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A Theoretical Justification For Using Dust-Removal System In Workplaces Of Receiving Points At Compound Feed Mills

ABSTRACT

Due to dust formation, labour conditions while producing feed compounds are often out of compliance with regulatory requirements. Dust is released at all stages of feed milling, particularly, during reception of raw material. Here, dust concentration is such that explosive mixtures can be formed. The work aims to theoretically justify improvements in labour conditions at receiving points of compound feed milling enterprises. The article accounts for the dust concentration and particle-size ratios, what provides a rationale for computing efficiency of dust-removal system. Harmful effect of dust on operators depends on its amount in the workplace air. The scheme of dust formation and removal at the feed milling enterprise receiving point has been designed. A methodology for determining the probability of an operator's staying in harmful working environment has been proposed. The structure of dust-removal system has been defined for specific conditions. Installation of enclosures for receiving bunker changes the spatial angle, that constrains discharge from the dust-removal system. The sharper the spatial angle, the higher the airspeed created by the dust-removal system near unloading area, though the structure and technology-related features of production need to be taken into consideration. Design properties of air ducts, treatment facilities, and other ventilation elements will enable creation of a properly structured dust-removal system. It has been inferred that labour conditions have improved due to optimum aerodynamic properties of the dust-removal system. An example has been considered of applying the material herein in practice.

Keywords: receiving point, dust, dust-removal system, air speed, labour conditions.

INTRODUCTION

Compound feed milling enterprises constitute a part of processing industry of the country's agro-industrial sector. Products of compound feed mills are used in animal and poultry husbandry, and fishery. The specifics of organizing a technological procedure therewith makes it impossible to create labour conditions in compliance with regulatory norms, giving rise to a threat to life and health of workers [1-21]. Almost all stages of the process line for producing feed compounds involve releasing certain amounts of dust, since bulk materials are processed, which are transported, ground, dried, and mixed. It should be noted that, during normal operation, large amounts of dust are released into the workplace air and atmosphere at the stage of receiving raw material in the form of grain (wheat, barley, maize) and ground materials (sunflower and soy-bean meals).

Raw material is delivered to receiving centres in bulk by automobile transport in dumping bodies of 12÷37 m^3 volume (8000÷25000 kg). While dumping, raw grain material and meals fall from truck bodies from the height of 1.2÷1.5m to a pit 1.95m deep, leading to a release of raw material and admixtures' particles of up to 2 mm size into the air of a receiving point from raw material due to air entrainment by falling bulk material (Fig.1).

As per regulatory requirements, grain raw material can contain up to 0.2% of mineral and 5% of extraneous impurities [1]. Sunflower and soy-bean meals are delivered crushed. Hence, the particles of either impurities for grain raw material, or crushed material as such for meals are released into the air.Concentration of dust in an operator's workplace of a receiving point during unloading exceeds maximum allowable concentration 16÷429 times (Table 1). Such a concentration remains unchanged within 3÷5 min at each unloading, decreasing thereafter to 1÷4 of MAC, what has long remained constant.

Table 1. Results of examining dust concentration in the workplace of a receiving point operator when dumping raw material

Name of raw material	Dust concentration, mg/m^3	MAC[1] of dust, g/m^3
Maize	191	6
Barley	903	6
Wheat	1703	6
Sunflower meal	2576	6
Soy-bean meal	1108	6
Bran	93	6

[1] Maximum allowable concentration

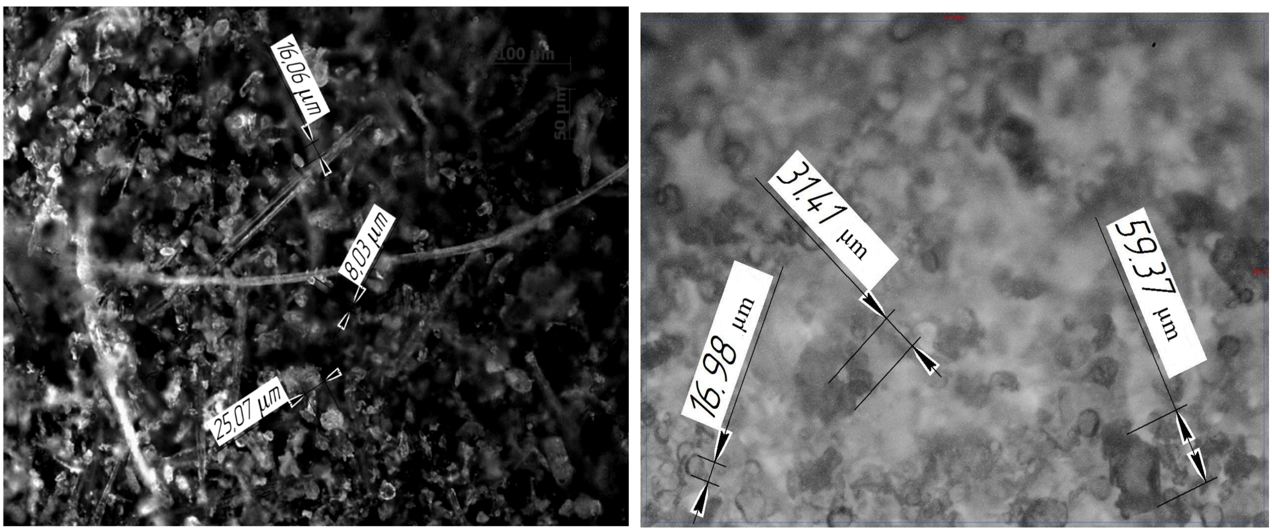
Figure 1. Process of dumping sunflower meal into a dump pit

Dust concentrations in the unloading area may reach values of 20÷35 g/m^3. The receiving centre premises are assigned to fire hazard rating B (explosive/flammable) category and C-IIa zone class, according to the enterprise documentation.

The research objective implies theoretical justification of indicators that affect labour conditions of operators working at receiving points of feed milling enterprises when employing a dust-removal system.

MATERIALS AND METHODS

The authors have carried out a preliminary particle size distribution analysis of some types of dust using microscopic examination (Fig.2). The resultant mean diameter d_m of dust particles and logarithmic mean square deviation lgσ of particles' sizes were determined. They amounted to 20÷30μm and 0.243÷0.312, respectively [22-25]. Concentration and particle size distribution need to be taken into account in estimation of the efficiency of dust-removal (cleaning) systems when predicting work-related diseases.



a ***b***

Figure 2. Micrograph of analytical filter with dust of: *a* – barley; b – bran

RESEARCH RESULTS AND DISCUSSION

As a result, labour conditions C_L of workers at the receiving point of feed milling enterprise are related to an increased dust release, hence, are defined by the probability of remaining in harmful labour conditions P_{hc} [15].

$$C_L \rightarrow f(P_{hc})$$

Fig.3 presents a scheme of dust formation and removal at the receiving point of a compound feed milling enterprise.

$$P_{hc}=f(c,t)$$

Dust concentration c in the workplace air depends on the m system m_r:

$$c=f(m_{e,} m$$

The mass of released dust m_d depends on the number of dust p – on mass (volume) M_R of supplied raw material (grain, meals, (

Harmful effect of dust on operators depends on its amount in the working area air, since the amount of dust accumulated in respiratory organs is directly proportional to its concentration. The time of staying in harmful labour conditions is another significant factor. Thus, the probability of the effect of adverse factors from dust is defined by the dust concentration in the air and the time of operator's work in conditions of the increased dust content.

$$m_d=f(n_d, \delta_d, \rho_p, M_R)$$

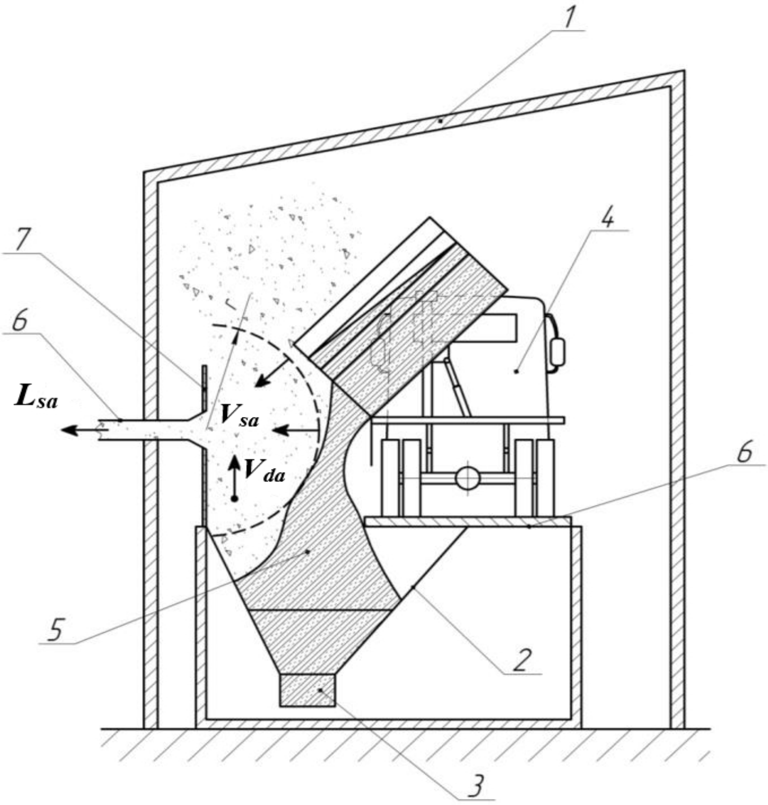


Figure 3. A scheme of dust formation and removal at the receiving point of compound feed milling enterprise: 1 – anti-rain housing; 2 – receiving bunker; 3 – conveyor; 4 – automobile; 5 – poured dust-forming material; 6 – dust-removal system air duct; 7 – side wall; L_{sa} – dust-removal system airflow rate; V_{sa} – speed of air created by dust-removal system close to unloading area;

V_{da} – dusty air speed.

To simplify the problem and to reduce dust concentration in the workplace air to the maximum, mass M_R (and its volume V_R) of delivered raw material will be considered constant for the maximum value, equal to 25t.The mass of removed dust m_r, in its turn, depends on dust properties (size of particles δ_r, absolute dust density ρ_p, number of particles n_r) and modes of dust-removal system operation (air flow rate L_{sa}), hence, the dependence can be written as follows [28]:

$$m_r=f(n_r, \delta_r, \rho_p, L_{sa})$$

Flow rate L_{sa} of air removed by the dust-removal system at the receiving point can be found using expression [26]:

$$L_{sa} = 3600 \times \left(F_o \cdot v_o + \frac{V_R}{t_u} \right); ,$$

where F_o – area of openings in the receiving bunker, m^2;
v_o – speed of air flow in openings, m/sec;
V_R – volume of raw material, m^3;
t_u – time of unloading, sec.

From whence: air flow rate L_{sa} is a constant value, since all the values from formula (6) are constant values:

$$L_{sa} = const$$

The intensity of forming dusts depends on the size of particles δ, that are in the air, the size of which ranges between 1 and 2000 μm at receiving points [27].

The size of removed dust particles δ_r depends on the speed of dust particles' hovering V_{hov}, speed V_{da} of dusty air and air speed V_{sa}, created by the dust-removal system close to the unloading area:

$$\delta_r = f(V_{hov}, V_{da}, V_{sa}).$$

Speed V_{da} of dusty air is determined depending on the volume of raw material V_R (mass of raw material M_R) and, hence, it is a constant value, and hovering speed V_{hov} depends on the size of particles and absolute density of dust. Hovering speed V_{hov} can be defined using the Stokes law:

$$V_{da} = \text{const},$$

$$V_{hov} = \frac{\delta^2 g(\rho_p - \rho_a)}{18\mu}.$$

Since raw material is dumped from the truck body, and dust is released over a long distance, local aspiration units must be installed evenly along the wall of the receiving bunker (Fig.4).

where V_i – component of air speed at the axis of discharge from each aspiration unit at the design point, m/sec.

n – number of aspiration units.

Component V_i of air speed at the axis of discharge from each aspiration unit at the design point will be found from expression

$$V_i = \frac{L_i \cdot x}{\phi_i (x^2 + (y+a)^2)^{1.5}}$$

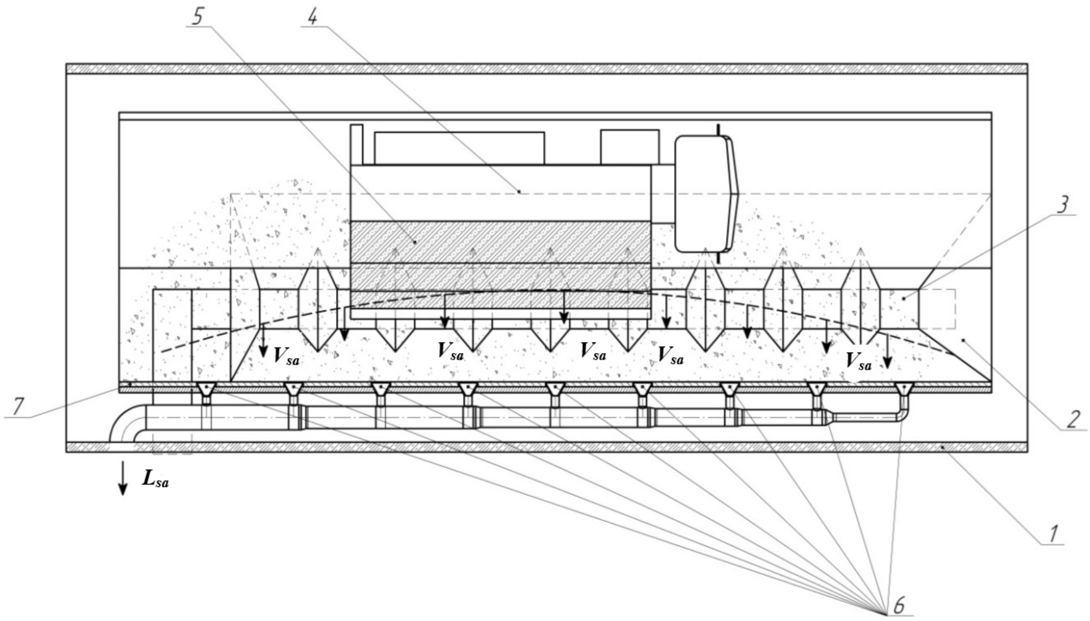


Figure 4. Scheme of forming dust and dust-removal at the receiving point of feed milling enterprise (top view): 1 – anti-rain housing; 2 – receiving bunker; 3 – conveyor; 4 – automobile; 5 – poured dust-forming material; 6 – dust-removal system air duct; 7 – side wall

where L_i – air flow rate through each aspiration unit, m^3/sec;

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

a – position of aspiration unit along the y-axis (Fig. 5), m, from $-n \cdot a$ to $+n \cdot a$;

φ_i – spatial angle that constraints discharge from dust-removal system, radian.

Spatial angle φ_i, that constraints dust-removal system discharge, can be altered by installing enclosures for the receiving bunker. The sharper the spatial angle φ_i, the higher the air speed V_{sa}, created by the dust-removal system close to unloading area in the direction of the aspiration unit, though the structure and technology-related features of raw material delivery to receiving bunkers need to be taken into consideration. Air flow rate L_i through each aspiration unit depends on the number of discharges and is defined as follows:

$L_i = L_{sa}/n$,

As an example, Fig.6 and Table 2 present the results of computing the speed of air flow V_i at the axis of discharge in the x-axis direction in the pouring area with various number of aspiration units, considering design features of the dump pit and dust-removal system elements (air flow rate L_{sa}= 46110 m^3/h, determined using expression (6)).

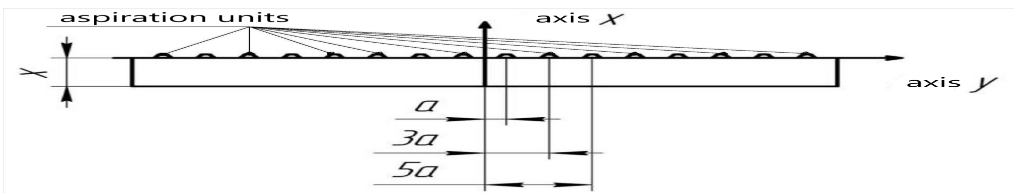


Figure 5. Scheme for computing air speed at distance x

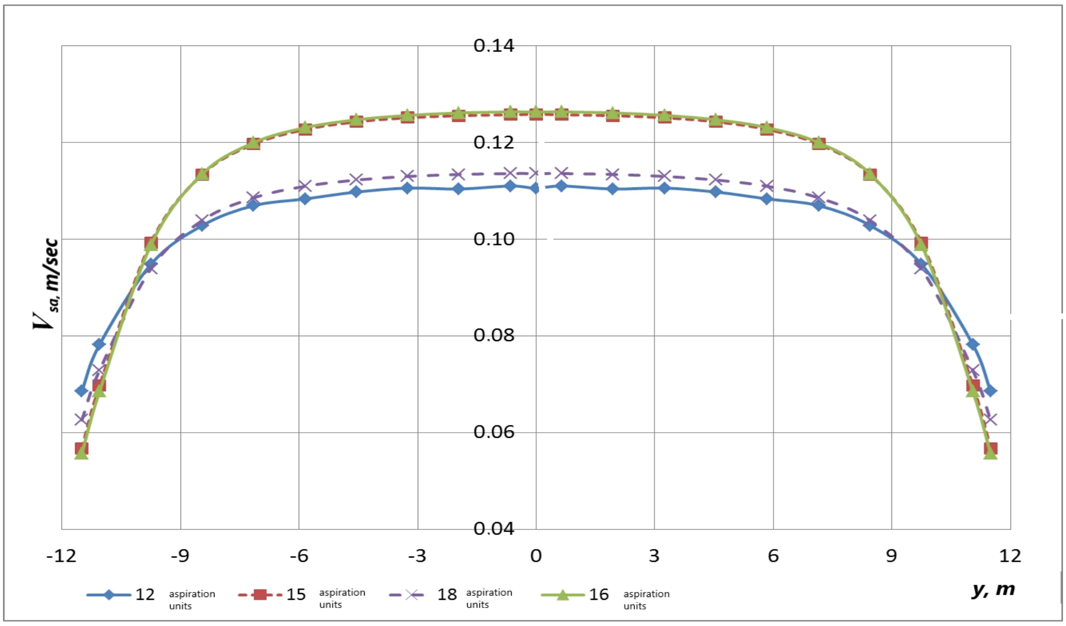


Figure 6. Graph of dependence of V_i, m/sec and position of the number of asiration units in dust-removal system along the *y*-axis

According to Fig.6 and Table 2, the use of 16 aspiration units will be most efficient, since in this case there has been ensured a higher speed of air V_{sa}, created by the dust-removal system within unloading area in the *x*-axis direction in the pouring zone, though the values are slightly higher than when installing 15 aspiration units. Design features of air ducts, treatment facilities, and other ventilation elements will also make it possible to create more rational design of the dust-removal system.

Allowance for expressions (7-14) will enable dependence (5) to take the form:

$$m_r = \left(M_R, x\right) f(n, \phi, \rho_p, V_{hov}),$$

thus

$$P_{hc} = \left(M_R, x\right) f(n, \phi, \rho_p, V_{hov}, t).$$

Table 2. Results of computations of airspeed V_i, m/sec, at the discharge axis in the x-axis direction

Position of point relative to the y-axis, m	Airspeed V_i, m/sec, while installing			
	12 aspiration units	15 aspiration units	16 aspiration units	18 aspiration 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
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Since labour conditions C_L of workers at receiving points are improved by reducing the probability of staying in harmful labour conditions P_{hc}, the following is obtained:

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

As an example, the dust-removal system has been computed considering geometric parameters of the receiving centre and above-mentioned dependences. Fig.7 presents a three-dimensional image of the proposed dust-removal system at the receiving point of a compound feed milling enterprise, and its design parameters are given in Table 3.

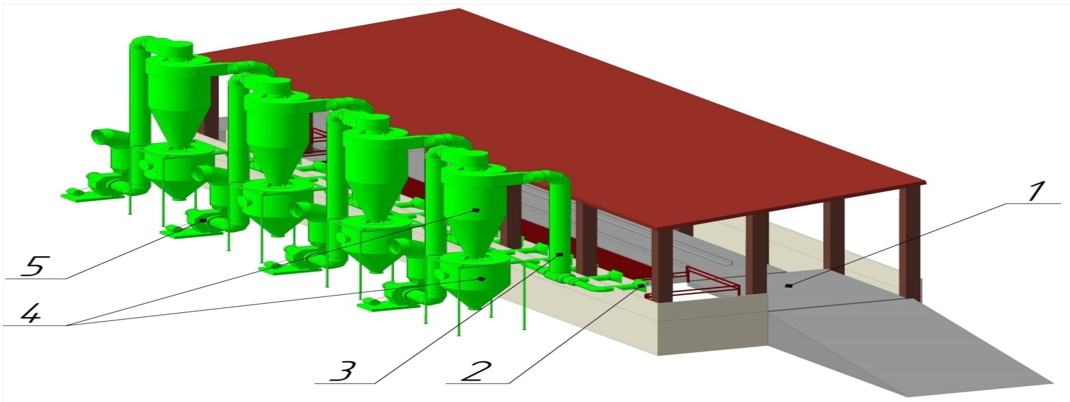

Figure 7. The proposed appearance of a receiving centre with dust-removal system:
1 – receiving point, 2 – aspiration units, 3 – air ducts, 4 – cyclone with bunker, 5 – ventilator

Thus, removal of dusty air during unloading decreases dust concentration in the operator's working area to the values close to MAC. It results in reducing the probability of occurrence of work-related diseases at the enterprise.

Table 3 – Parameters of dust-removal system at the receiving point of compound feed milling enterprise

Total airflow rate L_{sa}, m^3/h	Number of drains n	Airflow rate through each drain L_i, m^3/h	Spatial angle, constraining dust-removal system discharge φ_i, radian	Airspeed created by dust-removal system near dumping area in the direction of discharge V_{sa}, m/sec
48000	16	3000	1.2π	0.12

The local area of dust removal in the zone of unloading bulk dust-like plant-based materials, of explosion and fire hazard, has been newly explored in the article. The publication constitutes a final paper, which summarises the knowledge, previously obtained in the works of various authors [1-24].

CONCLUSION

The quality of operators' health in dusty labour conditions at a compound feed milling enterprise can be improved through comprehensive optimisation of the efficiency of dust-removal system oriented towards enhancing aerodynamic characteristics to reduce the time of a worker's staying in a dusty zone.

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