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STATISTICAL EVALUATION OF A FULL FACTORIAL EXPERIMENT ON DUST SUPPRESSION SYSTEMS IN PRIMARY COTTON PROCESSING FACILITIES

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Abstract: This article explores the development and implementation of a mechatronic system designed to control the concentration of dust particles generated in cotton processing enterprises. The primary objective of the system is to extinguish dust particles after the primary cleaning device by spraying water onto them, thus reducing their dispersion into the environment. A mechatronic module is employed to monitor the concentration of dusty air in the working zone and automatically regulate the concentration of fine dust particles emitted from the cyclone. The compact size of the mechatronic module enables its deployment in isolated areas within the enterprise premises. Control of the water spray system is achieved through digital input pins connected to switches, operating based on predefined algorithms. Specially developed algorithms govern the activation or deactivation of switches in response to variations in dust particle concentration. When the concentration exceeds a predetermined threshold, the switches are activated to initiate the extinguishing process for small dust particles. This automated approach ensures efficient and timely mitigation of dust concentration, contributing to a safer and healthier working environment within cotton processing facilities.

Keywords: Mechatronic systems, analytical expression, dispersed value, environmental tax, dust particle concentration control, cotton processing enterprises, environmental sustainability, industrial hygiene.

Introduction. Industrial emissions that contribute to atmospheric air pollution adversely affect both the environment and the production assets of enterprises. Polluting enterprises are required to pay an environmental tax for their emissions into the atmosphere. Moreover, significant investments are necessary for dust collection systems to ensure that waste is treated and meets the established standard values.

In cases where the analytical form of the response function is not explicitly known, it is common to approximate the response function using a polynomial expressed as a regression equation:

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<1}^{k} b_{ij} x_i x_j + \sum_{i<j<l}^{k} b_{ijl} x_i x_j x_l \qquad (4.1)$$

The estimated value of the optimization parameter, denoted as Y, has been calculated in this instance, x_i - independent input parameters were examined during the experiment to assess their impact; b_0, b_i, b_{ij} va b_{ijkb} - optimization criterion "Y" is selected to develop a mathematical model in the form of equation (1), using regression coefficients derived from the experimental results, along with the independent variables X_i- factors are selected for inclusion in the model; calculation of regression coefficients b_0, b_i, b_{ij}, b_{ijkb}, identifying the type of response and the associated planning function is essential for understanding how a system reacts to various inputs. This process involves analyzing the nature of the response, whether it is continuous, discrete, or categorical, and determining the corresponding planning function that governs the relationship between inputs and outputs. By effectively categorizing the response and aligning it with the appropriate planning function, one can enhance decision-making and optimize performance within the system.

The coded values of lowercase factors are utilized in the formulation of the experimental design and the initial analysis of experimental data. This approach allows for a standardized representation of factor levels, facilitating the systematic organization of the experimental plan and streamlining the subsequent data processing. x_1, x_2, ... relationship between coded X_i (dimensionless values) and physical (real) X_i variables can be expressed by the following equation:

$$X_i = \frac{x_i - x_{i0}}{\Delta i} \tag{4.2}$$

Δ_i - natural value change range.

X_{i0} - true value at zero degree, $X_{i0} = \frac{x_н - x_в}{2}$,

X_{min}, x_{max} - natural values of the lower and upper levels of a factor.

The encoding of factors involves shifting to the initial reference point (the center point, designated as 0) of the experiment and adjusting the scale accordingly. All coded factors are represented as dimensionless, normalized values. In the context of the experiment, these coded factors can assume values of -1, 0, and +1, which are referred to as factor levels. This normalization facilitates easier interpretation and comparison of the effects of different factors on the experimental outcomes.

The coefficients for independent variables in a polynomial regression model (1) indicate the extent of influence that each factor exerts on the response variable. A positive coefficient suggests that as the factor increases, the output parameter also increases. Conversely, a negative coefficient implies that an increase in the factor leads to a decrease in the value of the response variable (Y). This relationship is crucial for understanding the direction and magnitude of the factors' effects within the model.

A full factorial experiment is a research design in which every possible combination of factor level is systematically tested. This approach ensures that all interactions between the factors are explored, providing a comprehensive understanding of how different variables affect the outcome. By examining all combinations, researchers can obtain robust data that allows for detailed analysis of the effects and interactions among the factors involved. If there are "k" factors each varying at two levels, the total number of possible combinations of factor levels can be calculated as $N_2 = 2k$. Conversely, if the "k" factors are changed at three levels, the total number of combinations is given by $N_3 = 3k$. This exponential relationship illustrates how the number of experimental sets increases significantly with the addition of factors and levels.

We develop a regression equation to identify the optimal parameters for a device designed to capture small impurities, such as dust, in primary cotton processing plants.

This equation will enable us to analyze the relationships between various factors affecting the device's performance, allowing for improved efficiency in the purification process. By systematically evaluating these factors, we aim to establish a rational value that maximizes the device's effectiveness in removing impurities during cotton processing. First, let's make a two-level plan ($k = 2$), a three-factor experiment, where we consider the factors such as the location of the water spray device and the water in the device during use of the device. The initial factor (*kg·s/sm*²) water pressure in the sprinkler x_1-

Incorporating coding, the positioning of the spray device is established at a height h (cm) above the dust outlet, x_2- utilizing coding, the spray angle *α* (in radians) of the spray device is defined in relation to the wind direction, x_3- we commence with the coding presented in table 4.1.

To derive the regression equation, we formulate a two-level, three-factor experimental matrix for each response function ($k = 2$) This matrix assesses the accuracy of the reference, specifically its closeness to the values established by the traditional method $\bar{y}_{ui}$, $\bar{z}_{ui}$ and $\bar{r}_{ui}$ additionally, each of m the parallel experiments and n tests conducted is evaluated accordingly. Here we are

$$\bar{y}_{ui} = \frac{1}{n}\sum_{l=1}^{n} y_{ul}\,,\ \bar{z}_{ui} = \frac{1}{n}\sum_{l=1}^{n} z_{ul}\,,\ \bar{r}_{ui} = \frac{1}{n}\sum_{l=1}^{n} r_{ul}\ (l = 1.2...m).$$

We will examine the scenario of performing two experiments for each option with the designated quantity $N_2 = N = 8$, that $m = 2$ and we incorporate their values into Table 4.2. We conduct a preliminary statistical analysis of the experimental results for each response individually, following this sequence:

1) we analyze the replication m of several parallel experiments and present the results regarding the variances S_u^2 -associated with each of the studies.

$$S_u^2 = \frac{\sum_{p=1}^{2}(\bar{y}_{up} - \bar{y}_u)^2}{m-1} \tag{4.3}$$

in this case u - the number of the options ($u = 1.2..N$),

$p = 1.2.3..m$ - the identification number of the parallel experiment, m - the number of experiments conducted in each option $\bar{y}_u = \frac{1}{m}\sum_{p=1}^{m}\bar{y}_{up}$ - the mean value of all experiments for each option.

Statistic ($S^2_{u(\max)}$ - maximum value of dispersion in options)

$$G = \frac{S^2_{u(\max)}}{\sum_{u=1}^{N} S_u^2} \tag{4.4}$$

If we check on the Cochrane criterion, G_{α,k_1,k_2} the value is determined from the reference table, α - relevance degree $(0<\alpha<1)$, $k_1 = N$, $k_2 = m-1$- the quantity of degrees of freedom.;

2) If the inequality holds

$$G < G_{\alpha,k_1,k_2}, \tag{4.5}$$

then the uniformity of dispersion among the options m parallel experiments are not rejected, the reproducibility variance can then be characterized as the mean for the variants, it means.

$$S_y^2 = \frac{1}{N}\sum_{u=1}^{N} S_u^2 \tag{4.6}$$

In addition, this difference is used to assess the suitability of the model.

3) In order to inequality (5) unfulfilled, for variants, the dispersion becomes heterogeneous and the average cannot be calculated, and the following precautions should be taken:

a) clarify the measurement data in the variant with the maximum dispersion;

b) Experiments increase number m in each variant;
v) more accurate measurement of output parameters.

4) Using the formulas, we calculate the coefficients of regression

$$b_0 = \frac{1}{N}\sum_{u=1}^{N}\bar{y}_u,\ b_i = \frac{1}{N}\sum_{u=1}^{N} X_{iu}\bar{y}_u,\ b_{ij} = \frac{1}{N}\sum_{u=1}^{N} X_{iu}X_{ju}\bar{y}_u,\ b_{ijk} = \frac{1}{N}\sum_{u=1}^{N} X_{iu}X_{ju}X_{ku}\bar{y}_u \tag{4.7}$$

After determining the coefficients, we write the regression equation on the coded variables

$$\bar{y} = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i<1}^{k} b_{ij} X_i X_j + \sum_{i<j<l}^{k} b_{ijl} X_i X_j X_l \tag{4.8}$$

5) We rate the importance of regression coefficients according to the student test

Initially, let us examine the identical confidence interval Δb for all regression coefficients by formula

$$\Delta b = t_{\alpha,k}\frac{S_y}{\sqrt{N}} \tag{4.9}$$

$t_{\alpha,k}$ - student's criterion, α - relevance; $k = N(m-1)$ - number of degrees of freedom.

If the regression coefficients exceed confidence intervals in absolute value, they are considered significant, it means.

$$|b_0| \geq \Delta b,\ |b_i| \geq \Delta b,\ |b_{ij}| \geq \Delta b,\ |b_{ijk}| \geq \Delta b \tag{4.10}$$

6) We estimate the adequacy of the model in the absence of insignificant coefficients in the regression equation.

In order to (4.8) if we take the regression equation of appearance, then the dispersion of the experiments is similarly zero. In this case, all $N = 2^k$ The regression coefficients are calculated by N values y Therefore, in this case, there is no degree of freedom to test the adequacy of the model. In this case, the condition of adequacy is fully satisfied. The existential design is called saturated. If we do not take into account the insignificant coefficients in the regression equation (4.8), then the degree of freedom arises and then the model must be checked for compatibility. The adequacy check consists of comparing the exerimental values of the output parameter y with values calculated for input factors of different levels and their by formula $\bar{y}$- relative discrepancy (in percentage) is determined

$$R_0 = 100\left|\frac{\bar{y}-y}{y}\right| \tag{4.11}$$

To assess the adequacy of the linear model based on the Fisher criterion, we calculate the residual variance using the appropriate formula.

$$S_{oc}^2 = \frac{\sum_{u=1}^{8}(\acute{y}_u-\bar{y}_u)^2}{N-k-1} \tag{4.12}$$

$\acute{y}_u$- inferred value of indicator u - options $\bar{y}_u$ - actual value of the indicator, N - number of options, k - number of factors

Taking into account statistics

$$F = \frac{S_{oc}^2}{S_y^2} \tag{4.13}$$

and check the Fisher criterion F_{α,k_1,k_2} according to the table data, here α - relevance; $k_1 = N-k-1, k_2 = N(m-1)$ - number of degrees of freedom.

If the inequality

$$F > F_{\alpha,k_1,k_2} \tag{4,14}$$

then the adequacy hypothesis is rejected by the Fisher criterion, even if the discrepancy between the error line and the original model is negligible.

7) The geometric interpretation of the results of the experiment is described as a surface. The coordinate values of the factors are plotted along the axes x_1, x_2 and x_3... Then, several values of the output parameter are set sequentially, In each case, a surface is defined in three-dimensional space. $\bar{y} = const$ $x_1 x_2 x_3$, This is where the output constant value is stored $\breve{y} = const$... As a result, a family of surfaces is obtained for several values. We correct the values of some factors, for example, $x_3 = const$, you can create a row family in which values are stored $\breve{y} = const$ and $x_3 = const$

Production-prototype of mechatronic system for dust particles, atmospheric air at cotton ginning enterprises was prepared in the scientific laboratory of Namangan Machine-Building Enterprise and Namangan institute of Engineering and Technology. An overview of the device is shown in Figure 4.1.

Figure 1. Mechatronic system for cleaning the atmospheric air from dust particles in cotton ginning plants.

Production-prototype version of mechatronic system for cleaning the atmospheric air from dust particles at cotton ginning enterprises was piloted at Kosonsoy cotton ginning enterprise.

To identify the optimal parameters of the developed system, a full factorial experiment method was selected. The following are selected as the undesirable factors:

X_1 - P(pressure of the water), *kgs/sm²;*

X_2 - h (Spray height);

X_3 - α (Angle of spray direction), deg.

Using the above methodology, we plan the experiment based on the solutions obtained. Table 1 gives the margin of change of the incoming factors.

Table 1. Margin of Change of Incoming Factors.

Factors	Union	X	min	max	average
P(pressure of the water)	*kgє/cm2*	X_1	2	4	3
h (Spray height)	*cm*	X_2	50	150	100
α (Angle of spray direction)	*rad*	X_3	π/6	5π/6	π/2

S_u^2 (3) calculate values by formula:

$$S_u^2 = (\bar{y}_{u1} - \bar{y}_u)^2 + (\bar{y}_{u2} - \bar{y}_u)^2, \ (u = 1,2,3,4,5,6,7,8).$$

We build a planning matrix and experiment based on it. The planning matrix and the results obtained are presented in Table 2

Table 2. Input Parameters and Experimental Results.

№	Factors			Results of experiments			
	X1	X2	X3	$\bar{y}_{i1}$	$\bar{y}_{i2}$	$\bar{y}_u$	S_u^2
1	-	-	-	11,5	10,9	11,2	0,03
2	+	-	-	22,9	23,3	23,1	0,27
3	-	+	-	12,8	13,8	13,3	0,02
4	+	+	-	30,0	25,0	27,5	0,27
5	-	-	+	10,8	12,8	11,8	0,01
6	+	-	+	24,7	24,5	24,6	0,24
7	-	+	+	14,2	15,2	14,7	0,01
8	+	+	+	25,9	31,5	28,7	0,24

Assuming $S^2_{u(\max)} = S_4^2 = 0{,}273$, $\sum_{u=1}^{8} S_u^2 = 1{,}09$, calculate statistics

$$G = \frac{S^2_{u(\max)}}{\sum_{u=1}^{N} S_u^2} = 0.02$$

2. We check the Cochrane criterion with table data $G_{\alpha,,k_1,k_2}$, here $\alpha = 0.05$, $k_1 = N = 8$, And we have $G_{0.05,8,1} = 0.68$... At this stage $G < G_{0.05,8,1}$, then the uniformity of dispersion for inlet parameters is achieved in all options X_i are not denied. So, in this case, in terms of options, S_y^2 we can use the calculated difference on average. All output options (X_1-(p ($kg \cdot s/cm^2$)-the pressure of the water in the water sprayer, X_2-h(cm) - position of the sprayer device at a height from the dust air outlet, X_3-(rad)-regression equation for α spray angle with respect to wind direction of the sprayer - estimation of the compatibility of a mathematical model:

$$S_y^2 = \frac{1}{N} \sum_{u=1}^{N} S_u^2 = 0{,}272$$

4.Calculation of regression coefficients:

b_0: = 19,4;	b_1: = 6,6;	b_2: = 3,4;	b_3: = 0,6;
b_{12}: = 3,5;	b_{13}: = 0,87;	b_{23}: = 0,06;	b_{123}: = 0,1.

Regression equations in coded variables x_1, x_2 and x_3 for output option we write in the form

$$y = 19.4+6.6X_1+3.4X_2+0.6X_3+3.5X_1X_2+0.87X_1X_3+0.06*X_2X_3-0.1X_1X_2X_3$$

5. Estimation of regression coefficients by the Stewart criterion

First of all, We measure confidence interval Δb at $\alpha = 0.05$, $N = 8$, $m = 2$, $k = N(m-1) = 8$ Using table data ($t_{0.05,8} = 2.31$)

$$\Delta b = t_{\alpha,k} \frac{S_y}{\sqrt{N}} = 0{,}02$$

Comparative analysis of possibilities. b_i , b_{ij} and b_{ijk},

$|b_0| > \Delta b$, $|b_1| > \Delta b$, $|b_2| > \Delta b$, $|b_3| < \Delta b$, $|b_{12}| > \Delta b$, $|b_{13}| < \Delta b$, $|b_{23}| < \Delta b$, $|b_{123}| < \Delta b$

Thus, based on the Stewart criterion, for the regression equation b_{13}, b_{23}, b_{123} is irrelevant.

$$y = 19.4+6.6X_1+3.4X_2+0.6*X_3+3.5X_1X_2$$

To verify the suitability of the model of material strength according to the Fisher criterion, we find the residual dispersion.

$$S_{oc}^2 = \frac{\sum_{u=1}^{8}(\acute{y}_u - \bar{y}_u)^2}{N-k-1} = \frac{1}{4}\sum_{u=1}^{8}(\acute{y}_u - \bar{y}_u)^2 = 0{,}0006$$

We calculate the value of statistical data $F = S_{oc}^2 / S_y^2 = 0.32$ and compare it to the Fisher criterion

$$\alpha = 0.05,\ k_1 = N - k - 1 = 4,\ k_2 = N(m-1) = 8,\ F_{0.05,4,8} = 3.84$$

As $F < F_{0.05.4,8}$, in this case, The hypothesis of the adequacy of the regression equation model according to the Fisher criterion is not refuted. Thus, it is possible to replace the nonlinear model.

7) Geometric interpretation of the results of factor experiment.

Depending on factors, the process analysis was performed using the computer in Marle, MathCad. The maximum and minimum graphs of the parameter correlation obtained using the regression equation are shown in Figure 1

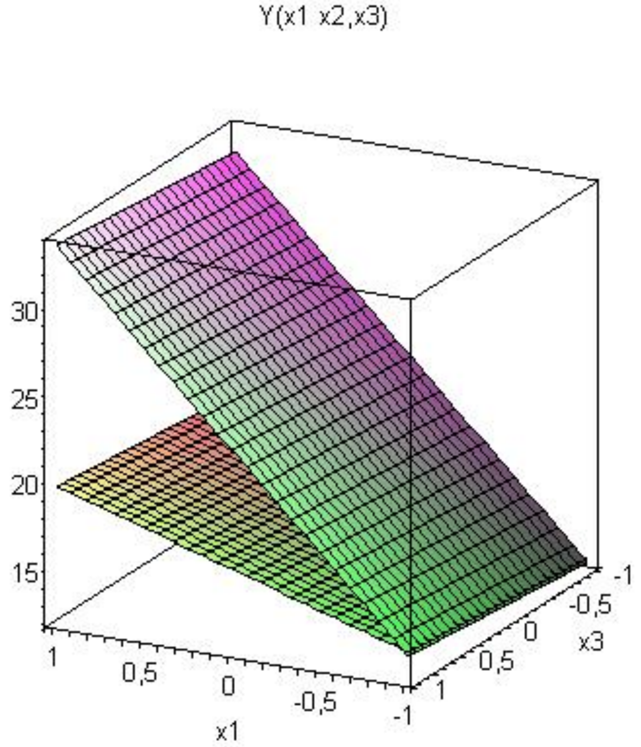

Figure 2. Based on formula, p=2..4 $kg \cdot s/cm^2$, $\alpha=\pi/6..\ 5\pi/6$ in variables in the state $h_1=50cm$ va $h_2=150cm$ 3D graphical view for a structured model.

Looking at the results, we can see that the 3D graphs all share the same character. Their difference lies in the values of the factors. Therefore, although the spatial location of the plane of factors in the graphs, the angle of deviation from which of them to the axis of the coordinate axis, the values of the factors in the coordinate axes are different, it can be seen that the graphs are all similar. These graphs represent the state of the outgoing parameter plane in the spatial coordinates of the three incoming factors.

From the resulting graphical analysis, it turned out that in our example the input factors are in the retention of fine dust, in terms of the location of the water spray equipment $p=4$ $kg\cdot s/sm^2$, $h=150$ sm, $\alpha=5\pi/6$ when it is expedient to do so.

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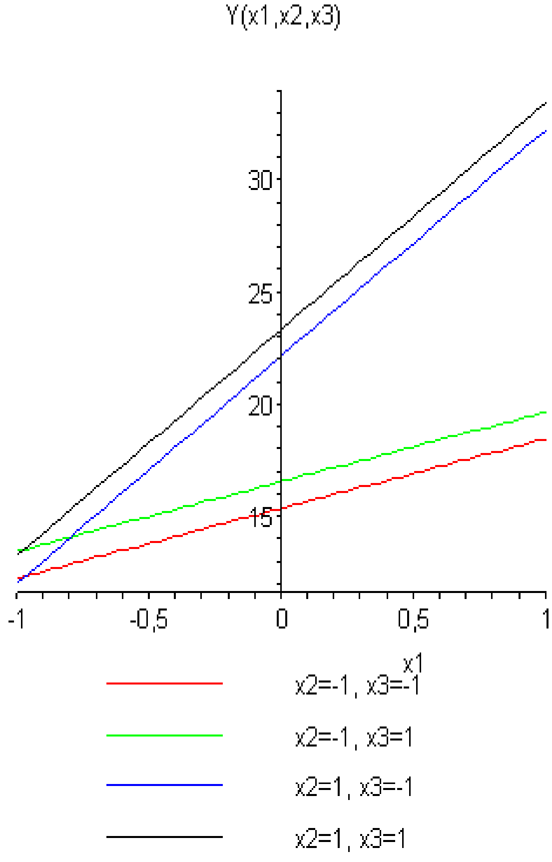

Figure 3. based on formula 1) $p=2..4$ $kg\cdot s/cm^2$, $\alpha=\pi/6$, $h_1=50cm$ va $h_2=150cm$; 2) $p=2..4$ $kg\cdot c/cm^2$, $5\pi/6$ $h_1=50cm$ va $h_2=150cm$; constructed model graph views for cases.

From the resulting graphical analysis, it turned out that in our example the input factors are in the retention of fine dust, in terms of the location of the water spray equipment $p=4$ $kg\cdot s/sm^2$, $h=150$ sm, $\alpha=5\pi/6$ when it is expedient to do so.

Since the function is checked only in the two values of the input factors - maximum and minimum, the parameter connection is from the plane, under the influence of which the change of the function will consist of a straight line. Therefore, it is impossible to determine the immortal value of a function from the obtained graphs. It will be possible to determine it (the measured value) by giving a constraint to one parameter and by analyzing the change in the function in other parameters and comparing the results with each other.

Atmospheric air pollution with emissions from industrial enterprises adversely affects both the environment and the production assets of enterprises. The polluter pays an environmental tax on emissions into the atmosphere. In addition, businesses must invest heavily in dust collection equipment to clean waste to established standard values.

Two criteria were used to evaluate the environmental and economic impact of using the Kosonsoy Cotton Refinery's mechatronic system for de-dusting particles:

1) the cleaning efficiency (cyclones) compared to the devices currently in use;

2) the amount of dust waste in the production area scale that can be reduced with this device.

In order to evaluate the effectiveness of the cleaning of dust from gases in the proposed dust extraction system, it is necessary to determine the masses of all dust fractions formed at the plant during cotton cleaning. The total mass of dust that must be cleaned M_i defined. Then all n dust fractions M_i masses are determined by the following formula:

$$M_i = p_i M_\Sigma \,, \; i = 1, \dots, n \; (1)$$

Here p_i - the mass fractions of each dust fraction before cleaning, in unity. n - number of fractions.

M_i remove dust after cleaning i- mass of the share is determined by the formula:

$$m_i = (1 - \eta_{c,i}) M_i, \; (2)$$

Here $\eta_{c,i}$- i- fraction refining coefficient, units.

(1) and (2) comparing the ratios, we collect them for all fractions and obtain the mass volume of all the powder formed during the production. Evaluation is carried out according to the following formula:

$$M_\Sigma = \frac{m_\Sigma}{\sum_{i=1}^{n} p_i (1 - \eta_{c,i})}, \; (3)$$

here m_Σ dusting mass of all fractions,

$$m_\Sigma = \sum_{i=1}^{n} m_i .$$

Emission (value), fractional composition of the powder (p_i value) and based on the available data on the calculated fractional cleaning factors, the value is calculated primarily using the formula (3). Further, in the ratio (1), the masses of all fractions before cleaning are determined.

Suggested dust cancellation $\eta_{ec,i}$ fractional purification coefficients are determined by using a mechatronic device for detection and monitoring of dust particles and taking into account the same variation in particle size in each individual fraction.

Masses of all dust fractions after cleaning with a dust extraction system $\eta_{c,i}$ parameters $\eta_{ec,i}$ is defined by the formula (2) replaced by (3).

The amount of dust waste generated during the initial processing process of cotton and cleaned by existing dust collectors (cyclones) and when using a dust detergent system is shown in Figure 1.

In 2022, the total amount of dust emitted from the Kosonsoy cotton refinery (seasonally) was 7,081 kilograms (PM_{10} and $PM_{2.5}$ relative to size dust particles). When using the dust exhaust system, the yield for 1 season was 4840 kilograms.

Table 3. Key economic indicators.

№	Bullets	Mass of dust waste per year (kg)	Mass of dust waste per year (UZS)
1	Environmental damage per year for the plant	7081 kg	24.8 mln. soum
2	The amount of dust being emitted into the environment through the use of a dust extraction system in the proposed project	4840 kg	16.9 mln soum
3	Cost-effectiveness (environmental damage per season)	2241 kg	7.8 mln.soum

According to the expression, the mass of dust waste of the Kosonsoy cotton ginning plant will be 7081 kg per year (PM_{10} and $PM_{2.5}$ in relation to dust particles in size). Environmental damage for the plant is 24.8 million sums per year.

For the treatment of waste from the Kosonsoy cotton ginning plant, the amount of dust emitted into the environment will be reduced by 2241 kg through the use of a dedusting system of the proposed project. This helped to reduce the damage caused to the environment by 7.8 million sums per season.

Conclusion

1. Production-pilot version of mechatronic system for dust dust cleaning of atmospheric air at cotton ginning enterprises was prepared and tested at Kosonsoy cotton ginning enterprise, the efficiency and efficiency of the system was determined.
2. When conducting full-factor experiments in order to determine the optimal parameters of the mechatronic system for purification of atmospheric air from dust particles in cotton refineries, it was established that the optimal parameters of the incoming factors are:

Pressure of the water $p=4\ kg{\cdot}c/cm^2$,
sprayer height $h=150\ cm$,
Spray direction angle $\alpha=5\pi/6$.

3. It was found that the use of the mechatronic system for purification of atmospheric air from dust particles at cotton ginning enterprises at the cotton ginning plant "Kosonsoy" reduces the amount of dust emitted into the environment by 2241 kg.

Cost efficiency from the introduction of mechatronic system for purification of atmospheric air from dust particles in cotton ginning enterprises amounts to 7.8 million sums per year.

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