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Theoretical Rationale Of Adopting Dust Removal Systems In Workplaces Of Reception Points At Mixed Feed Milling Plants

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Abstract

The labour conditions of mixed feed production do not always meet regulatory requirements due to dust generation. Dust forms in all the phases of mixed feed production, especially during the acceptable of raw materials. The concentration of dust observed in this phase can cause the formation of explosive mixtures. This work provides the theoretical underpinning of improving the labour conditions at reception points of mixed feed milling plants. The article takes into account the concentration and particle-size distribution of dust, which provides the ground for calculating the efficiency of the dust removal system. The harmful effect of dust on the operator is conditioned by its amount in the work zone air. A diagram of dust generation and removal at the reception point of a mixed feed milling plant is elaborated. A procedure of determining the probability of the operator's staying in harmful labor conditions is proposed. The dust removal system design for specific conditions is determined. The space angle limiting the discharge of the dust removal system is modified by installing safety enclosures for the feed hopper. The smaller is this angle, the higher is the airflow speed created by the dust removal system near the unloading area; however, it is necessary to consider the structure and technology features of the production process. The structural features of air ducts, treatment facilities, and other ventilation elements will allow designing an efficient dust removal system. A conclusion is made that better labour conditions are ensured by optimizing the aerodynamic characteristics of the dust removal system. A practical example of using the material provided in the article is considered.

Key words: reception point, dust, dust removal system, airflow speed, labour conditions

INTRODUCTION

Mixed feed manufacturers are part of the processing sector of the national agrofood industry.

The products of these manufacturers are used in livestock breeding, poultry farming, and fishery. However, the peculiarities of the production process organization do not allow creating labour conditions meeting regulatory requirements and pose health and life threats to the workers

[1-21]. Certain amounts of dust are generated in almost all of the sections of the mixed feed production line because the processing covers bulk materials which are then transported, pulped, dried, and mixed. It should be noted that in normal operating conditions dust is generated in large amounts in the air of the work zone and in the atmosphere at the stage of accepting materials as cereals (parsley, corn, wheat) and crushed materials (sunflower and oil seed residues).

The raw materials are supplied as bulk cargo to reception points by lorries with a body of 12 to 37 m^3 (equivalent to a capacity of 8 000 to 25,000 kg). The unloading is attended by the falling of the grain material and oil seed residues from a height of 1.2 to 1.5 m into a dump pit of 1.95 m in depth; as a result, the air of the reception point is polluted with raw material and impurity particles

of up to 2 mm in size because the air is ejected by the falling bulk material (Fig. 1).

According to regulatory requirements, grain raw materials can contain up to 0.2 % of mineral impurities and up to 5 % of thrash [1]. Sunflower and soya oil seed residues are supplied as crushed materials. Therefore, the particles emitted into the air are either the ones from grain material impurities or those from crushed oil seed residues.

In the course of unloading the concentration of dust in the operator’s workplace at the reception point is 16 to 429-fold as high as the maximal allowed concentration (MAC) (Table 1). This concentration holds up for 3 to 5 minutes at each unloading and then goes down to 1÷4 MAC, and this levels holds up for quite a long period.

Table 1. Results of analyzing the dust concentration in the operator’s workplace at the reception point during the unloading of raw materials

Raw material	Dust concentration, mg/m^3	Dust MAC, g/m^3
Corn	191	6
Parsley	903	6
Wheat	1 703	6
Sunflower oil seed residues	2 576	6
Soya oil seed residues	1 108	6
Bran	93	6

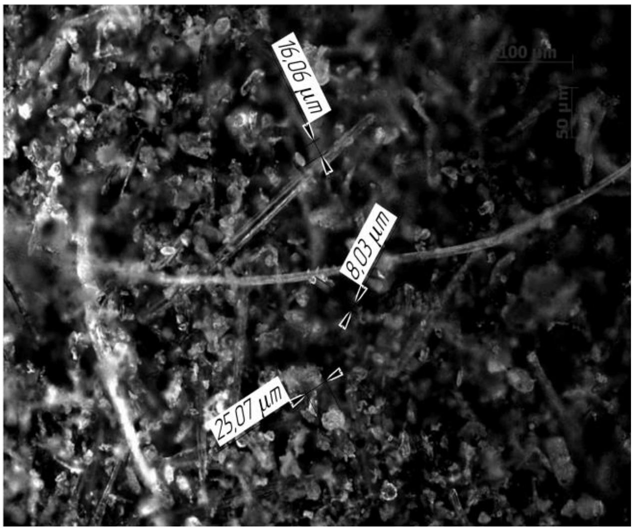
Figure 1. Unloading sunflower oil seed residues into a dump pit

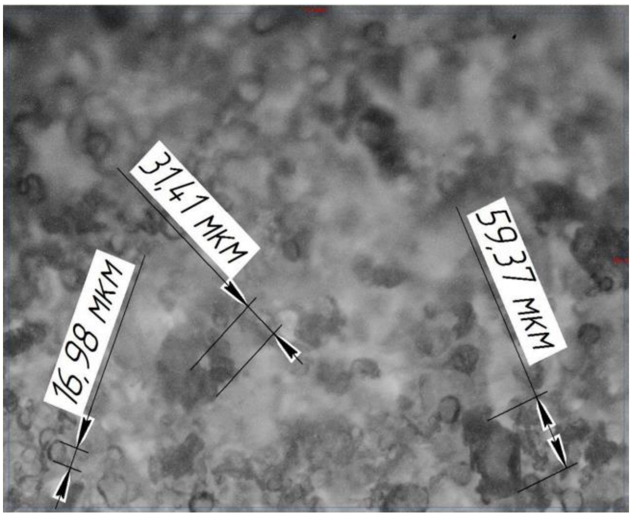
The concentration of dust in the unloading area can be as high as 20÷35 g/m^3. According to the manufacturer's documents, the spaces of reception points are referred to explosion hazard class B (explosion and fire hazard) and zone class B-IIa.

This study provides the theoretical underpinning of the indicators affecting the labour conditions in the workplaces of operators at reception points of mixed feed milling plants when using a dust removal system.

MATERIALS AND METHODS

Some kinds of dust have been exposed to the preliminary particle-size distribution analysis by microscoping (Fig. 2). As a result, several parameters have been determined, such as median dust particle diameter d_m and logarithmic mean square deviation lgσ of particle size. Their respective values were 20÷30 µm and 0.243÷0.312 [22-25]. The concentration and distribution of dust particles must be considered in assessing the efficiency of dust removal systems when making occupational disease forecasts.





a b

Figure 2. Micrograph of the quantitative filter clogged with parsley dust (a) and bran dust (b)

мкм – > µm

RESULTS AND DISCUSSION

As a result, lconditions C_L, in which employees working at the reception point of a mixed feed milling plant exercise their labour duties, are characterized by increased dust generation and, therefore, determined by the probability of working in harmful labor conditions P_{HC} [15] as

$$C_L \rightarrow f\,(P_{HC}) \quad (1)$$

For the diagram of the dust generation and removal at the reception point of a mixed feed milling plant see Fig. 3.

The harmful effect of dust on the operator is determined by its amount in the work zone air for the amount of dust accumulated in the respiratory organs is directly proportionate to is concentration. Another significant factor is the time of staying in harmful labor conditions. Thus the probability of the harmful effect of dust is determined by the concentration of dust in the air and the period the operator works in highly dusty conditions.

$$P_{HC} = f\,(c,\, t) \quad (2)$$

Concentration c of the dust in the work zone air depends on respective amounts m_{rc} and m_{rm} of the emitted dust received and removed by the dust removal system:

$$c=f(m_n,m_r) \quad (3)$$

Emitted dust amount m_n also depends on number of particles n_{pt}, their size δ_n, absolute particle density ρ_{pt}, and also on weight (volume) M_{rw} of received raw materials (cereals, oil seed residues, or bran), ranges from 8 (12 m^3) to 25 t (37 m^3) , and is calculated [2] as

$$m_n=f(n_n,\delta_n,\rho_{pt},M_{rw}) \quad (4)$$

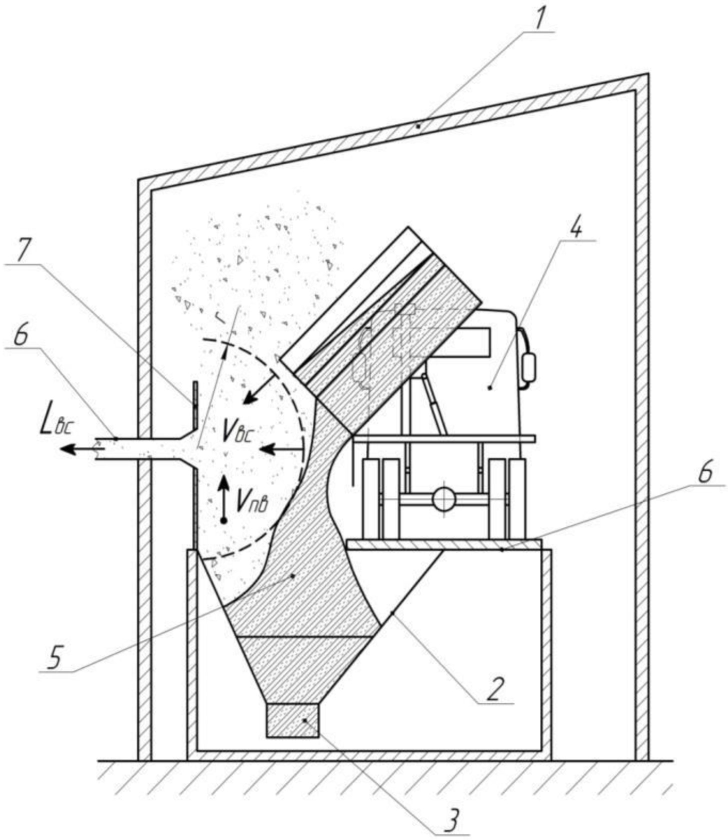


Figure 3. Diagram of dust generation and removal at the reception point of a mixed feed milling plant: 1 is the rain shelter; 2 is the feed hopper; 3 is the conveyor; 4 is the lorry; 5 is the poured dust-generating material; 6 is the air duct of the dust removal system; 7 is the side wall; L_{air} is the air consumption by the dust removal system; V_{air} is the airflow speed created by the dust removal system near the unloading area; V_{dta} is the dusty air flow speed

To make the task simpler and reduce the dust concentration in the work zone air as much as possible, weight (volume V_{rw}) M_{rw} of received raw materials will be taken at its constant maximum of 25 t.

In its respect, weight m_{rm} depends on the dust characteristics (particle size δ_{rn}, absolute particle density p_{pt}, number of particles n_{pt}) and the operating modes of the dust removal system (air consumption L_{air}), which is why the dependence is recorded according to [28] as

$$m_{rm}=f\,(n_{rm},\delta_{rm},\rho_{pt},L_{air}) \quad (5)$$

Consumption L_{air} of the air removed by the dust removal system at the reception point is calculated according to [26] as

$$L_{air}=3600\times\left(F_{hl}\cdot v_{ahl}+\frac{V_{rw}}{t_{dcrg}}\right); \quad (6)$$

where F_{hl} is the area of the gain hopper holes, м^2;

$v_н$ is the speed of the airflow through the holes, m/s;

V_{rw} is the raw material volume, m^3;

t is the unloading period, s.

It follows herefrom that L_{air} is constant because all of the quantities in formula (6) are constant, which is recorded as:

$$L_{air}=\text{const} \quad (7)$$

The dust generation intensity depends on size δ of the particles suspended in the air of the reception zone; this size ranges from 1 to 2 000 µm) [27].

Removed particle size δ_{rm} depends on dust particle hovering speed V_{hov}, dusty airflow speed V_{duair} , and airflow speed V_{air}, created near the unloading area by the dust removal system:

$$\delta_{rm}=f\,(V_{hov},V_{duair},V_{air}) \quad (8)$$

Dusty airflow speed V_{duair} is determined depending on raw material volume V_{rm} (raw material weight M_{rm}); therefore, V_{duair} is constant and V_{hov} depends on the particle size and absolute particle density and is determined according to the Stokes law; both quantities are expressed, respectively, as

$$V_{duair}=\text{const} \quad (9)$$

$$V_{hov}=\frac{\delta^2 g(\rho_{pt}-\rho_{air})}{18\mu} \quad (10)$$

Since raw material is dumped from the lorry side, and dust is released over a long distance, local suction units must be evenly mounted along the wall of the gain hopper (Fig. 4).

where V_i is the component of the airflow speed along the axis of discharge from each suction unit at the design point, m/s; n is the number of suction units.

Component V_i of the airflow speed along the axis of discharge from each suction unit at the design point is found as [28]:

$$V_i = \frac{L_i \cdot x}{\varphi_i (x^2 + (y+a)^2)^{1,5}}, \quad (12)$$

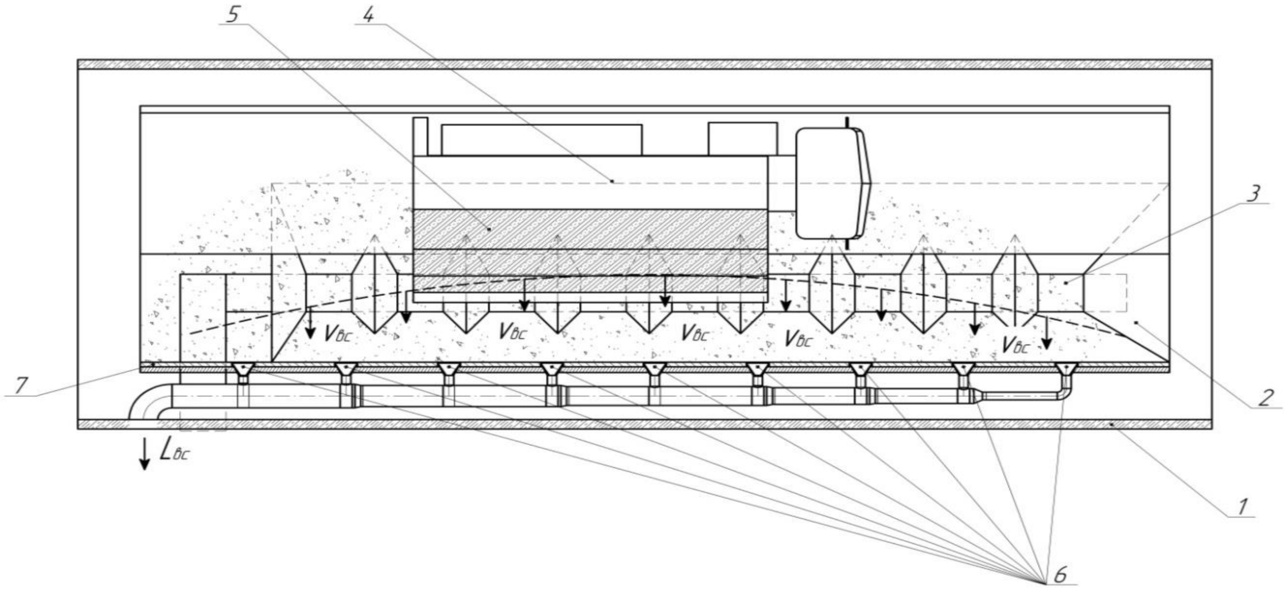


Figure 4. Diagram of dust generation and removal at the reception point of a mixed feed milling plant (top view): 1 is the rain shelter; 2 is the feed hopper; 3 is the conveyor; 4 is the lorry; 5 is the poured dust-generating material; 6 is the air duct of the dust removal system; 7 is the side wall

where L_i is the airflow rate through each suction unit, m^3/s;

y is the coordinate of the design point along the y-axis (Fig.4), m;

a is the suction unit position along the y-axis (Fig. 5), m, from –n·a to +n·a;

ϕ_i is the spatial angle limiting the runoff from the dust removal system, radian.

Spatial angle ϕ_i, limiting the discharge from the dust removal system, is altered by installing enclosures for the gain hopper. The sharper is ϕ_i, the higher is the airflow speed V_{air}, created by the dust removal system close to the unloading area in the direction of the suction unit; however, the structure and technology features of delivering raw materials to gain hoppers must be taken into account.

Airflow rate L_i through each suction unit depends on the number of discharges and is defined as

$$L_i = L_{air}/n, \quad (13)$$

For example, see Fig. 6 and Table 2 for the results of calculating speed V_i of the airflow along the discharge axis in the direction of the x-axis in the pouring area with various number of suction units, considering the structural features of the dump pit and elements of the dust removal system (airflow rate L_{air}= 46,110 m^3/h, determined by formula (6)).

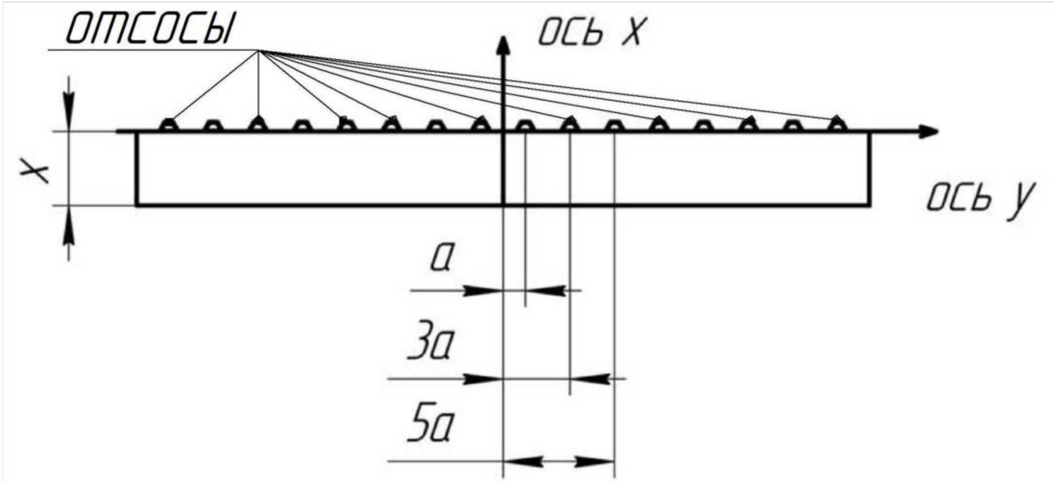


Figure 5. Diagram of calculating the airflow speed at distance x

Отсосы – > Suction units

ось – > axis

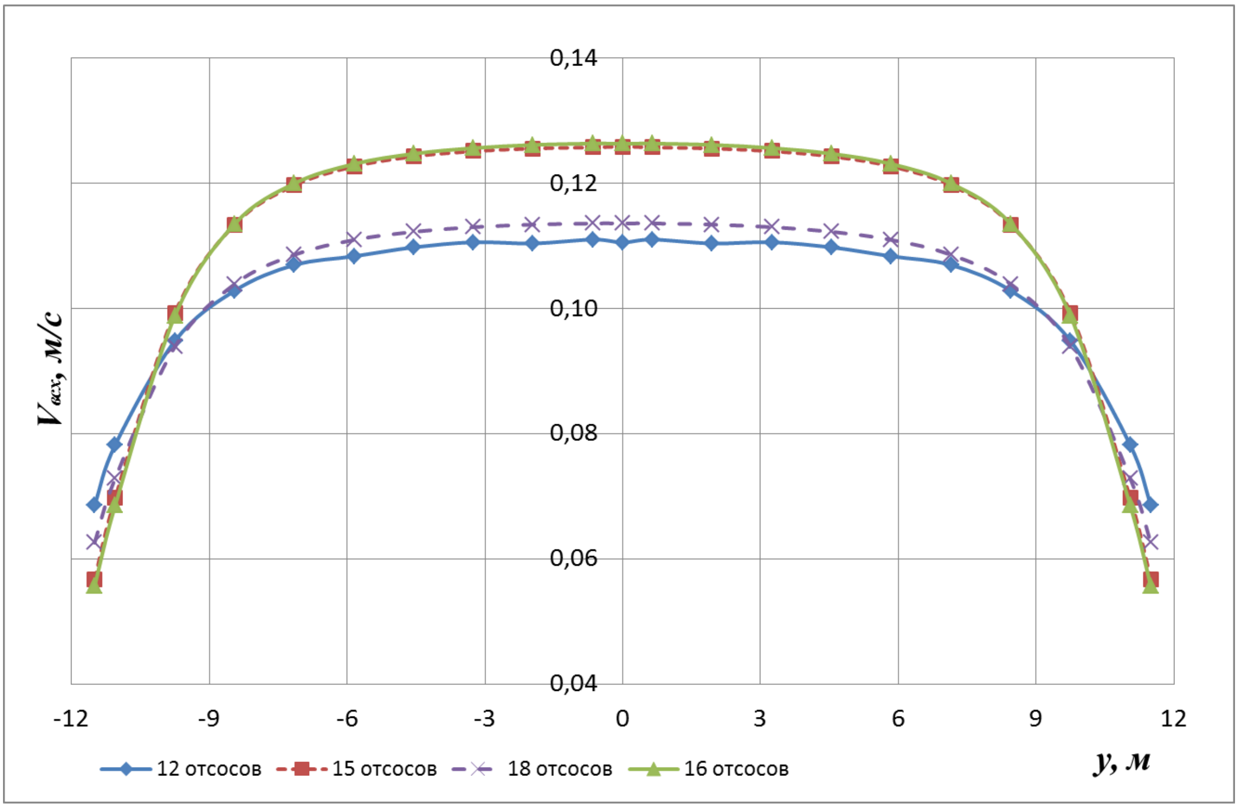


Figure 6. Dependence of V_i, m/s from the position and number of suction units in the dust removal system along the y-axis

всх – > air;

отсосов – > suctions;

м – > m

According to Fig.6 and Table 2, the highest efficiency is achieved by using 16 suction units, since their use ensures higher airflow speed V_{air}, created by the dust removal system near the unloading area in the direction of the x-axis in the pouring zone; however, the values attained are only slightly higher than in case of 15 suction units. The structural features of air ducts, treatment facilities, and other ventilation elements also allow creating a more rational dust removal system design.

Considering expressions (7-14), formula (5) is recorded as

$$m_y = (M_{rm}, x) f(n, \phi, \rho_{pt}, V_{hov}) \quad , \tag{14}$$

thus

$$P_{HC} = (M_{rm}, x) f(n, \phi, \rho_{pt}, V_{hov}, t) \quad . \tag{15}$$

Table 2. Results of calculating airflow speed V_i, m/s, along the discharge axis in the direction of the x-axis

Position of the point relative to the y-axis, m	Airflow speed V_i, m/s, at installation			
	12 suction units	15 suction units	16 suction units	18 suction units
-11.5	0.06856	0.05667	0.05559	0.06255
-11.05	0.07818	0.06968	0.06851	0.07283
-9.75	0.09481	0.09929	0.09882	0.09388
-8.45	0.10284	0.11340	0.11350	0.10389
-7.15	0.10694	0.11966	0.11998	0.10857
-5.85	0.10833	0.12270	0.12309	0.11095
-4.55	0.10977	0.12428	0.12472	0.11225
-3.25	0.11058	0.12513	0.12563	0.11299
-1.95	0.11039	0.12556	0.12613	0.11340
-0.65	0.11101	0.12573	0.12635	0.11358
0	0.11056	0.12586	0.12632	0.11359
0.65	0.11101	0.12573	0.12635	0.11358
1.95	0.11039	0.12556	0.12613	0.11340
3.25	0.11058	0.12513	0.12563	0.11299
4.55	0.10977	0.12428	0.12472	0.11225
5.85	0.10833	0.12270	0.12309	0.11095
7.15	0.10694	0.11966	0.11998	0.10857
8.45	0.10284	0.11340	0.11350	0.10389
9.75	0.09481	0.09929	0.09882	0.09388
11.05	0.07818	0.06968	0.06851	0.07283

11.5	0.06856	0.05667	0.05559	0.06255

Since labour conditions C_L for employees working at reception points are improved by reducing the probability of staying in harmful labour conditions P_{hc}, the obtained formula is

$$\begin{cases} P_{hc} = (M_R, x) f(n, \phi, \rho_p, V_{hov}, t); \\ n = optimal; \\ \phi_i, t \to \min. \end{cases} \quad (16)$$

The dust removal system has been computed as an example, taking into account the geometric parameters of the reception point and the aforementioned dependences. Figure 7 presents a 3D image of the proposed dust removal system at the reception point of a mixed feed milling plant, whereas the design parameters of the system are given in Table 3.

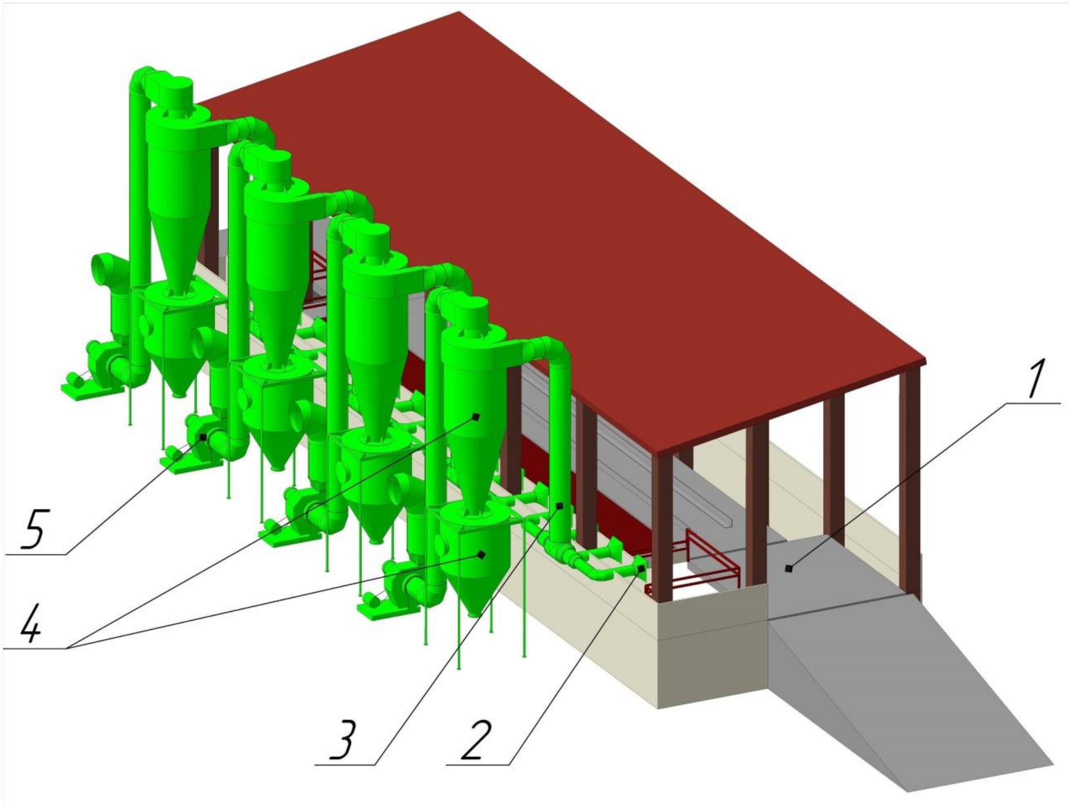


Figure 7. Tentative configuration of the reception point with a dust removal system:

1 is the reception point, 2 is the suction unit, 3 is the air ducts, 4 is the cyclone collector with a hopper, 5 is the fan

Thus, the removal of dusty air in the course of discharging reduces the dust concentration in the operator's working area to the values close to MAC, which makes less likely the occurrence of occupational diseases at the enterprise.

Table 3. Parameters of the dust removal system at the reception point of a mixed feed milling plant

Aggregate air consumption L_{air}, m^3/h	Discharged amount	Air consumption in each discharge L_i, m^3/h	Spatial angle ϕ_i limiting the dust removal system discharge, radian	Airflow speed V_{air} created by the dust removal system near the unloading area in the direction of discharge, m/s
48000	16	3 000	1.2π	0.12

This work is the first ever case of studying the local area of dust removal in the zone of discharging explosive and fire-prone bulk dustlike plant materials, of explosion and fire hazard. The publication is the final paper summarising the knowledge obtained in the earlier works of various authors [1-24].

CONCLUSION

The health of the operators working in dusty conditions at mixed feed milling plants can be improved by optimizing the aerodynamic characteristics of the dust removal system for cutting the time the operators have to stay in the dusty environment.

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