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ANALYSIS OF OPTIMIZATION OF THE MESH DRUM PARAMETERS OF A COTTON CONDENSER

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Abstract

This study investigates the optimization of mesh drum parameters in a cotton condenser to reduce aerodynamic resistance and dust emissions. Experimental design methods were applied to determine rational diffuser angle and mesh diameter values.

Keywords: Cotton condenser, mesh drum, aerodynamic resistance, dust filtration, diffuser angle, experimental design, regression analysis, optimization, cotton processing, ventilation efficiency.

Introduction

A large number of technological processes are accompanied by dust generation. Dust particles may be either toxic or non-toxic. Even non-toxic dust can carry harmful microorganisms, contribute to the spread of infections in production facilities, cause inflammation of the upper respiratory tract, and contaminate skin tissues, thereby promoting the proliferation of pathogenic microorganisms. Working in dusty environments often leads to eye diseases. In addition to the aforementioned effects, harmful dust can enter the bloodstream through the respiratory system, digestive organs, and skin, causing intoxication of the human body. Therefore, the concentration of dust in industrial premises should not exceed the permissible exposure limits, and periodic monitoring of airborne dust concentration is required.

Numerous studies have been devoted to the design of dust filtration equipment. Depending on the intended purpose, various design approaches are applied. Dust filtration devices are generally designed to achieve the following objectives:

- Reduction of aerodynamic resistance;
- Adaptation of device dimensions and geometry to installation conditions;
- Reduction of resource consumption (materials, manufacturing time, and labor costs).

Studies conducted at cotton-processing enterprises indicate that the reduction of aerodynamic resistance has not been considered a primary design objective. Instead, the main focus has been on compactness and resource savings, resulting in filtration units with relatively high aerodynamic resistance.

For the present study, the method of experimental design was selected.

The primary objective of the research was to reduce dust emissions into the atmosphere. Therefore, the output parameter was chosen as:

Y (U_1) – aerodynamic resistance of the dust filtration system.

The input factors were:

- **X_1** – angle of impact of the dust-laden airflow;
- **X_2** – diameter of the mesh surface.

A full factorial experimental design of type **2^2** was employed.

For factor **X_1**, the upper limit was selected as the diffuser expansion angle commonly used in industrial practice, namely **60°**. The lower limit was determined based on the diffuser length and width constraints. A smaller expansion angle results in a longer drum. The diffuser inlet section consisted of a circular cross-section with a diameter of 300 mm.

According to the geometric scheme:

$$\alpha = arctg\,(b/l) \qquad (1)$$

The drum width was 1700 mm, with a half-width of 850 mm. Considering the condenser width BBB:

$b = B/2 - d/2 = 425 - 150 = 275$ mm.

Based on recommendations from engineering personnel, the diffuser length should not exceed 3 m for operational convenience. Therefore:

$$\alpha = arctg\,(b/l) = arctg\,(275/3000) = 0{,}0914\ rad = 5.22^0 \approx 6^0$$

Thus, the minimum diffuser expansion angle was taken as **12°**.

For factor $\mathbf{X_2}$, the upper limit was determined by the height of the vertical section of the front wall of the 5KV condenser and was equal to **450 mm**, while the lower limit corresponded to the existing separator inlet height of **250 mm**.

Levels and intervals of factor variation

Table 1.

Factors	Levels of factor variation			Variation Interval
	-1	0	+1	
X_1-Dust-laden airflow impact angle, °	12	36	60	24
X_2 - Mesh surface diameter, m;	1.3	1.5	1.7	0.20

A mobile pneumatic transport unit installed at the Kosonsoy Cotton Processing Plant was utilized for the experiments. Two adjustable diffusers were manufactured:

1. A diffuser with an adjustable expansion angle;
2. A diffuser with an adjustable rectangular side height.

The experiments involved measuring the static pressure before the diffuser (P_{1st}) and after the diffuser (P_{2st}), followed by determination of their absolute and relative changes.

The aerodynamic resistance coefficient was calculated using:

$$\zeta = (P_{1ct} - P_{2cn})/ P_{2cn} \qquad (2)$$

The experiments were conducted according to four combinations of input factors at their lower and upper levels, with each experiment repeated three times. Based on the obtained results, the arithmetic mean values of the pressure measurements were calculated, after which the aerodynamic resistance coefficients were determined and entered into the corresponding table. The experimental results are presented in **Table 2**.

Processing of the experimental data yielded the following regression equation:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 \qquad (3)$$

The coefficients of the regression equation were calculated using the following formulas:

Experimental design matrix for the 2² factorial experiment and the obtained results

Table 2.

	Input Factors (IF)		Factors in Natural Units		Y_{u1}	Y_{u2}	Y_{u3}	Yo'r
	x_1	x_2	x_1, grad	x_2, mm				
1	-	-	12	250	0.12	0.12	0.11	0.12
2.	+		60	250	0.63	0.66	0.65	0.65
3.	-	+	12	450	0.22	0.3	0.26	0.26
4.	+	+	60	450	0.76	0.80	0.82	0.79

$$b_i = \frac{1}{N}\sum_{u=1}^{N} x_{iu}\overline{Y}_u (i = 0,1,...,M); \qquad (4)$$

$$b_{ij} = \frac{1}{N}\sum_{u=1}^{N} x_{iu}x_{ju}\overline{Y}_u (i \neq j); \qquad (5)$$

$$b_{ijl} = \frac{1}{N}\sum_{u=1}^{N} x_{iu}x_{ju}x_{lu}\overline{Y}_u (i \neq j \neq l). \qquad (6)$$

Processing of the experimental data yielded the following regression equation:

$$Y = 0.455 + 0.265\, x_1 + 0.07\, x_2 \qquad (7)$$

The calculated regression coefficients resulted in the following model:

$$t_R\{b_i\} = \frac{|b_i|}{S\{b_i\}};$$

The critical value of Student's t-test was taken from reference

$$t_T[P_D = 0{,}95; \quad f = 8(3-1) = 16] = 2{,}12.$$

The regression coefficients were tested for significance with respect to the investigated parameters. One of the coefficients was found to be equal to zero and, therefore, statistically insignificant.

After excluding the insignificant coefficient, the regression equation can be written in the following form:

$$Y = 0.455 + 0.265\, x_1 + 0.07\, x_2 \qquad (8)$$

The adequacy of the model was confirmed using the **Fisher criterion**.

Analysis of the regression model demonstrated that the influence of the diffuser side height on aerodynamic resistance follows a linear increasing trend, although its effect is less pronounced than that of the airflow impact angle.

Since linear equations do not possess an internal optimum, optimization was performed under boundary constraints. The objective was to minimize aerodynamic resistance subject to the following conditions:

- Drum length not exceeding 3 m;
- Diffuser side height not exceeding 450 mm.

Thus, the optimization problem was formulated as:

$$Y = 0.455 + 0.265\, x_1 + 0.07\, x_2 \rightarrow \min \qquad (9)$$

The regression equation was analyzed using **Maple 2020** software for various combinations of input parameters. The following rational design parameters were obtained:

- Diffuser expansion angle: **15°**;
- Mesh surface diameter: **0.35 mm**.

A prototype of the improved filtration device was subsequently manufactured at the Bog'dod Cotton Processing Plant.

Conclusion

The study revealed that existing dust collection devices used in cotton processing enterprises exhibit high aerodynamic resistance. Through a full factorial experimental design (2^2), the effects of the diffuser expansion angle ($\mathbf{X_1}$) and mesh surface diameter ($\mathbf{X_2}$) on the aerodynamic resistance coefficient (ζ) were investigated.

Based on the regression analysis, the following optimal parameters were determined:

- Diffuser expansion angle: **15°**;
- Mesh surface diameter: **350 mm (0.35 m)**.

Implementation of these parameters significantly reduced the aerodynamic resistance of the filtration device and improved the energy efficiency of the ventilation system.

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