

Research Of Aerodynamics Of Recirculation Systems With Forced Aspirated Air

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Abstract

Development of the concept of forced aspirated air recirculation was the purpose of this work. In this method, the air should enhance hydraulic resistance of reloading trough. For this scheme there were conducted analytical studies to determine the conditions that contribute to the reduction of emissions of recirculation systems. Reducing emissions implies both at the expense of recycling, and by reducing the volume of air ejected material is overloaded. The conditions for increasing the value of the hydraulic resistance are one-slit and two-slit air valve. Analytical studies have shown the need to clarify the experimental value of the coefficient of local resistance to the air valve. The experimental study of aerodynamic characteristics of the air valve, as well as aspiration systems with forced recirculation. The result of this research was to clarify the relationship with the local resistance coefficient of air valves. This allows calculating the aerodynamic parameters of aspiration systems with forced recirculation. Depending on the relative flow in the recirculation line and the coefficient of local resistance of the upper shelter obtained conditions that reduce, continuity and growth of volumes of air, bulk material ejected by a closed trough. The conditions affect the relative decline in the volume of ejected air.

Keywords: aspirated air, hydraulic resistance, reloading trough, system with forced recirculation, air valve.

INTRODUCTION

The most effective and common way to deal with concentrated sources of dust is aspiration. Shelter is provided with a dust source local exhaust, creating a vacuum in it, under the influence of which leaks in places formed a counter air flow prevents the penetration of dust premises. Thus, to localize the source, shelter aspirated dust-laden air is supplied into the dust cleaning apparatus, then a fan ejected it to the atmosphere [1]. Shelter with local exhaust, duster, fan and ducts form the aspiration system (AS) [2]. A comparison of the performance of the fresh air (on the condition of equality vacuum in the lower shelters) conventional AS and aspiration system with forced recirculation (Fig. 1) shows that this recirculation system not only reduces, but even keeps the volume aspiration, an equal volume of normal AS. The main reason for that is to reduce pressure loss in the upper shelter, causes a drop in the rate of air through leaks. Wherein a decrease in the pressure loss in the path – "upper shelter – trough – lower shelter" will increase in the volume of air moving through the trough at any place and method of supplying the recycle stream, when it generates no additional flow resistance (noise) in the path of the ejected stream air [3].

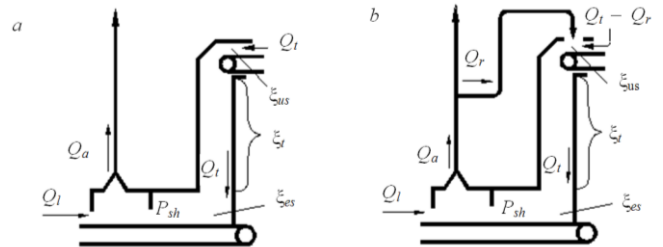


Fig. 1. Diagram of a conventional exhaust system (a) and systems with forced recirculation (b)

The aim of this work is to create a scheme recirculation aspiration system, which provides a fundamentally new way of feeding–recirculating air flow, providing increased hydraulic resistance handling trough.

Development of concept system with forced aspirated air recirculation.

Increased hydraulic resistance offered by the trough system (Fig. 2) is attained by feeding the recirculated air in the form of flat jets directed at an angle of 90 degrees to the flow of the ejected material overridden. Thus, the recycle stream of air creates a kind of cross–section of the trough the air valve (AV), free flowing material is overloaded and prevents the penetration of air from the upper shelter.

Transshipment of bulk mineral in the production condition can be both vertical and inclined trough [4]. In the first case, the air valve may be configured as two opposing flat jets in the second – in the audio form.

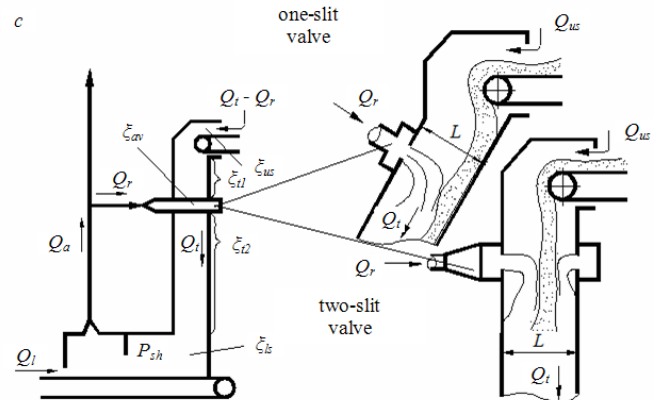


Fig. 2. Schematic diagram of the proposed aspiration system

If neglected, the value of the dynamic pressure in the lower shelter, then the expression for the magnitude of the vacuum in the shelter of the proposed AS will be as follows:

$$P_{sh} = \left(\xi_{ls} + \xi_{t2} + \xi_{av} \right) k Q_t^2 + \left(\xi_{us} + \xi_{t1} \right) k Q_t - Q_r^2, \quad (1)$$

where $[\xi]_{av}$ – coefficient of local resistance (CLR) of the air valve, $[\xi]_{t1}$ and $[\xi]_{t2}$ – CLR trough before and after the air valve respectively, Q_t – the amount of air entering the shelter on a trough under the influence of the properties of the bulk material is ejected and pressure capacity of the process equipment, $k = \rho / 2 S_t^2$ – geometric characteristics of the trough. When the distributor is located recycle stream in the upper section of the reloading trough ($\xi_{r1} = 0, \xi_{r2} = \xi_r$) have

$$P_{sh} = \left(\xi_{ls} + \xi_t + \xi_{av} \right) k Q_t^2 + \xi_{us} \cdot k Q_t - Q_r^2, \quad (2)$$

Comparison between (1) and (2) clearly shows the usefulness of the installation of the distributor of the recycle stream in the lower section of the upper shelter, which will provide the maximum possible flow resistance path "upper shelter – trough – the lower shelter".

Analytical study of the aerodynamic characteristics of the air valve.

The air flow in the trough reloading equipped with air valve (Fig. 3) is a variable gas flow rate [5]. Changing airflow Q_1 , entering into the trough of the upper shelter, is due to the entrance of this channel recycle stream Q_r . As a result, the air flow coming from the trough to shelter.

$$Q_2 = Q_1 + Q_r. \quad (3)$$

Value Q_2 will generally depend on the hydraulic resistance trough, vacuum in shelter P_{sh} and ejected properties of reloaded material.

Hydraulic resistance of the trough determined by the values $[\xi]_1$ and $[\xi]_2$ and action AV ($[\xi]_{av}$). Vacuum in the shelter P_{sh} is defined on the basis of the design shelter [2, 6, 7, 8, 9]. Consider way of the merge air flows AV, whose volume V will be equal to the volume of the trough concluded between sections 1-1 and 2-2. The equation of change of momentum, according to which the momentum of external forces acting on the selected volume, must be equal to the change of momentum of a given mass of gas is [10]:

$$\int_S \rho \cdot \vec{\vartheta} \cdot \vec{\vartheta}_p \cdot ds = - \int_S P \cdot \vec{n} \cdot ds + \int_S \vec{\tau}_n \cdot ds + \int_V \rho \cdot \vec{M} \cdot dv, \quad (4)$$

where $[\vartheta]_p$ – the projection of the velocity vector $[\vartheta]$ the outer normal to a selected volume of gas V ; \vec{n} – the unit outward normal; $[\tau]_n$ – shear stresses on

the court with the outward normal n ; \vec{M} – vector of external mass forces acting on the selected volume, per unit mass; S – the surface of the selected volume V .

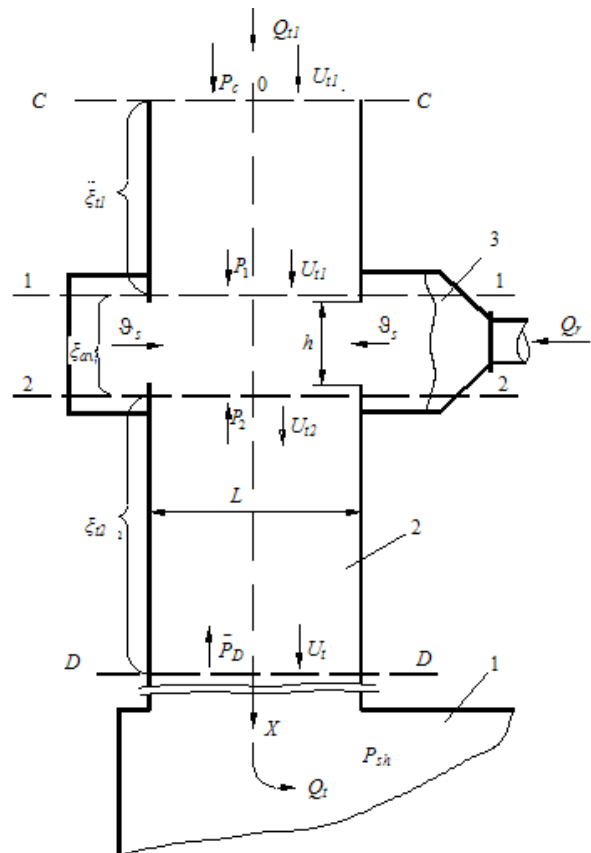


Fig. 3. Reloading trough air valve: 1 – shelter; 2 – trough; 3 – air valve

We take a number of assumptions.

1. The gas parameters in the selected volume unchanged.
2. We consider the steady motion.
3. The motion is assumed continuous. Merging flow occurs instantaneously and uniformly at all points of the scope of the AV. Flow rate at all points before and after valve are the same.
4. Shear stresses on the walls of the trough AV and the area of the walls are the small, from which it follows that $\int_S \vec{\tau}_n \cdot ds \approx 0$.
5. The mass forces acting on the selected volume are negligible due to its small size and low density gas, i.e. $\int_V \rho \cdot \vec{M} \cdot dv \approx 0$.

Based on the above assumptions, the expression (4) can be written as follows:

$$\int_S \rho \cdot \vec{\vartheta} \cdot \vartheta_p \cdot ds = - \int_S P \cdot \vec{n} \cdot ds. \quad (5)$$

In projection on the OX (Fig. 3):

$$\rho \cdot U_2 \cdot U_2 \cdot S_2 - \rho \cdot U_1 \cdot U_1 \cdot S_1 = P_1 \cdot S_1 - P_2 \cdot S_2, \quad (6)$$

where S_1, S_2 – area of the corresponding sections are equal the cross trough $S_i = LB$, where B – its width; P_1 и P_2 – static pressure in the relevant sections, U_1 and U_2 – air velocity before and after AV.

Dividing (6) to S_1 , we obtain:

$$P_1 - P_2 = \rho \cdot U_2^2 - \rho \cdot U_1^2. \quad (7)$$

Adding to the left and right sides of the resulting expression

$$\frac{\rho \cdot U_1^2}{2} - \frac{\rho \cdot U_2^2}{2},$$

obtain

$$P_1 + \frac{\rho \cdot U_1^2}{2} - \left(P_2 + \frac{\rho \cdot U_2^2}{2} \right) = \rho \cdot U_2^2 - \frac{\rho \cdot U_2^2}{2} + \frac{\rho \cdot U_1^2}{2} - \rho \cdot U_1^2. \quad (8)$$

The left side of (8) is the difference of total pressures in the sections 1-1 and 2-2, i.e.

$$\Delta p_{1-2} = p_1 - p_2 = \rho \frac{U_2^2 - U_1^2}{2}. \quad (9)$$

From (3) we obtain equation of flow

$$U_1 \cdot S_t + \vartheta_s \cdot S_s = U_2 \cdot S_t, \quad (10)$$

where $[\vartheta]_s$ – air velocity in the slits AV; S_s – area of slits. With a length approximately equal to the width of the slits of trough have

$$S_s = B \cdot n \cdot h, \quad (11)$$

where h – the height of the slit, n – number of slits of AV. The relation (10) with (11) gives $U_1 \cdot B \cdot L + \vartheta_b \cdot B \cdot n \cdot h = U_2 \cdot B \cdot L$, then

$$U_2 = U_1 + \left(\vartheta \cdot h / L \right) \vartheta_s, \quad (12)$$

and after introducing $f = S_s / S_t = nh / L$, obtain

$$U_2 = U_1 + f \cdot \vartheta_s. \quad (13)$$

Substituting (13) into (9) we obtain

$$\Delta p_{1-2} = \rho \frac{U_1 + f \cdot \vartheta_s}{2}^2 - U_1^2 = \rho \cdot \left(U_1 + f \cdot \vartheta_s \right) \frac{f \cdot \vartheta_s}{2}, \quad (14)$$

from which we find

$$U_1 = \frac{\Delta p_{1-2}}{\rho \cdot f \cdot \vartheta_s} - \frac{f \cdot \vartheta_s}{2}. \quad (15)$$

From the relations (14) and (15) seen that the pressure loss in the air valve and speed U_1 depend on the feed rate of the recycle stream $[\vartheta]_s$ and relationships S_s/S_t . And at $\vartheta_s = 0$ $\Delta p_{1-2} = 0$, which indicates the absence of the hydraulic resistance of the air shutter. In this case, the value Q_1 will depend on the value of the hydraulic resistance between the sections (C-C) – (1-1) and (2-2) – (D-D).

Complete loss of pressure between these sections, respectively amounts to:

$$\Delta p_{C-1} = \xi_1 \frac{\rho \cdot U_1^2}{2}; \quad \Delta p_{2-D} = \xi_2 \frac{\rho \cdot U_2^2}{2}, \quad (16)$$

where $[\xi]_1$ and $[\xi]_2$ – CLR trough sections before and after the AV assigned to the corresponding dynamic pressure. Pressure loss in the passage in the AV, expressed in terms of the relevant CLR $[\xi]_{av}$, divided by the dynamic pressure after the confluence of the streams Q_1 and Q_r .

$$\Delta p_{1-2} = \xi_{av} \cdot \rho \cdot U_2^2 / 2. \quad (17)$$

We express the value of CLR air valve (14)

$$\xi_{av} = \frac{\Delta p_{1-2}}{\rho \cdot U_1^2 / 2} = \frac{f \cdot \vartheta_s \left(U_1 + f \cdot \vartheta_s \right)}{U_2^2},$$

or taking into account (13)

$$\xi_{av} = f \frac{\vartheta_s}{U_2} \left(2 - f \frac{\vartheta_s}{U_2} \right) = \frac{S_s}{S_t} \cdot \frac{\vartheta_s}{U_2} \left(2 - \frac{S_s}{S_t} \cdot \frac{\vartheta_s}{U_2} \right). \quad (18)$$

Given that $S_s \cdot \vartheta_s = Q_r$, a $S_t \cdot U_2 = Q_2$, we obtain

$$\xi_{av} = \frac{Q_r}{Q_2} \left(2 - \frac{Q_r}{Q_2} \right). \quad (19)$$

Entering $q = Q_r / Q_2$ (relative return air flow), the value of CLR

air trough can be represented as follows

$$\xi_{av} = q \left(\xi_1 - \xi_2 \right) \quad (20)$$

As we can see, with the increase in the value of recycling $[xi]_{av}$, i.e. hydraulic resistance AV increases. When fully blocking the flow Q_1 ($q=1$), CLR reaches a maximum value $\xi_{av}=1$, which corresponds to the fully closed air valve.

One of the most important characteristics of the AS is working vacuum in the shelter. Since in this case we consider the reloading trough in isolation from the shelter, the similar characteristics to the trough will discharge in a section D–D (Fig. 3) P_{DD} .

To find the dependence P_{DD} from the aerodynamic parameters of the air valve, first determine the amount of pressure loss Δp_{C-D} between the sections (C–C) and (D–D). Based on the expressions (16) and (18) we have:

$$\begin{aligned} \Delta p_{C-D} &= \xi_1 \frac{\rho \cdot U_1^2}{2} + f \frac{\vartheta_s}{U_2} \left(2 - f \frac{\vartheta_s}{U_2} \right) \frac{\rho \cdot U_2^2}{2} + \xi_2 \frac{\rho \cdot U_2^2}{2} = \\ &= \xi_1 \frac{\rho \cdot U_1^2}{2} + \left(\frac{2f \cdot \vartheta_s}{U_2} - \frac{2f^2 \cdot \vartheta_s^2}{U_2^2} + \xi_2 \right) \frac{\rho \cdot U_2^2}{2}. \end{aligned} \quad (21)$$

Opening parentheses and performing the necessary reductions, we obtain

$$\Delta p_{C-D} = \xi_1 \frac{\rho \cdot U_1^2}{2} + \rho \cdot f \cdot \vartheta_s \cdot U_2 - \frac{\rho}{2} f \cdot \vartheta_s^2 \cdot U_2^2 - \xi_2 \frac{\rho \cdot U_2^2}{2}. \quad (22)$$

On the other hand Δp_{C-D} equal to the difference between the total pressure in the sections of the C–C (P_{atm}) and D–D ($P_D + \rho \cdot U_2^2 / 2$), i.e.

$$\Delta p_{C-D} = P_{atm} - P_D - \rho \cdot U_2^2 / 2. \quad (23)$$

In view of $P_{atm} - P_D = P_{DD}$, we have:

$$\Delta p_{C-D} = P_{DD} - \rho \cdot U_2^2 / 2. \quad (24)$$

Equating the expressions (22) and (24) to obtain a vacuum in section D–D:

$$P_{DD} = \xi_1 \frac{\rho \cdot U_1^2}{2} + \rho \cdot f \cdot \vartheta_s \cdot U_2 - \frac{\rho \cdot f \cdot \vartheta_s^2 \cdot U_2^2}{2} + \frac{\rho \cdot U_2^2}{2}. \quad (25)$$

Given that $f \vartheta_s = Q_r / S_f$; $U_2 = Q_2 / S_f$; $U_1 = Q_1 / S_f$, have

$$P_{DD} = \xi_1 \frac{\rho \cdot Q_1^2}{2 \cdot S_f^2} + \frac{\rho \cdot Q_r \cdot Q_2}{S_f^2} - \frac{\rho \cdot Q_r^2}{2 \cdot S_f^2} + \frac{\rho \cdot Q_2^2}{2 S_f^2}, \quad (26)$$

or where the $Q_r = Q_2 - Q_1$,

$$P_{DD} = \frac{\xi_1 \cdot \rho \cdot (Q_2 - Q_1)^2 / 2 + \rho \cdot Q_r \cdot Q_2 - \rho \cdot Q_r^2 / 2 + \rho \cdot Q_2^2 / 2}{2 \cdot S_f^2}. \quad (27)$$

After transformations we obtain

$$P_{DD} = \frac{0,5 \rho (\xi_1 + \xi_2) Q_2^2 + \rho \cdot Q_r [2 (\xi_1 - \xi_2) + 0,5 \cdot Q_r (\xi_1 - 1)]}{S_f^2}. \quad (28)$$

In view of $Q_r = q Q_2$, relation (28) takes the following form:

$$P_{DD} = \frac{0,5 \rho (\xi_1 + \xi_2) Q_2^2 + \rho \cdot q \cdot Q_2 [2 (\xi_1 - \xi_2) + 0,5 (\xi_1 - 1) q]}{S_f^2}. \quad (29)$$

The resulting expression are interrelated geometric parameters of reloading trough defining values $[xi]_1$, $[xi]_2$, $[xi]$, и air flow rate to the (Q_1 , Q_r) and after merging (Q_2) AV in the magnitude of vacuum at the lower part of the trough P_{DD} . At $q=0$ have

$$P_{DD} = \frac{0,5 \rho (\xi_1 + \xi_2) Q_2^2}{S_f^2}. \quad (30)$$

The resulting value represents the dependence of the vacuum in the D–D cross section without an air valve that corresponds to the conventional AS.

Fig. 4 shows a graph of the vacuum in the section D–D of the trough on the relative flow recirculation air with the other parameters included in the equation (29) is equal to unity.

At $q=0$ we value of vacuum P_{DD} , corresponding normal AS, at $q>0$ – aspiration system with forced recirculation.

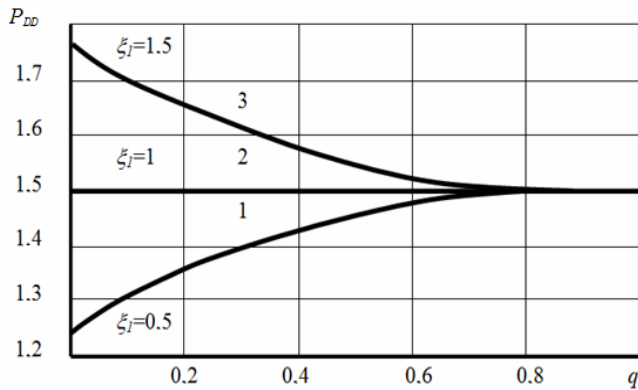


Fig. 4. Dependence of vacuum in the trough on the relative flow of the recirculating air (29)

Line 2 is a relation of the vacuum in the lower section the trough from relative flow in the recirculation line $\xi_1=1$, that is, the resistance of the section of the trough to the air valve equal to the maximum possible value of resistance AV. With increasing q , i.e. transition mode with AS with partial recirculation vacuum in the trough does not change. Consequently, the amount of air supplied from the trough Q_2 the lower shelter and determining the value of aspiration, remains constant, i.e., normal performance AV and recirculation will be the same. The gain in this case can only be obtained by reducing the emissions of exhaust system, equal to qQ_2 .

At $\xi_1 < 1$ (Curve 1) with increasing q increases with the magnitude of the vacuum the same amount of aspiration. Therefore, keeping the vacuum value, we can reduce the amount of aspiration. The magnitude of this decrease will be higher than the above q and less $[xi]_1$.

At $\xi_1 > 1$ (curve 3) with increasing q vacuum in the trough falls and to maintain the desired vacuum aspiration must increase, which may block the gain in reducing the volume of emissions produced by recycling.

It follows that the use of partial recycling is advantageous in those cases where the air flow resistance of the gate is greater than or at least equal to the resistance between the reloading trough sections C–C and 1–1 (Fig. 3). Naturally, the value of this resistance is the smaller, the smaller the distance between these sections, which confirms the validity of the assumption about the feasibility of placing the distributor of the recycle stream at the junction of the upper shelter with overload trough.

If we neglect the dynamic pressure in the lower shelter and enter $\xi_1 = \xi_{its}$, $\xi_2 = \xi_{av} + \xi_r + \xi_{is}$, a certain value, in accordance with (29) will be a vacuum in the lower shelter P_{sh} aspiration system with forced recirculation having aerodynamic characteristics similar to those shown in Fig. 4.

However, a graph obtained on the basis of expression (29) allows evaluating the quality picture aerodynamic systems with forced recirculation of air aspirated. The main reason for that is that the expression (29) includes the dependence (19) for the CLR air valve obtained from the assumptions, significantly simplifying the mechanism of merging of the

streams that naturally distorts the quantitative evaluation of the aerodynamic drag AV.

Experimental study of aerodynamic characteristics of the air valve

Main purpose of the pilot study was to clarify the value of the hydraulic resistance of air valves and aerodynamic characteristics of the aspiration system. Studies were carried out on a specially designed test bench, allowing simulate AS reloading knot at idle, i.e. in the absence of air ejection particulate material. This in practice can be observed at idle or unloaded feed conveyor.

Determining influence relations flows $Q_r / Q_i = q$ and the ratio of areas $S_s / S_i = f$ on the coefficient of local resistance of the air valve. Influence f and q on value CLR at air valve approximately equal (Fig. 5), i.e. level specified by the hydraulic resistance can be obtained due to a change in the recirculation line flow and by varying the height of slits of air valves.

When q changing from 0.55 to 0.85 magnitude CLR one-slit AV practically stable and slightly different from the maximum value attained at $q \approx 0.7$. A substantial increase of the hydraulic resistance one-slit valve (in the range of q) can be achieved by reducing the height of the slit, i.e. increasing the air velocity in it. However, reducing the height of the slit, i.e. its area, will result in an increase of the hydraulic resistance in the recirculation line.

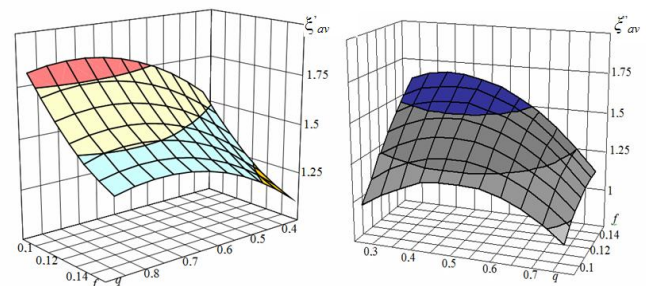


Fig. 5. Response surface f and q CLR of air valves

For the two-slit AV highest hydraulic resistance observed in a narrow range of q , which with increasing height of the slit is shifted downward volume of air in the recirculation line.

By increasing the relative flow of recirculation air for one-slit and two-slit shelter growth takes place, and then, after some stabilization a drop in the hydraulic resistance. In our opinion, this process can be explained as follows.

Flowing out of the slit plane jet recirculation air entraining deflected stream from the upper shelter into the trough, and eventually destroyed, wherein the jet core destruction may occur both before and after the rotation by 90° . With an increase the velocity of the deviating, the flat jet covers most of the trough section, which promotes the growth of flow resistance. But on the other hand, if the jet, make a turn at an angle of 90° degrees, kepted its dynamic structure, it will contribute to the ejection entraining air stream, which is located between it and the opposite wall of the trough, which

explains the drop in the hydraulic resistance of the AV for large values of q . Particularly sharp drop in the value of the CLR is seen in the two-slit AV, as deflection of the jet he contributes not only razing the flow, but also a counter current of air, which at high q unlike the stationary wall of the trough will not interfere with, and contribute to the action of the jet is ejected.

The curves shown in Figure 5, indicate the appropriateness of one-slit AV at large ($q \approx 0.55 \dots 0.85$), and the two-slit – at low ($q \approx 0.25 \dots 0.5$) recycling volumes.

CONCLUSION

Experimental study of aerodynamic characteristics of the aspiration system with forced recirculation.

In the course of study is determined by the experimental dependence is a volume aspiration of hydraulic resistance path "upper shelter – trough – lower shelter," and produced and compared with the calculated values.

Figure 6 shows the dependence of the volume of air sucked through leaks shelter Q_l from recycling volumes Q_r at a constant flow rate of aspirated air Q_a . Q_l increase due to an increase in shelter dilution caused by the increase in hydraulic resistance path – "trough – lower shelter" by the amount due to the action of one-slit AV, as evidenced by changes of curves 1...3, reminding according to CLR air valve (Fig. 5, a). At $q=0$ and volume of aspiration $Q_a=400$ kgph, we have the usual AS with vacuum in a shelter, characterized by an $Q_l=420$ kgph (curve 3). When the amount of recycling $Q_r=400$ kgph and $Q_a=1000$ kgph (curve 1), we have a system with forced aspiration recycling can increase the vacuum in the shelter ($Q_l=480$ kgph) compared with conventional AS and reduce the amount of aspiration to 30 %.

However, these results were obtained at the lowest-possible aerodynamic resistance of the upper shelter experimental bench. By increasing the resistance of the upper shelter, achieved through the installation of metal grids, the relative change Q_l changed both quantitatively and qualitatively. Changes in the volume of air ejected from the growth rate in the recirculation line are also ambiguous (Fig. 7).

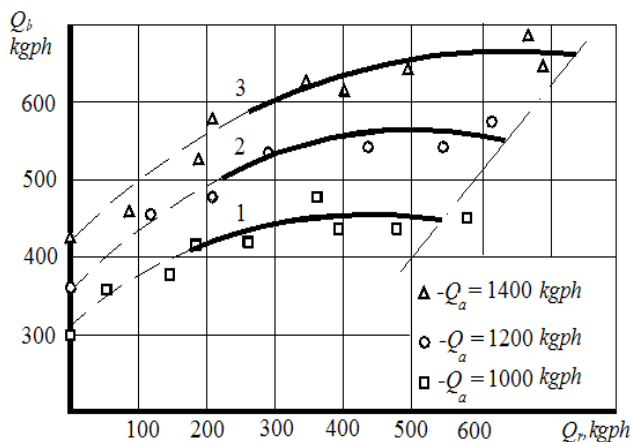


Fig. 6. Dependence Q_l of Q_r at $Q_a = \text{const}$: 1...2 – settlement; Δ , \circ , \square – experimental value

Curves 1...4 show a decrease in the volume of ejected air at constant vacuum P_{sh} in the shelter, i.e. in this case, to increase the recirculation volume $q \approx 0.9$ reduces the flow of air aspirated through the fall Q_l .

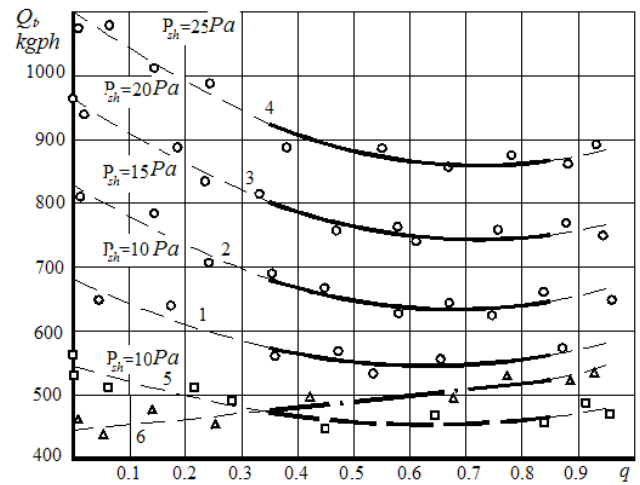


Fig. 7. Dependence Q_l from the q at $P_{sh} = \text{const}$: 1...6 – settlement; Δ , \circ , \square – experimental value

By increasing the resistance of the lower shelter, by decreasing the clearance between the end of the vertical partition and the conveyor belt cover also holds the ejection decline (curve 5), but in this case the value of Q_l reduced by 14 %, and for curve 1 with the same negative pressure in the shelter reduction in ejection will be 21 %. Therefore, the increasing of hydraulic resistance of the lower shelter, eventually leads to the independence of the volume of air ejected from the recirculation line in the flow system.

The curve 6 has been obtained by setting the upper shelter section of metal grid, simulating an upper shelter having a high hydraulic resistance. In this case the use of recycling is impractical, since the ejection volume increases.

RESULTS

The conducted analytical researches has allowed determining conditions that reduce emissions recirculation systems, both through recycling and by reducing the volume of air ejected reloaded material, and also showed the need to clarify the experimental value of the CLR air valve.

Increasing the value of the hydraulic resistance of the air valve may be achieved either by relative flow of recirculating air q , and by changing the ratio of the areas of the slit and trough f . And, for one-slit AV reduction f implies growth of hydraulic resistance, and for the two-slit decline.

As a result, the experimental studies have provided updated according to CLR air valves that allow calculating the aerodynamic parameters of aspiration systems with forced recirculation.

We obtain conditions for reduction, persistence and increase in volumes of air, bulk material ejected by closed trough, depending on the relative flow in the recirculation line q and CLR top shelter $[xi]_{us}$.

Relative reduction in the volume of ejected air depends on of hydraulic resistance of the air valve, and the resistance of the lower shelter, with an increase in the relative decline in volumes which ejected air tends to zero.

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