usually have isotropic and universal properties.

In the "SOLIDWORKS Flow Simulation" model, the instantaneous speed u_i is separated into a speed filtered on a defined scale and a Subgrid Scale Speed (SGS) $u_i^{'}$ as follows:

$$u_i = \bar{u}_i + \overline{u_i'} \tag{11}$$

Speed design values in the SOLIDWORKS Flow Simulation model are obtained by spatial filtering of dusty air using the Navier–Stokes equations. The filtration process separates the dust from the air (SGS) with impurity mixed with the improved unit internal surfaces. The permissible separation of SGS is modeled using the SGS model.

Discretization of the limited dust air volume in Fluent provides filtering itself as follows [21]:

$$\overline{\phi}(x) = \int_{\mathrm{v}} \overline{\phi}(x')\, G(x,x')dx' \tag{12}$$

where x and x' are spatial coordinates, v is the size of the calculation cell and G is the filter function, which are defined as follows:

$$G(x,x') = f(x) = \begin{cases} \dfrac{1}{V}, & x' \leq V \\ 0. & in\ another\ case\ it\ will\ be\ x' = 0 \end{cases} \tag{13}$$

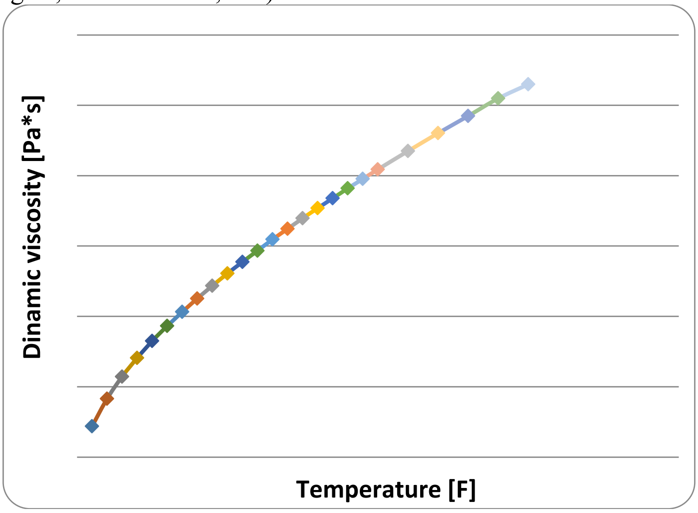
Considering the dusty air filtration process as continuous and applying it to the Navier–Stokes equations, we get the following equation [22]:

$$\frac{\partial \overline{U}_i}{\partial X_j} = 0. \tag{14}$$

$$\frac{\partial \overline{U}_i}{\partial t} + \frac{\partial}{\partial X_j}\left(\overline{U}_i \overline{U}_j\right) = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial X_i} + \frac{\partial}{\partial X_j}\left(2v\overline{S}_{ij} + T_{ij}\right) \tag{15}$$

where p is the permissible static pressure, $\overline{S}_{ij} = \frac{1}{2}\left(\frac{\partial \overline{U}_i}{\partial X_j} + \frac{\partial \overline{U}_j}{\partial X_i}\right)$ is the stress level tensor acting on the inner surface of the determined cyclone (three selected object with dimensions x, y, z), v is the kinematic air viscosity and $T_{ij} = \overline{u}_i\overline{u}_j - \overline{u_i u_j}$ s the SGS tensor, which can also be seen in the graph below (Figure 8).

The SGS model is used to represent the impact of unresolved issues (such as minor additions, mergers, modifications, etc.).



Values of changes of viscosity (Pa*s) and air temperature (F)

Fig. 8. Dynamic viscosity graph of dust air temperature inside the simulated improved unit**.**

From the graph in Figure 8, where the front lines are presented, it can be seen that as the air temperature increases, the dynamic viscosity increases as well. Therefore s, based on the theoretical results, we have witnessed that the proposed new improved dust cleaning unit technology has very high advantages. Firstly, the efficiency of dusty air cleaning has increased from 55-65% to 85-95%, and secondly, the concentration of dust released into the atmosphere has decreased from 250 mg/m^3 to 92 mg/m^3, i.e. 2.7 times less.

4 Conclusion

The history of dusty air cleaning cyclones of the ginneries has been deeply studied and analyzed.

The composition of the dusty airflow coming out of ginneries has been studied and analyzed.

Depending on the composition of dusty air, a new unit has been designed, which was improved up to the cyclone separator.

In order to improve the cleaning efficiency of the cyclone and the airflow dust-cleaning unit, the research plan has been drawn up. The second one was to develop the structure of the cyclone turbulence reduction and airflow dust-cleaning unit using the Stairmand program, to simulate and obtain the results using the SOLIDWORKS Flow Simulation program, and to analyze the results obtained from the modeled areas of variable speed.

Large vortex unit simulation has been modeled by SOLIDWORKS Flow Simulation software.

Speed design values in the SOLIDWORKS Flow Simulation model have been obtained by spatial filtering of dusty air using the Navier–Stokes equations.

The simulation results show that SOLIDWORKS Flow Simulation achieved positive results in the simulation of both the average dusty airflow area and the variable dusty airflow area, and it has been proved that it is possible to improve the efficiency of dusty air cleaning. Accurate simulation of speed pulsations is a key requirement to improve cyclone cleaning performance, especially for small particulates from air.

References

1. O. Murodov, A. Sh. Adilova, *Analysis of the composition of the dusty waste produced during cotton processing* (Tashkent Institute of Textile and Light Industry, 2022).
2. O. J. Murodov, A. S. Adilova, In IOP Conference Series: Earth and Environmental Science **1112(1)** 012150 (2022). https://doi.org/10.1088/1755-1315/1112/1/012150
3. M. T. Khojiev, I. Z. Abbazov, S. Sangirov, Comparative analysis of the work of dust collectors in ginneries *Actual problems of innovative technologies in the context of integration of science, education and production* (Tashkent, November 20-21, 2014) pp. 176-178
4. O. J. Murodov, P. N. Rudovskiy, A. R. Korabelnikov, Substantiation of parameters and finite element modeling of hie movement of a cotton-air mixture in a cotton separator *Proceedings of Higher Educational Institutions, Series Technology of the Textile Industry* **1**, 266-271 (2022)
5. O. Zh. Murodov, N. A. Saidova, A. Sh. Adilova, Collection of articles of the 10th International youth scientific conference **5(10)** 283-287 (2022)
6. S. A. Gazieva, B. D. Kurbonov, M. E. Nurov, Kh. I. Ibrogimov, P. N. Rudovsky, Bulletin of higher educational institutions. Textile industry technology **5(347)** 131-135 (2013)
7. A. Ilkhom, X. Muksin, A. Orof, K. Ruxsora, International Journal of Engineering and Advanced Technology **8(3)** 279-283 (2019)
8. S. Yunusov, A. Sultonov, M. Rakhmatov, T. Bobomurotov, M. Agzamov, E3S Web of Conferences **304** 03028 (2021)

9. A. R. Korabelnikov, D. A. Lebedev, A. G. Shutova, *Allocation of trash impurities from the surface of a layer of fibrous material*, Proceedings of higher educational institutions. Textile industry technology **4(340)** 143-147 (2012)
10. E. Zikriyoev, *Cotton primary processing. Textbook.* (Tashkent, 2002), 408
11. K. Elsayed, C. Lacor, Chemical Engineering Science **65(22)** 6048-6058 (2010)
12. A. J. Hoekstra, J. J. Derksen, H. E. A. Van Den Akker, Chemical Engineering Science **54** 2055-2065 (1999)
13. B. Zhao, Y. Su, J. Zhang, Chemical Engineering Research and Design **84** 1158-1165 (2006)
14. O. Murodov, Zh. Adilova Aziza Shukhratovna, Science and Innovative Development **4 (**2022) 28-35
15. L. Xiaodong, Y. Jianhua, C. Yuchun, N. Mingjiang, C. Kefa, Chem. Eng. J. **95** 235-240 (2003)
16. P. Warzecha, A. Boguslawski, Arch. Combust **30(3)** (2010)
17. B. Zhao, Chem. Eng. Process **44(4)** 447-451 (2005)
18. G. Solero, A. Coghe, Exp. Therm. Fluid Sci. **27** 87-96 (2002)
19. Paul Onubi Ayegba, Lawrence C. Edomwonyi-Otu, Engineering Reports **2(3)** e12138 (2020). https://doi.org/10.1002/eng2.12138
20. S. K. Shukla, P. Shukla, P. Ghosh, Eng. Appl. Comput. Fluid Mech. **5(2)** 235-246 (2011)
21. J. Jiao, Y. Zheng, G. Sun, China Particuol. **3(4)** 219-223 (2005)
22. C. Fredriksson, *Exploratory experimental and theoretical studies of cyclone gasification of wood powder* (Lulea University of Techn., 1999)