

STUDY OF SMALL-SIZE INERTIAL LOUVER-COUNTERCURRENT DUST COLLECTOR

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Abstract. The diagram of a small-sized inertial dust collector of grain cleaning machines is presented. The dust collector contains an inlet pipe, two louver-countercurrent cleaners, a sedimentary chamber, an air outlet channel, and a dust removal device. Reducing the overall dimensions of the dust collector in height is achieved by making the louver separator L-shaped and dividing its vertical section into two, having a common inlet pipe and one sedimentation chamber. The air outlet channel is located between the louver surfaces. Experimental studies to determine the main design and technological parameters were carried out on a model with a width of 0.3 m using the methods of single-factor and multi-factor experiments. The influence of the main structural and technological factors of the dust collector on the efficiency of air purification and hydraulic resistance is studied. Adequate regression equations for these processes with a probability of 0.95 are obtained. The optimal design and technological parameters of a small-sized louver-countercurrent dust collector are: the depth of the inlet pipe is 0.25 m, the horizontal section length of the louver grid of 0.4 m, the depth of the inlet pipes of the vertical louver separators 0.08 m, the length of the vertical louver grids of 0.4-0.5 m, the height of the output window louver and counter-current separators 0.04-0.05 m and 0.045-0.055 m, the depth of the sedimentation chamber 0.8 m, the airflow rate at the inlet to the dust collector $7.5-9.0 \text{ m}\cdot\text{s}^{-1}$. With these combinations of parameters, the effect of air purification in laboratory conditions was 95.0-97.5% with a hydraulic resistance of the dust collector no more than 150 Pa. At the same time, the height of the dust collector decreased by 0.4-0.5 m. In real operating conditions as part of a grain cleaning machine the effect of air purification was 92.6-94.5% with a hydraulic resistance of 63 Pa, which corresponds to the claimed requirements.

Keywords: grain cleaning machine, inertial dust collector, air purification, hydraulic resistance.

Introduction

Grain purification from impurities is based on the use of differences in the physical and mechanical properties of the components contained in it. The most effective is the use of air systems for separation of light impurities from the grain at all stages of its processing. High-performance grain cleaning machines, for example, OZF-80/40/20, SVU-60, MPU-70 (Russia), K-527A10, U12.2.4, U15.2.4 (Germany), S1 (Sweden) are equipped with powerful pneumatic separation systems. The maximum air consumption in them is $10000-15000 \text{ m}^3\cdot\text{h}^{-1}$ or more [1; 2]. The exhaust air removed from the machines must be cleaned of dust and light impurities to the maximum permissible dust concentration. For this purpose, various dry inertial single - and multi-stage dust collectors are used: chamber, louver, cyclone, rotary, countercurrent [3-6]. For preliminary air purification, pneumatic systems are equipped with sedimentary chambers. At the next stage of air purification, louver or cyclone dust collectors are most often used. Louver dust collectors have a lower efficiency of air purification than cyclone and rotary ones, but due to their low hydraulic resistance, sufficiently high productivity and ease of connection with other elements, they are widely used in pneumatic systems of grain cleaning machines [7], as well as in various industrial installations. In [8], the possibility of using a louver dust collector to remove dust in a railway tunnel was studied. At the air velocity at the entrance to the dust collector of $1-4 \text{ m}\cdot\text{s}^{-1}$, the efficiency of dust capture was 30-50%. When cleaning the air entering the turbines, an increase in the efficiency of particle collection by the louver dust collector is achieved by adding one or two slits on the dust container [9]. To increase the degree of mechanical separation of dust in the filter unit [10], the louver dust collector is used as a preliminary separator with subsequent post-treatment of the air flow in the cyclone. The paper [11] shows the influence of the parameters of the louver grating on the efficiency of fractional collection. This dust collector is proposed to be used as a fractional one. The problem of using louver dust collectors for cleaning the exhaust air in the pneumatic systems of high-performance machines is the large area (length) of the louver grate, which increases the overall dimensions of the dust collector and the grain cleaning machine in height.

The purpose of this study is to reduce the height and substantiate the design and technological parameters of an inertial louver-countercurrent dust collector for grain cleaning machines, which has an air purification effect of 90-95% and a hydraulic resistance of up to 150-200 Pa.

Materials and methods

The diagram of a small-sized louver-counter-current dust collector is shown in Fig. 1 [12]. The dust collector contains an inlet pipe 1, two louver-counter-current cleaners 3 and 15, a sedimentation chamber 9, a transverse air outlet channel 4, and a dust removal device 10. The louver-counter-current cleaner 3, in order to reduce the overall dimensions, is made L-shaped [13]: the louver separator 2 is located horizontally, the louver separator 5 is located vertically. The inlet sections of the purifiers 3 and 15 are connected to the common inlet pipe 1, and the counter-current separators 6 and 13 are connected to the sedimentation chamber 9. The air outlet channel 4 is located above the sedimentary chamber 9. The width of the dust collector is equal to the width of the pneumatic system of the machine. The inertial dust collector works as follows. The air flow removed from the pneumatic system of the grain cleaning machine, containing light impurities and dust, enters the inlet pipe 1 of the inertial dust collector and moves to the louver-counter-current cleaners 3 and 15. Moving in the louver separators 2, 5 and 14, the purified air passes between the plates of the louver grate, and the dust particles under the action of inertia forces tend to maintain the original direction of movement, and their main mass, together with part of the air, is directed to the exit windows 7 and 12 of the louver separators. In the counter-current separators 6 and 13, the air flow with dust turns 180°. Dust particles due to the forces of inertia and gravity settle in the chamber 9 and are brought out through the device 10. The purified air through the exit windows 8 and 11 rushes together with the air passed through the louver grate into the transverse air outlet channel 4 and is removed from the dust collector.

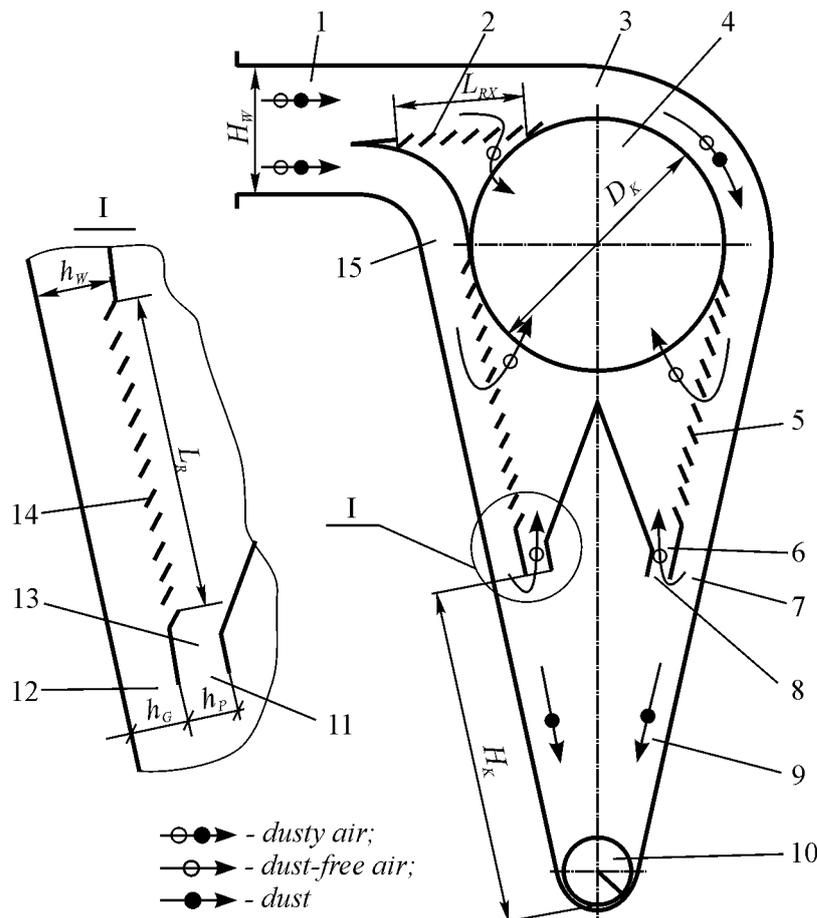


Fig. 1. **Diagram of small-sized louver-counter-current dust collector:** 1 – inlet pipe; 2, 5, 14 – louver separators; 3, 15 – louver-counter-current cleaners; 4 – transverse air outlet channel; 6, 13 – counter-current separators; 7, 12 – output windows of louver separators; 8, 11 – output windows of counter-current separators; 9 – sedimentation chamber; 10 – dust removal device

Reducing the overall dimensions of the dust collector in height is also achieved by dividing the vertical louver surface into two parts and placing them on both sides of the transverse air outlet channel. The movement of air flows in the sedimentation chamber 9, coming out of the windows 7 and 12 of the

louver separators, is turbulent jet. At the same time, the horizontal components of the air flow velocities are directed towards each other, which helps reduce their turbulence and improve the conditions for dust deposition. As a result, the prerequisites for reducing the height of the sedimentation chamber are created. In addition, the parallel operation of the louver-countercurrent cleaners 3 and 15 reduces the overall hydraulic resistance of the dust collector.

Experimental studies to determine the main design and technological parameters of the dust collector were carried out by planning a multi-factor and one-factor experiment on a model with a width of 0.3 m and natural dimensions in a longitudinal-vertical plane. The depth of the inlet pipe 1 dust collector was $H_w = 0.25$ m, length of the louver grid of the horizontal separator 2 $L_{RX} = 0.4$ m, depth of the input pipes of the vertical louver separators 5 and 14 $h_w = 0.08$ m, the diameter of the transverse air outlet channel 4 $D_K = 0.5$ m. The louver grid was a set of plates of the length l , installed with a step S at an angle β relative to its frontal surface. According to the recommendations of scientific research by Stepanov G.Y. and Zitser I.M. [14], the parameters of the louver grid were: $l = S = 0.025$ m, $\beta = 30^\circ$.

As dust, wooden sawdust with terminal velocity from 0.2 to 4.5 m·s⁻¹ was used, the aerodynamic properties of which are close to the properties of light impurities removed from the pneumatic systems of grain cleaning machines.

The efficiency of the dust collector was evaluated by the effect of air purification E_o and the hydraulic resistance P_{SV} . The effect of purification the air from dust E_o (%) characterizes the ratio of the mass of the captured dust m_y to the mass of the dust entering the dust collector m_w . To measure the mass of dust, an electronic scale VLTK-500M was used with an accuracy of 0.1 g. The total mass of the dust sample was 1000 g, the experiment time was 2 minutes. The hydraulic resistance P_{SV} (Pa) is the difference in the total pressure of the air flow at the inlet P_{V1} and outlet P_{V2} of the dust collector [15]. The air flow pressure was measured using a Pitot-Prandtl tube and a micromanometer MMN-2400, the air temperature was measured with an electronic thermometer, the relative humidity was measured with an aspiration psychrometer MV-4M, the atmospheric pressure was measured with a barometer BAMB, and the velocity of dust particles hovering was measured with a pneumatic classifier Petkus K-293. The obtained pressure values resulted in standard conditions. The experiments were carried out in three repetitions.

Results and discussion

At the first stage of the dust collector study, a second-order Box-Benken experiment plan was implemented for four factors [16]. The factors, levels and steps of their variation were selected taking into account the results of the study of the louver-countercurrent dust collector [17] and are presented in Table 1.

Table 1

**Factors, levels and steps of their variation in the study
of a small-sized inertial louver-countercurrent dust collector**

Coded designation of factors	Name of the factors, their designation and unit of measurement	Levels of factors			Variation steps
		-1	0	+1	
x_1	Air flow velocity at the entrance to the dust collector, v_w , m·s ⁻¹	6	8	10	2
x_2	Height of the output window of the vertical louver separators, h_G , m	0.035	0.045	0.055	0.010
x_3	Height of the output window of the countercurrent separators, h_p , m	0.04	0.05	0.06	0.01
x_4	Length of the louver grid of the vertical louver separators, L_R , m	0.4	0.5	0.6	0.1

Since the design of the dust collector has two parallel working louver-countercurrent cleaners, their parameters were changed in pairs (simultaneously in both cleaners). The study was performed at a depth of the sedimentation chamber of the dust collector $H_K = 0.9$ m. After processing of the experimental

results, the regression equations for the effect of air purification from light impurities and dust E_O (%) and hydraulic resistance of the dust collector P_{SV} (Pa):

$$E_O = 95.13 - 0.41x_1 + 0.46x_2 + 0.22x_3 - 2.42x_4 - 1.16x_1^2 + 0.25x_1x_2 - 0.35x_1x_3 - 0.03x_1x_4 - 1.11x_2^2 - 1.43x_2x_3 + 0.45x_2x_4 - 1.90x_3^2 + 0.23x_3x_4 - 0.10x_4^2; \tag{1}$$

$$P_{SV} = 102.6 + 35.5x_1 - 9.2x_2 - 10.6x_3 - 23.3x_4 + 10.9x_1^2 + 1.0x_1x_2 - 1.0x_1x_3 - 5.1x_1x_4 + 2.9x_2^2 - 2.1x_2x_3 + 2.6x_2x_4 - 3.0x_3^2 + 1.3x_3x_4 + 5.0x_4^2. \tag{2}$$

The analysis of equations (1) and (2) was performed using two-dimensional sections of the response surface (Fig. 2).

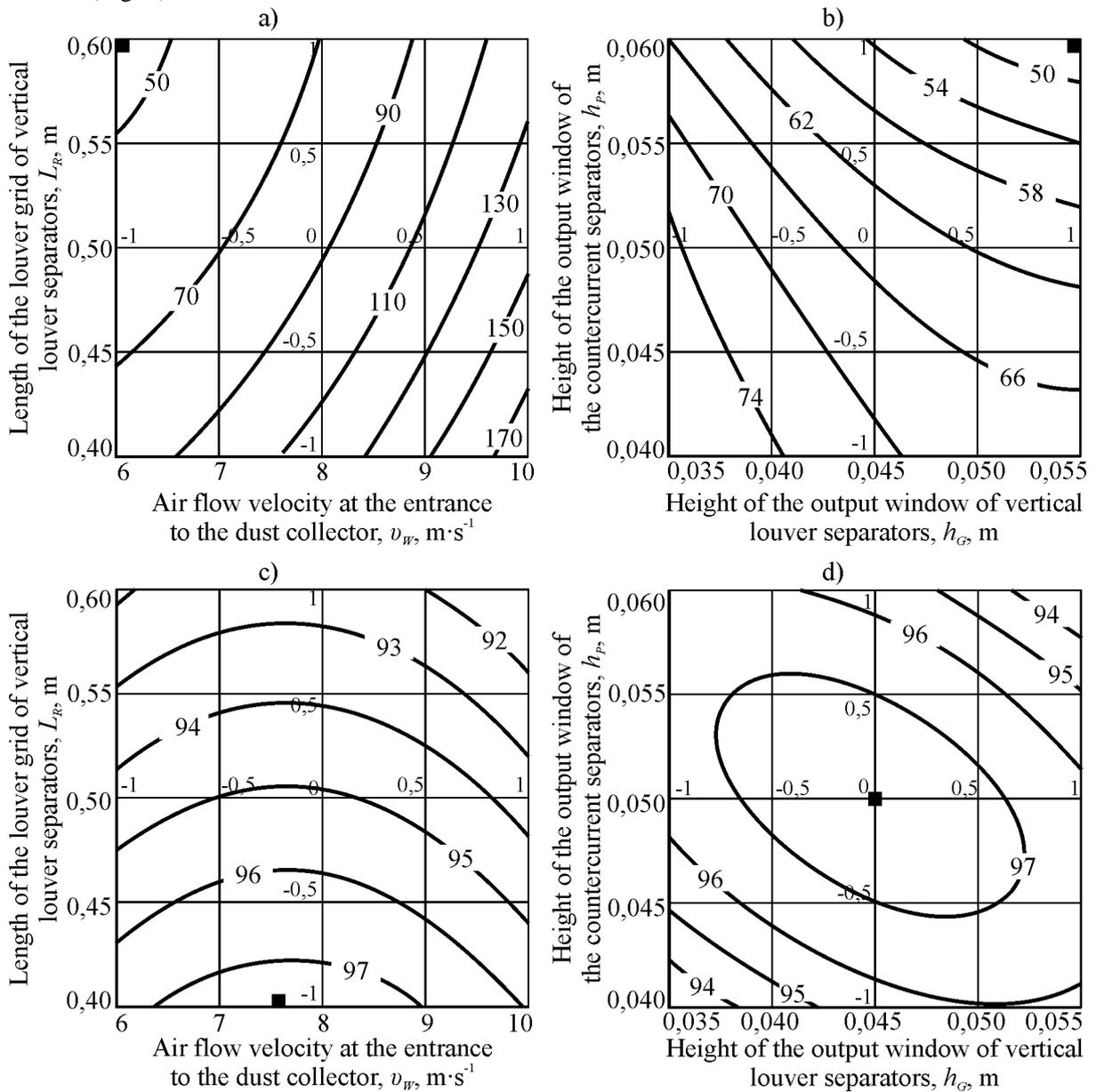


Fig. 2. Two-dimensional sections of the response surface of the air purification effect E_O (a) and (b) and the hydraulic resistance of the dust collector P_{SV} (d) and (c): a – at $x_2 = -0.02$ ($h_G = 0.045$ m); $x_3 = 0.02$ ($h_P = 0.05$ m); b – at $x_1 = -0.18$ ($v_W = 7.6$ m·s⁻¹); $x_4 = -1$ ($L_R = 0.4$ m); c – at $x_2 = 1$ ($h_G = 0.055$ m); $x_3 = 1$ ($h_P = 0.06$ m); d – at $x_1 = -1$ ($v_W = 6.0$ m·s⁻¹); $x_4 = 1$ ($L_R = 0.6$ m)

The maximum value of the effect of air purification from light impurities $E_{Omax} = 97.5\%$ is achieved at $x_1 = -0.18$ ($v_W = 7.6$ m·s⁻¹); $x_2 = -0.02$ ($h_G = 0.045$ m); $x_3 = 0.02$ ($h_P = 0.05$ m) and $x_4 = -1$

($L_R = 0.4$ m). The greatest influence on the effect of air purification from light impurities and dust E_O is exerted by the length of the louver grid L_R . Thus, an increase in L_R from 0.4 to 0.6 m (at $v_W = 7.6 \text{ m}\cdot\text{s}^{-1}$, $h_G = 0.045$ m and $h_P = 0.05$ m) leads to a decrease in E_O by 5.2% (from 97.5 to 92.3%). These experimental results can be explained by the fact that with an increase in the length of the louver grid L_R , the air velocity in the countercurrent separator decreases and the depth of the sedimentation chamber H_K decreases. This leads to a deterioration of their operation and, as a result, to a general decrease in the effect of air purification from light impurities and dust.

An increase in the velocity v_W of the air flow at the entrance to the dust collector from 6.0 to 7.6 $\text{m}\cdot\text{s}^{-1}$ (at $h_G = 0.045$ m, $h_P = 0.05$ m and $L_R = 0.4$ m) increases the effect of air purification from light impurities E_O by 1.2% (from 96.3 to 97.5%). A further increase in v_W to 10.0 $\text{m}\cdot\text{s}^{-1}$ leads to a decrease in E_O by 1.7% (from 97.5 to 95.8%). This can be explained as follows. The efficiency of air purification in the louver separator increases with the increase in the air velocity along the louver grid, since the inertia forces acting on the particle increase. With an increase in the air velocity at the entrance to the countercurrent separator, its efficiency also increases, while the operation of the sedimentation chamber deteriorates. Therefore, at first, with an increase in the velocity of the air flow at the entrance to the dust collector v_W , the efficiency of air purification as a whole increases, and then decreases.

An increase in the height of the output window of the louver separator h_G from 0.035 to 0.045 m (at $v_W = 7.6 \text{ m}\cdot\text{s}^{-1}$, $h_P = 0.05$ m and $L_R = 0.4$ m) leads to an increase in the effect E_O by 1.2% (from 96.3 to 97.5%). A further increase in h_G to 0.055 m leads to a decrease in E_O by 1.3% (from 97.5 to 96.2%).

Increasing the height of the output window of the countercurrent separator h_P from 0.04 to 0.05 m (at $v_W = 7.6 \text{ m}\cdot\text{s}^{-1}$, $h_G = 0.045$ m and $L_R = 0.4$ m) increases the effect E_O by 1.9% (from 95.6 to 97.5%). A further increase in h_P to 0.06 m reduces the E_O by 1.9% (from 97.5 to 95.6%).

The minimum value of the hydraulic resistance of the dust collector $P_{SV} = 47$ Pa is achieved at $x_1 = -1$ ($v_W = 6.0 \text{ m}\cdot\text{s}^{-1}$); $x_2 = 1$ ($h_G = 0.055$ m); $x_3 = 1$ ($h_P = 0.06$ m) and $x_4 = 1$ ($L_R = 0.6$ m). The greatest influence on the P_{SV} is exerted by the air flow velocity at the entrance to the dust collector v_W . Thus, an increase in v_W from 6.0 to 10.0 $\text{m}\cdot\text{s}^{-1}$ (at $h_G = 0.055$ m, $h_P = 0.06$ m and $L_R = 0.6$ m) increases the hydraulic resistance of the dust collector P_{SV} by 76 Pa (from 47 to 123 Pa).

An increase in the length of the louver grid L_R from 0.4 to 0.6 m (at $v_W = 6.0 \text{ m}\cdot\text{s}^{-1}$, $h_G = 0.055$ m and $h_P = 0.06$ m) leads to a decrease in P_{SV} by 35 Pa (from 82 to 47 Pa).

An increase in the height of the output window of the louver separator h_G from 0.035 to 0.055 m (at $v_W = 6.0 \text{ m}\cdot\text{s}^{-1}$, $h_P = 0.06$ m and $L_R = 0.6$ m) reduces the hydraulic resistance of the dust collector P_{SV} by 19 Pa (from 66 to 47 Pa).

Increasing the height of the output window of the countercurrent separator h_P from 0.04 to 0.06 m (at $v_W = 6.0 \text{ m}\cdot\text{s}^{-1}$, $h_G = 0.055$ m and $L_R = 0.6$ m) reduces the P_{SV} by 20 Pa (from 67 to 47 Pa).

From the analysis of regression equations (1) and (2) and two-dimensional sections of the response surface, it follows that the maximum effect of air purification from light impurities E_{Omax} and the minimum hydraulic resistance of the dust collector P_{SVmin} are achieved with a different combination of the studied factors, so it is necessary to find a compromise solution. As a result of the analysis, the following optimal combination of the studied factors was selected: the velocity of the air flow at the entrance to the dust collector $v_W = 7.5\text{-}9.0 \text{ m}\cdot\text{s}^{-1}$; the length louver grid $L_R = 0.40\text{-}0.50$ m; the height of the output window louver separator $h_G = 0.04\text{-}0.05$ m; the height of the output window countercurrent separator $h_P = 0.045\text{-}0.055$ m.

In order to verify the reliability of the results of the experiment planning, an experiment was conducted with the following combination of factors: $v_W = 8.0 \text{ m}\cdot\text{s}^{-1}$, $L_R = 0.5$ m, $h_G = 0.045$ m and $h_P = 0.05$ m. The effect of air purification from light impurities was $E_O = 94.7\%$ vs. 95.1% according to the regression equation (1), and the hydraulic resistance of the dust collector was $P_{SV} = 101.4$ Pa vs. 102.6 Pa according to the regression equation (2) with a probability of 95%, which confirms their adequacy and reliability of the study results.

At the next stage of the study, one-factor experiments were carried out to determine the optimal depth of the sedimentation chamber of the dust collector H_K . Since the effect of H_K on the hydraulic resistance of the dust collector P_{SV} is insignificant, the optimization criterion was the effect of air purification from light impurities and dust E_O . The experiments were carried out at constant design

parameters of the dust collector: $L_R = 0.5$ m, $h_G = 0.045$ m and $h_P = 0.05$ m. The variable factors were the depth of the sedimentation chamber of the dust collector H_K and the air flow velocity at the entrance to the dust collector v_W .

The study found that in the whole range of change of the depth of the sedimentation chamber of the dust collector H_K from 0.5 to 0.9 m by increasing the velocity of the air flow at the entrance of the dust collector v_W 4.5 to 7.5 m·s⁻¹, the effect of air purification E_O increases. A further increase in the velocity v_W to 8.5 m·s⁻¹ reduces the E_O . So, for example, at $H_K = 0.8$ m, the effect of air purification E_O first increases by 3.2% (from 93.5 to 96.7%), and then decreases by 0.5% (from 96.7 to 96.2%). The decrease in the effect E_O is explained by the fact that with an increase in the air flow velocity at the entrance to the dust collector $v_W > 7.5$ m·s⁻¹, the conditions for the deposition of light impurities in the sedimentation chamber deteriorate to a greater extent than they improve in the inertial separators.

With an increase in the depth of the sedimentation chamber H_K from 0.5 to 0.9 m, the effect of air purification E_O at all speed modes increases by about 1.8%. The most intense growth of the E_O is observed with an increase in the H_K from 0.5 to 0.8 m. With a further increase in the H_K , the growth of the E_O slows down and becomes insignificant. It follows that the depth of the sedimentation chamber should be $H_K \geq 0.8$ m.

A small-sized louver-countercurrent dust collector with optimal design parameters is used in the MPZ-50 grain pretreatment machine. The evaluation of the efficiency of this dust collector was carried out on the preliminary cleaning of a pile of winter rye and barley at a machine capacity of 30-35 t·h⁻¹. The air supply to the dust collector was 2.2 m³·s⁻¹, and its hydraulic resistance was 63 Pa. The effect of air purification was 92.6 and 94.5%, when processing a pile of winter rye and barley, which meets the stated requirements. At the same time, the height of the dust collector in comparison with the L-shaped one decreased by 0.4-0.5 m due to the division of the vertical section into two parallel functioning ones [11; 15].

Conclusions

The optimal design and technological parameters of a small-sized inertial dust collector for pneumatic systems of grain cleaning machines are determined: the depth of the inlet pipe $H_W = 0.25$ m; the length of the horizontal louver grid $L_{RX} = 0.4$ m; the depth of the input pipes of the vertical louver separators $h_W = 0.08$ m; the velocity of the air flow at the entrance to the dust collector $v_W = 7,5-9,0$ m·s⁻¹; the length of the vertical louver grid $L_R = 0.4-0.5$ m; the height of the output window louver and countercurrent separators $h_G = 0.04-0.05$ m, and $h_P = 0,045-0,055$ m; the depth of the sedimentation chamber $H_K \geq 0.8$ m. With these combinations of parameters, the effect of air purification under laboratory conditions was 95.0-97.5% with a hydraulic resistance of the dust collector of no more than 150 Pa. In real operating conditions, as part of a grain cleaning machine, the effect of air purification was 92.6-94.5% with a hydraulic resistance of 63 Pa of the dust collector, which corresponds to the claimed requirements. At the same time, the height of the dust collector due to the division of the vertical section into two decreased by 0.4...0.5 m.

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