Creation of a new energy-efficient design of the dustexhaust system

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Abstract. Aspiration systems of processing enterprises (local exhaust ventilation) consume a lot of electricity. The article discusses the new energy-efficient design of the aspiration system when using inclined overload gutters. Energy efficiency is the use of the principle of partial recirculation of aspirated air and the Coanda effect when it is fed directly into the transshipment chute. The article discusses in detail the new effective unit for supplying recirculated air to the reloading chute. The use of the proposed design will reduce more than twice the energy consumption of aspiration systems and the energy intensity of general ventilation systems that supply air to the room. The article provides theoretical information on the operation of systems, the results of the experiment.

Keywords: dust-extracting ventilation, energy efficiency, aspiration system, recirculation, Coanda effect, bulk solids reloading

1. Introduction.
Different technological processes of production and processing of bulk solids in many industrial sectors including construction, mining, metallurgy, coal industry etc. are accompanied with intensive dust emission to the operating area [1-3]. Despite its local character, the indicated (concentrated) sources of dust emission have a dominant influence on the amount of dust in the working areas. The major reason for spreading of the dust is ejection, i.e. air entrainment by the flow of the reloaded bulk solid [4-8].

The only effective way to remove dust when producing bulk materials is to use integrated dedusting systems, which include dust collection systems, means to combat secondary dust emission (Central Vacuum Systems) and general ventilation. Dust collection systems remove dusty air in the places of its occurrence, the Central Vacuum System removes settled dust on surfaces in the room, general ventilation is necessary both to compensate for the volumes of air removed by dust collection systems and to maintain the required parameters of the air in the working area.

The energy intensity of the aspiration systems is determined by the power consumed by the fan, which depends on the volume of aspirated air moved through the air ducts of the system and their hydraulic resistance, a significant part of which (more than 50%) consists of pressure losses in cyclones - the most common dust collectors of the system [9]. Also, the energy intensity of the aspiration systems depends on the cost of cleaning the aspiration air [10].
2. Actuality.
According to the researches, a number of enterprises spend up to 20% of their circulating assets [11–13] for the maintenance of dust-extraction systems and that influences their competitiveness. The reason for that is, first of all, the use of non-effective engineering solutions and the faults in design.

The most promising direction for the improvement of traditional aspiration systems, which makes it possible to significantly reduce the dust emission of the system, is recirculation (return to the reloading chute) of the part of aspirated air (the volume of ejected air). This technical solution allows, due to low power consumption, to reduce both the required performance of the dust collection system and the gas treatment station and the system of general ventilation.

Analysis of the aerodynamics of existing aspiration systems indicates a lack of attention paid to the issues of optimal organization of the supply of recirculated air into the reloading chute. In this connection, the relevance of the development of the method of supplying recirculation air and the technical means of its implementation, which allow to influence the process of formation of the volume of ejection air, is obvious

Thus, the main idea of the presented scientific article is to reduce the energy intensity of both the aspiration systems and the entire dedusting complex due to the supply of recirculated air into the reloading inclined chutes.

3. Task setting. Computation methods
In the works of O.D. Neykov and I.N. Logachev [14, 15], V.A. Minko [16, 17] the movement of air through the chute under the action of ejection of bulk material is considered as the movement of air in the channels with a certain hydraulic characteristic under the action of pressure drop. In general cases, when transferring unheated bulk materials, the volumes of ejection air flowing through the chute \( Q_e \) into the lower cover will be:

\[
Q_e = F \frac{P_e + P_{ob} + \Delta P_u}{0.5 \rho \sum \xi},
\]

where \( F \) is the cross-sectional area of the chute; \( \sum \xi \) is the sum of local resistance coefficients (LRC) of the chute and cover; \( P_{ob} \) is the pressure in the executive devices of the aspirated equipment; \( \Delta P_u \) - is the pressure difference caused by the effect of local exhaust (negative pressure in the cover \( \Delta P_u \)); \( P_e \) is the ejection pressure.

The ejection pressure is a function of the drag coefficient of the material particles, the volume concentration of the material, the average particle diameter, the material flow and its density, the relative velocity of the air and the material in the chute, depending on the height and angle of material incidence.

Most of the above parameters are either uncontrollable (density of air and material, particle size distribution, particle shape, etc.), or poorly-controlled under production conditions (vacuum in the cover, height of material incidence, tilt angle of the overload chute, cross-sectional area of chute etc.).

The only parameter that allows reducing the volume of aspiration under production conditions is the increase in the hydraulic resistance of the "upper cover - chute - lower cover" channel along which the ejected air flow moves.

The hydraulic resistance of the specified channel is determined by the total coefficient of local resistance, calculated by the formula:

\[
\sum \xi = \xi_v + \xi_g + \xi_n,
\]

where \( \xi_v, \xi_g, \xi_n \) is LRC respectively of the upper cover (of the feed conveyor), chute and lower cover (receiving conveyor), related to the air velocity in the chute.
Sealing the upper cover, contributing to an increase in $\xi_v$, is currently the most difficult task under production conditions due to the design of the boot part of the gutter and the reasons for its operational nature. The most promising solution is to reduce the volume of driving air by increasing the hydraulic resistance of the channel "chute - lower cover".

To increase the LRC of the lower cover, various methods are used [18-24], which consist of installing various mechanical obstacles on the path of the driving air flow (partitions, chains, zigzag plates, etc.), some of which can also serve as dust precipitators.

To increase the LRC of the reclaim chute, along with the reduction of its cross section, the installation of various mechanical valves and gates in the path of bulk material is used [25].

However, it should be noted that the above methods of increasing the hydraulic resistance of the "chute - lower cover" channel are not widely used due to some complication of the structures of the cover and chutes, reducing their operational reliability (wear and possibility of jamming of control elements, hanging of the overloaded material, etc.).

The second direction to achieve a significant reduction in the amount of dust-loaded air emitted by the dust-exhaust system into the atmosphere is the use of air recirculation.

More optimal is the partial recirculation of aspirated air, which can be natural or forced.

Forced recirculation is carried out by an external activator of draft, natural - due to the pressure gradient that occurs in the chute as a result of the ejection of air by the bulk material [13]. The areas of overpressure and vacuum of the chute are connected by an aerodynamic channel. This channel (bypass) can be placed inside the chute (coaxially with it or at its side walls), as well as outside the chute.

![Figure 1. Schematic diagram of the recirculation dust-exhaust system using the Coanda effect for with vertical reloading chute [26]: 1. upper aspiration hood; 2. lower cover; 3. reloading chute; 4. aspiration tube; 5 fan; 6. pressure tube; 7 dust cleaning device (cyclonic dust collector); 8 purified air exhaust; 9. bypass pipe; 10. distributor of air-dust concentrate; 11. gate valve.](image-url)
adjustment should be carried out during the period of the absence of material supply. The aspirated air is cleaned in the cyclone 7, and then divided with the help of the flap 11 into the recirculation air and air removed from the system. The analysis of the aerodynamic parameters of dust-exhaust systems with forced recirculation indicates a lack of attention paid to the issues of optimal organization of the recirculation air supply to the reclaim chutes. Existing methods, as a rule, are reduced to a kind of replacement of the driving air flow by the recirculation air. In this connection, the relevance of the development of the method of supplying recirculation air and the technical means of its implementation, which allow to influence the process of formation of the volume of ejection air, is obvious.

There are a number of studies related to the issue [13]. However, in our opinion, the most promising direction today is the use of the Coanda effect when supplying the air to the reclaim chutes. There is a development proposed by the chair of "Heat and gas supply and ventilation" of the Belgorod State University of Technology n.a. V.G. Shukhov ‘Figure 1’ [26], however, this solution is suitable for material transferring along a vertical chute ($\alpha = 90^\circ$), with certain concerns for the possibility of material entering the distribution channel. At the same time, in practice, in most cases, there is the use of inclined chutes; in this regard, the use of the design [26] is unacceptable due to the blockage of the Coanda channels.

4. The results of the research and its discussion

We have carried out a search experiment as a result of which we proposed a method for supplying recirculation air using the Coanda effect [27] when material is transferred through inclined chutes figure 2 . The operation of the system is organized in such a way that air is sucked out from the lower cover 2 by the fan 5 through the aspiration tube 4, this air flows through the pressure tube 6 to the inlet of the dust-cleaning device 7 to separate the air-dust concentrate. The purified air through the tube 8 enters the atmosphere or the next stage of cleaning, and the air-dust concentrate due to the bypass pipe 9 is discharged into the distributors 10 of air-dust concentrate located on the upper edge of the reloading chute in series. Distributors 10 of air-dust concentrate provide the supply of air-dust concentrate in the chute 3 through the Coanda air ducts 11. At the same time, due to the special form of the Coanda air ducts 11, ensuring the occurrence of the Coanda effect, the flow of air-dust concentrate “sticks” to the chute, which allows to increase the angle between the directions of movement of the air-dust concentrate and the air dusty stream moving in the flow. This is explained by the fact that on the one side of the jet of air-dust concentrate the surface of the chute 3 prevents free flow of the air dusty stream, and on the other side the part of the air dusty stream is carried along. As a result, the aerodynamic resistance of the system increases, which reduces air consumption. It should be noted that the number of consecutive distributors 10 ‘figure 2’ may vary depending on the flow rate of recirculation air and the speed of its entry into the reloading chute.

The principal difference between the design and ‘figure 1’ [26] is that the recirculation air is supplied through the Coanda channels, which are located successively in the upper part of the reloading chute. This eliminates the possibility of channel blockage with overloaded material 12 ‘figure 2’ moving along the bottom of the chute.

We have conducted studies of the effectiveness of the proposed design using the COSMOSFloWorks software package [28], which is based on the continuity equation; Navier-Stokes and stationary three-dimensional flow in accordance with the $k-\varepsilon$ turbulence model. Studies were carried out for the dust-exhaust system containing two distributors, at the air velocity in the Coanda channel of 10 m / s. Some graphical experimental results of the proposed design are presented in figure 3, a .

Analyzing the obtained graphical results, we can distinguish two extensive zones of vortex formation in the chute, before and after the supply of recirculation air, which significantly increase the aerodynamic resistance $\xi$ equation (2), thereby reducing the volume of the ejected air $Q_e$. Also, the used Coanda effect can be seen at the upper edge of the reloading chute.

To evaluate the performance of the proposed design, a series of comparative experiments were carried out with the design for a vertical chute [26] under the same initial conditions. The results of the experiment ‘figure 3’ showed that the arrangement of the Coanda channels in a row in the proposed
structure is more efficient than from opposite sides. For example, in ‘figure 3, a, c, e’, there is a more extensive impact of the Coanda effect [28] (beyond the calculated area) compared to the similar ‘figure 3, b, d, f’. Also one of the tasks was to determine the flow rate of ejected air passing through the chute $Q_e$, which turned out to be more than two times lower when using the proposed one-way air supply.

Figure 2. Schematic diagram of the dust-exhaust system with forced recirculation: 1. upper aspiration hood; 2. lower cover; 3. reloading chute; 4. aspiration tube; 5 fan; 6. pressure tube; 7 dust cleaning device (cyclonic dust collector); 8 purified air exhaust; 9. bypass pipe; 10. distributor of air-dust concentrate with the Coanda channel; 11. gate valve. 12 overloaded material.
Figure 3. Graphical results of the experiment (air inlet velocity $v = 10 \, \text{m/s}$, pressure drop in the lower and upper cross sections of the reloading chute 20 Pa, identical cross sections of the chute and Coanda channels, chute height 1.2 m: a, b) air flow pattern in the developed and similar aspiration cover construction, respectively; c, d) distribution of the velocity field in the cross section of the chute in the developed and similar design of the aspiration hood, respectively; e, f) air flow lines in the de-
veloped and similar aspiration hood, respectively.
It should be noted that the effect described by us was obtained at an air speed in the Coanda channel of 10 m/s, a distance between Coanda channels $c = 150$ mm and a channel height of 20 mm, figure 2, and, therefore, for the construction to work under different conditions (air velocity, number of channels, geometric parameters) more research is required.

5. Conclusion
The article presents a new design of the dust-exhaust system, which not only meets the structural requirements to prevent blockage of the channel, but also more than twice reduces the volume of ejection air in relation to the analogue, which in turn will reduce the energy consumption of both dust-exhaust systems and general ventilation systems by 30-70% depending on the parameters of the transfer.

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