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EJECTION OF AIR BY THE STREAM OF BULK MATERIALS IN A VERTICAL PERFORATED CHANNEL

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Abstract. Were obtained and solved the hydrodynamic equations for estimating inter-component communication in a vertical perforated chute when moving there gravitational flows of granular materials and ejected air. Identified parameters that provide the greatest decrease in volumes of ejection through recycling air. The research is being supported by the Council for Grants of the President of the Russian Federation (projects NSH-588.2012.8), RFBR (project number 12-08-97500-p_center_a), and Strategic Development Plan of BSTU named after. V. G. Shukhov.

1 INTRODUCTION

Aspiration is one of the most effective ways for dust abatement during accelerations of granular materials [1-3]. With increasing of technological equipment increases power consumption of aspiration system, and growing losses of granular material by suction dust-laden air from the suction covers. And for it occurs requirement to achieve the greatest hygienic effect of less. The main ways of reducing the energy intensity of aspiration is to reduce the volume of air entering through thinnesses [4-11] and the volume of the ejected air flow granular materials due to the organization in the loading chute ejected air circulation. In order to ensure air circulation is used a bypass chamber, coupled aerodynamically with a cavity loading chute. In this paper we consider flow of particles in a perforated round tube around which provides a cylindrical chamber with bypass transit exchange of air between the reloading hideouts node aspiration of the lower hideout (fig.1).

The purpose of the research was obtaining quantitative performance indicators of the decision.

2 INITIAL EQUATIONS

Movement of ejected and return air is carried out by aerodynamic forces falling in the channel loaded material particles and the vacuum in the lower cover, created by the fan of the suction system. Moreover, recycling of ascending air in the bypass chamber through holes is performed as a uniform perforation walls of the groove and through the end openings at the ends of the bypass chamber, through which air enters from the inner chamber into the cavity of the lower cover bypass chamber and is not in the upper cavity suction cover, by reducing vacuum in the latter and thereby reducing the transit air Q_1.

As ascending movement of air flow raises, its consumption also increases due to continuous supply through the perforations of the walls of chute at the bottom of the air ejection portion and decreases in the upper part of the bypass chamber.

Thus, there are two rings of recirculated air: internal small ring in which air is circulated ejected air, and the large outside ring along which performed so-called transit exchange of air between the hideouts of reloading unit.

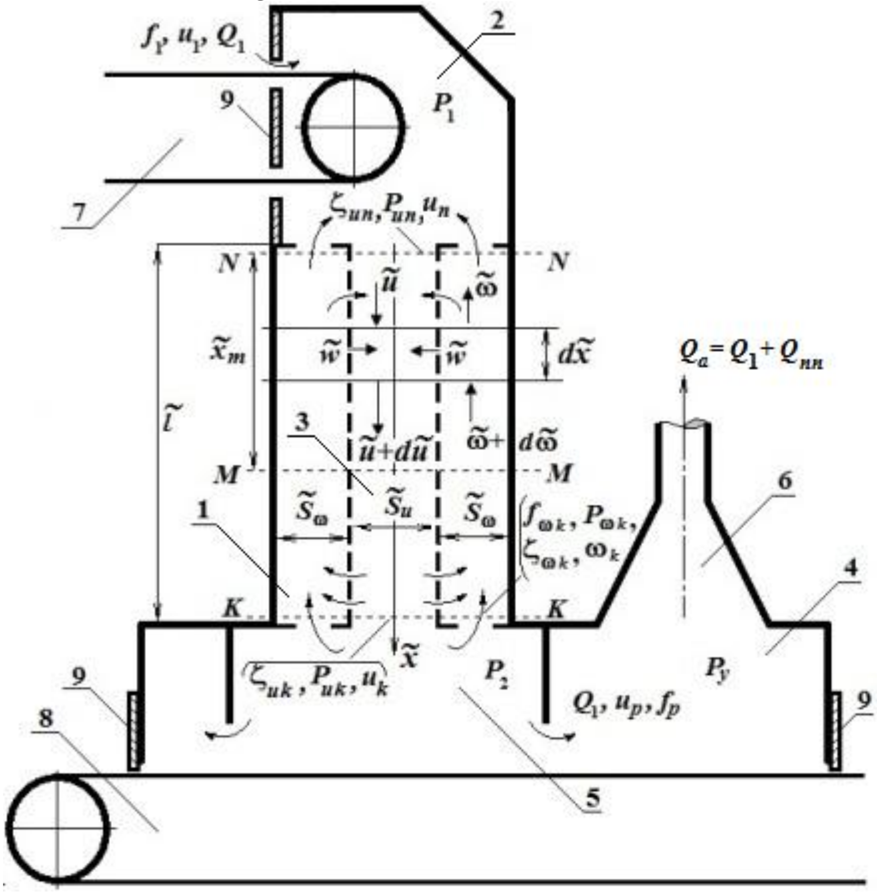

Figure 1: Scheme of ejection and recycled air in the chute with a combined bypass chamber: 1 - bypass chamber the transit passage of recycled air, 2 - top cover, 3 - gutter with perforated walls, 4 - bottom cover with the internal chamber for receiving 5 Loaded material, 6 - Aspiration pipe, 7 and 8 - the upper and lower conveyors 9 - sealing aprons

For the formation boundary conditions we distinguish three distinct section: the initial N - N (remotely on ε infinitesimal distance from the origin, i. e, if $\tilde{x}=0+\tilde{\varepsilon}$), the final K - K (under section $\tilde{x}=\tilde{l}-\tilde{\varepsilon}$) and the intermediate-extreme M - M (cross-section, remote on the distance $\tilde{x}_m$ from the origin), in which there is the extreme speeds (loses) ejected and return air.

We will denote dimensional quantities upper index "~", averaged over the length $\tilde{l}$ - lower index s (instead of the simple traits of the letter), the dimensionless quantities - the same symbols, but without the "~". The equations of continuity due to the fact that the cross-sectional areas of trough and bypass chamber are constant and equal, respectively, $\tilde{S}_\omega$ and

$\tilde{S}_u$ but perforated wall is uniform along the length of chute, so they assume the form:

$$du/dx = \tilde{S}_0 w/\tilde{S}_u;\ d\omega/dx = \tilde{S}_0 w/\tilde{S}_\omega, \tag{1}$$

where $\tilde{S}_0 = \tilde{\Pi}\tilde{l}\varepsilon_0$ - is total area of the perforations holes of the walls of the gutter ($\tilde{\Pi}$ - the perimeter of the gutter cross section; $\tilde{l}$ - the length of the gutter; ε_0 - the degree of perforation.

Taking into account that ratio $r = \tilde{S}_\omega/\tilde{S}_u$ is constant over the length, the system can be written (1) in the form:

$$du = rd\omega \Rightarrow u - r\omega = z - \text{const} = u_n - r\omega_n = u_k - r\omega_k. \tag{2}$$

To determine the physical nature of the constant z write an obvious balance of air flow for hideouts:

$$\tilde{Q}_1 + \tilde{\omega}_n\tilde{S}_\omega = \tilde{u}_n\tilde{S}_u, \tilde{u}_k\tilde{S}_u = \tilde{Q}_1 + \omega_k\tilde{S}_\omega \Rightarrow \tilde{u}_n = r\tilde{\omega}_n + \tilde{Q}_1/\tilde{S}_u, \tilde{u}_k = r\tilde{\omega}_k + \tilde{Q}_1/\tilde{S}_u, \tag{3}$$

where $\tilde{Q}_1$ - consumption of air transit, m^3/s. By comparing this system of of equations with (2), we have $z = \tilde{Q}_1/\left(\tilde{v}_k\tilde{S}_u\right)$, where constant z – is an expense ratio of of the "global pass through" to the maximum possible air flow of ejected air. Due to the fact that $\tilde{Q}_1$ is a part ejected air (total volume flow of air out of the lower cover, $\tilde{Q}_a = \tilde{Q}_1 + \tilde{Q}_{nn}$, where $\tilde{Q}_{nn}$ - volumetric flow rate of of air entering through leakages of cover), the constant z is the unknown quantity of our main objectives.

We also mention to an important relationship, easily obtained from the (3) $\tilde{S}_u(u_k - u_n)\tilde{v}_k = \tilde{S}_\omega(\omega_k - \omega_n)\tilde{v}_k = \tilde{Q}_R$, where $\tilde{Q}_R$ - volumetric flow rate of of air flow between the air ejected in the trough and the air flow recycled to the bypass chamber. Recycling coefficient is determined by the obvious relation $R_z = \tilde{Q}_\omega/\tilde{Q}_u = 1 - z/u_k$.

The dynamic equation of the rising air flow in the bypass chamber takes the form:

$$dp_\omega + 4\omega d\omega = 0;\quad p_\omega = 2\tilde{p}_\omega/(\tilde{\rho}\tilde{v}_k^2);\quad \omega = \tilde{\omega}/\tilde{v}_k. \tag{4}$$

The equation of ejected air in a perforated chute:

$$dp + 4udu = \text{Le}(v-u)\left|v-u\right|/v\cdot dx,\ \text{Le} = 1.5\psi\beta_k\tilde{l}/\tilde{d}_e, \tag{5}$$

where ψ - the drag coefficient of particles; β_k - the volume concentration of particles at the end of the gutter; d_e - equivalent the particle diameter of granular materials; $\tilde{v}_k$ - granular velocity at the end of the chute.

The condition of air flow through the perforations wall of the gutter: $p_\omega - p_w = \zeta_0\left|w\right|w$, where w - the dimensionless velocity of the air overflow, which is considering the first equation (1) can be written as:

$$w = du/\left(E\sqrt{\zeta_0}dx\right), \tag{6}$$

где $E = \tilde{S}_0/\left(\tilde{S}_u\sqrt{\zeta_0}\right)$ - dimensionless parameter that characterizes the degree of perforation of the wall gutters and the local drag factors (l.d.f.) holes.

Before proceeding to the integration of the equations (4) and (5), we formulate the boundary conditions. We shall assume that area of of end cross sections the gutter and the bypass chamber equal to the cross-section of the gutter and the camera. In this regard, the boundary conditions for the air velocity will have the following form:

in the initial section *N-N* (if $x=0$) $\quad u(0)=u_n$; $\omega(0)=\omega_n$; (7)

$$w(0)=u'(0)/\left(E\sqrt{\zeta_0}\right)=\gamma_w(0)\sqrt{\left|p_\omega(0)-p_u(0)\right|/\zeta_0},\ \gamma_w(0)=\text{signum}\left(p_\omega(0)-p_u(0)\right); \quad (8)$$

in the final section *K-K* (if $x=1$) $\quad u(1)=u_k$; $\omega(1)=\omega_k$; (9)

$$w(1)=u'(1)/\left(E\sqrt{\zeta_0}\right)=\gamma_w(1)\sqrt{\left|p_\omega(1)-p_u(1)\right|/\zeta_0},\ \gamma_w(1)=\text{signum}\left(p_\omega(1)-p_u(1)\right). \quad (10)$$

The boundary conditions for the static pressure can be expressed in terms l.d.f. and the magnitude of the excess pressure in the shelter reloading units:

in the initial section *N-N* $\quad p_u(0)=p_1-\zeta_{un}u_n^2;\ p_\omega(0)=p_1-\zeta_{\omega n}\omega_n^2$ (11)

in the final section *K-K* $\quad p_u(1)=p_2-\zeta_{uk}u_k^2;\ p_\omega(1)=p_2-\zeta_{\omega k}\omega_k^2,$ (12)

where ζ_{un}, ζ_{uk} - l.d.f. respectively entrance of ejected air into the chute and exit out of the gutter; $\zeta_{\omega n}$, $\zeta_{\omega k}$ - l.d.f. respectively output from the upstream bypass air chamber and its input into the chamber; p_1, p_2 - excessive static pressure, respectively, in the upper (not ejected) cover and in the receiving chamber of the lower (ejected) cover. The value of the latter can be expressed in terms l.d.f. thinnesses of the upper cover (ζ_1), septum of receiving chamber (ζ_p), dimensionless vacuum in the the ground cover (p_y) and the required parameters *z*:

$$p_1=-\zeta_1\left(\tilde S_u/\tilde f_1\right)^2 z^2=-\zeta_1^* z^2,\quad \zeta_1^*=\zeta_1\left(\tilde S_u/\tilde f_1\right)^2; \quad (13)$$

$$p_2=p_y+\zeta_p\left(\tilde S_u/\tilde f_p\right)^2 z^2=p_y+\zeta_p^* z^2,\quad \zeta_p^*=\zeta_p\left(\tilde S_u/\tilde f_p\right)^2, \quad (14)$$

where $\tilde f_1$ - the total area of the upper cover of leaks; $\tilde f_p$ - the total area of the gap between the walls of the receiving chamber of the lower cover and loaded with a conveyor belt; $\tilde S_u$ - cross sectional area of the gutter.

3 PARTICULAR CASE OF BYPASSING

We consider the case of granular materials through a chute with impenetrable walls (if $\zeta_0\to\infty$, $E=0$). With a small margin of error can be put

$$u_n=u_k=u\equiv u_c-\text{const},\quad \omega_n=\omega_k=\omega\equiv\omega_c-\text{const}. \quad (15)$$

In this case, integration is possible for dynamics equations of ejected air (5) in a final form, such as a stream of uniformly accelerated falling particles, speed of which $v=\sqrt{(1-n^2)x+n^2}$; $n=\tilde v_0/\tilde v_k$ can be as an independent variable of integration, $\tilde v_0$ - velocity of the particles entering into the chute.

The initial equation then, due to the fact that $dx=2vdv/(1-n^2)$, will take a simple form $dp_y=2\text{Le}(v-u_c)\left|v-u_c\right|dv/(1-n^2)$, the final decision is with the boundary conditions (11), (12) and with (15) has the form:

$$\mathrm{Eu}+u_c\left|u_c\right|=\left(\left|1-u_c\right|^3-\left|n-u_c\right|^3\right)\mathrm{Bu}/3\,, \tag{16}$$

where Eu - the Euler's criterion:

$$\mathrm{Eu}=\left(p_2-p_1\right)/\zeta_u\,, \tag{17}$$

$\mathrm{Bu}=2\mathrm{Le}/\left(\zeta_u(1-n^2)\right)$ - the criterion Butakova-Neykova, $\zeta_u=\zeta_{un}+\zeta_{uk}$ - the amount l.d.f. of the trough.

According to (13) and (14), the Euler's number can be expressed in terms of the local drag factors (l.d.f.) of leakages of the upper cover (ζ_1^*) and partitions of the receiving chamber (ζ_p^*), related to the speed of the ejected air u_c.

$$\mathrm{Eu}=\left(\zeta_n^* z_c\left|z_c\right|+p_y\right)/\zeta_u\,, \tag{18}$$

$$z_c=u_c-r\omega_c\,,\ \zeta_n^*=\zeta_1^*+\zeta_p^*\,. \tag{19}$$

On the other side of the equation (4) with $\omega=\omega_c$, $dp_\omega=0$, from which, using the same boundary conditions for the pressure, we obtain: $p_2-p_1=\zeta_\omega\omega_c\left|\omega_c\right|$, $\zeta_\omega=\zeta_{\omega n}+\zeta_{\omega k}$ - the amount l.d.f. of bypass chamber, and therefore the criterion of Euler (17) can be written in terms of the speed of the upstream

$$\mathrm{Eu}=\omega_c\left|\omega_c\right|\zeta_\omega/\zeta_u\,. \tag{20}$$

Then the equation (16) will become: $\omega_c\left|\omega_c\right|\zeta_\omega/\zeta_u+u_c\left|u_c\right|=\mathrm{Bu}\left(\left|1-u_c\right|^3-\left|n-u_c\right|^3\right)/3$, taking into account (19), (18) and (20) we find the following equations to determine the parameter z_c, velocity of ejected air in the channel and the speed of the upstream recirculating air in the bypass chamber:

$$f/\zeta_u+F\left|F\right|=\mathrm{Bu}\left(\left|1-F\right|^3-\left|n-F\right|^3\right)/3\,, \tag{21}$$

$$u_c=F;\qquad \omega_c=f/\sqrt{\zeta_\omega\left|f\right|}\,;\qquad f=\zeta_n^* z_c\left|z_c\right|+p_y\,;\qquad F=z_c+rf/\sqrt{\zeta_\omega\left|f\right|}\,. \tag{22}$$

Having determined the solution of equation (21) the amount of z_c, is possible to find air consumption $\tilde{Q}_1$, injected into the lower cover as a result of the dynamic interaction of the flow of granular materials and the vacuum in the cover $\tilde{Q}_1=z_c\tilde{v}_k\tilde{S}_u$, as well as the return air flow in the bypass chamber $\tilde{Q}_R=\omega_c\tilde{v}_k\tilde{S}_\omega$ and air consumption $\tilde{Q}_u$, coming from the chute into the inner chamber: $\tilde{Q}_u=u_c\tilde{v}_k\tilde{S}_u$. Naturally, under isothermal conditions should be observed apparent balance of these costs $Q_R+Q_1=Q_u$.

To determine the air flow coming from the trough bottom cover closed end holes bypass chamber (i.e. if $\tilde{Q}_R=0$) necessary to solve the equation (16) considering that $u_c=u_0=z_c$:

$$\mathrm{Eu}_0+u_0\left|u_0\right|=\mathrm{Bu}\left(\left|1-u_0\right|^3-\left|n-u_0\right|^3\right)/3\,,\qquad \mathrm{Eu}_0=\left(\zeta_n^* u_0^2+p_y\right)/\zeta_u\,. \tag{23}$$

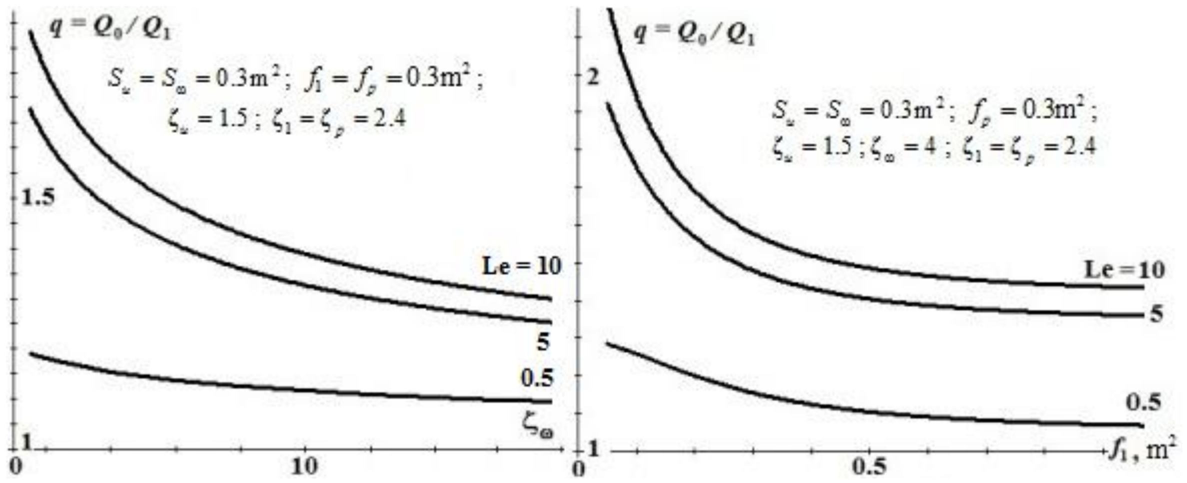

Figure 2: Changing the relative air flow injected into the lower cover stream of bulk material according to l.d.f. bypass chamber ζ_ω and from the area of the upper cover of thinnesses f_1 if $v_0 = 3\text{m/s}$; $v_k = 10\text{m/s}$; $P_3 = -10\text{Pa}$; Q_1 - with a bypass chamber; Q_0 - if $\zeta_\omega \to \infty$

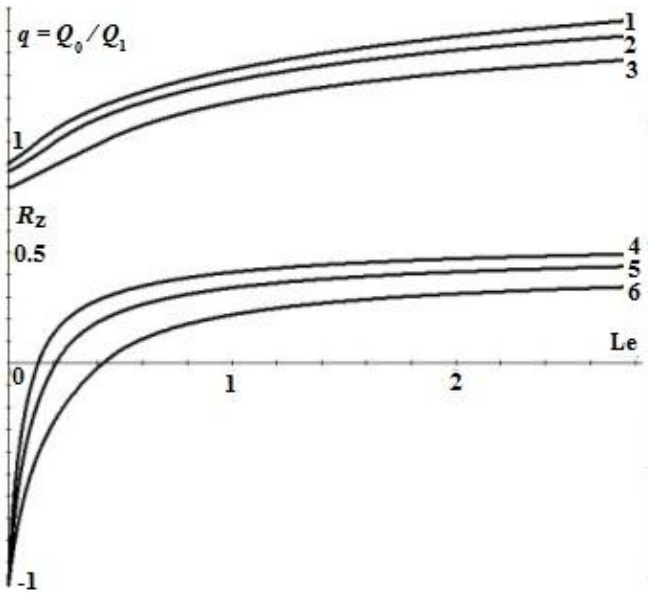

Figure 3: Changes of relative airflow $q = Q_0 / Q_1$ and the rate of ejected air, depending on the size of Le (if $S_u = S_\omega = 0.3\text{m}^2$; $f_1 = f_p = 0.3\text{m}^2$; $v_k = 10\text{m/s}$; $\zeta_1 = \zeta_p = 2.4$; $n = 0.3$; vacuum in cover $P_3 = -10\text{Pa}$, generated by the fan of suction installation): 1 - q if $\zeta_u = \zeta_\omega = 1.5$; 2 - q if $\zeta_u = \zeta_\omega = 2.4$; 3 - q if $\zeta_u = \zeta_\omega = 4.8$; 4 - R_z if $\zeta_u = \zeta_\omega = 1.5$; 5 - R_z if $\zeta_u = \zeta_\omega = 2.4$; 6 - R_z if $\zeta_u = \zeta_\omega = 4.8$

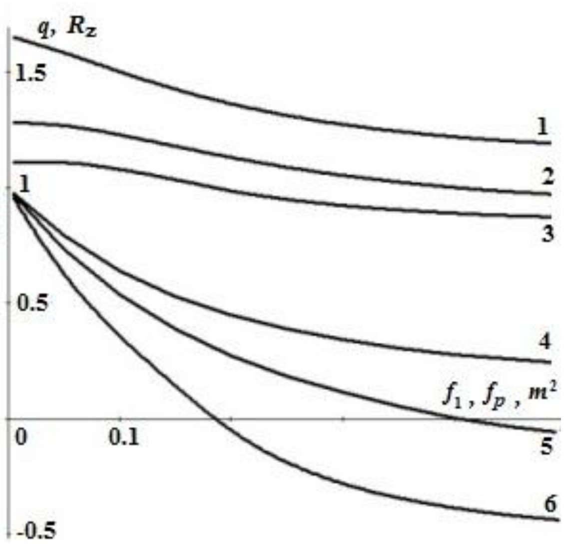

Figure 4: Change the relative airflow $q = Q_0 / Q_1$ and the rate of recycle air R_z depending on the size leakages f_1 (if $f_p = 0.3\text{m}^2$), or from the square of the gap receiving f_p (if $f_1 = 0.3\text{m}^2$) if $S_u = S_\omega = 0.3\text{m}^2$; $\zeta_1 = \zeta_p = \zeta_u = \zeta_\omega = 2.4$; $v_k = 10\text{m/s}$; $n = 0.3$; $P_3 = -10\text{Pa}$: 1 - q by Le = 1.0; 2 - q if Le = 0.3; 3 - q if Le = 0.1; 4 - R_z if Le = 1.0; 5 - R_z by Le = 0.3; 6 - R_z if Le = 0.1

Determined from equation (23) the speed u_0 , find the flow range of air $Q_0 = u_0 \tilde{v}_k \tilde{S}_u$, coming from the chute to the lower cover in the absence of the bypass chamber. Consumption of this air is increasing (fig.2-3) compared with the chute at overloading through the bypass chamber with low aerodynamic resistance ($\zeta_\omega < 2$) and with a small area of the upper cover of thinnesses ($f_1 < 0.2$ m^2) particularly when big numbers of ejection ($\mathrm{Le} > 5$). With the growth of the parameter of ejection Le, the recycle coefficient is also changing R_z (fig.3) from -1 till the positive "asymptotic" values if $\mathrm{Le} \geq 3$. Negative numbers of R_z at small values of Le explained by the fact that because of the large depression in the lower cover ($p_3 \leq -10$) and the small capacity of ejecting the flow of granular materials, bypass chamber plays the role of a parallel airduct through which air from the top cover comes into the receiving chamber – so there is a "negative recycle" ($\omega_c < 0, q < 1$). This can be avoided by increasing aerodynamic resistance ζ_n^* and reducing the area of thinnesses f_1 and f_p (fig.4).

Noticeable the role of sealing the upper cover and the device receiving chamber with a small gap for the passage of the material. Of course, in the absence of the camera there is a "positive recycling" which is suitable for only when the vacuum in the top cover through good sealing will have more vacuum created by the fan in the lower cover.

4 EFFICIENCY OF COMBINED BYPASSING

Let's go back to the general statement of the problem. Let us estimate how much will change recycled air circulation with two rings. For this purpose we linearize the the original equations (4) and (5) by asuming: $udu \approx \bar{u}du;\ \omega d\omega \approx \bar{\omega}d\omega$. Obtained results do not significantly differ from the solutions of the original system of nonlinear equations. This is connected to the fact that loss of pressure in the movement of air in these channels is mainly determined by local losses, but no changes velocity of pressure. Furthermore, we assume a linear variation of the mass forces inter-component communication in the flow of granular materials:

$$\mathrm{Le}|v-u|(v-u)/v \approx k\mathrm{Le}(v-u); \quad k = \overline{|1-u/v|} \approx 1-\bar{u}/\bar{v}. \tag{24}$$

The line above (expression) is averaging values along the length of the gutter (or bypass camera). In order to simplify the right side of the linear equation, we replace the uniformly accelerated flow of material at an accelerated (conditional) flow which velocity is determined by the trinomial $\bar{v} = b_0 + b_1 x + b_2 x^2/2$. Then the averaged velocity of the particles is $\bar{v} = b_0 + b_1/2 + b_2/6$, where $b_0 = n; b_1 = \sqrt{8(1+n^2)} - 3n - 1; b_2 = 4\left(1+n-\sqrt{2(1+n^2)}\right)$.

As for the the pressure losses in the perforations walls of the gutter, we assume that they depend linearly (rather than square) on the speed $p_\omega - p_u = \zeta_0 \overline{|w|} w$, where $\overline{|w|}$ - the average absolute value of the speed of the streamlined air in holes; ζ_0 - l.d.f. holes (assuming as a rule $\zeta_0 = 2.4$-as for a hole for in an infinitely thin wall). By (6), the last relation can be written as:

$$p_\omega - p_u = \overline{|w|}\sqrt{\zeta_0}du/(Edx). \tag{25}$$

With adoption of a simplifications and relations between the velocities (2), the initial equations $\omega = (u-z)/r; \bar{\omega} = (\bar{u}-z)/r$ (4) and (5) assume the following form:

$$dp_\omega/dx + 4(\bar{u}-z)du/(r^2 dx) = 0; \quad dp_u/dx + 4\bar{u}du/dx = k\mathrm{Le}(v-u). \tag{26}$$

Subtracting the second equation from the first, and using (25), we obtain the following system of differential equations:

$$u'' - 2Au' - Bu = -Bv, dp_{\omega} + 4\left(\bar{u} - z\right)dw / r^2 = 0, \quad (27)$$

where $A = 2E\left(\bar{u} - (\bar{u} - z)/r^2\right)/\left(\overline{|w|}\sqrt{\zeta_0}\right)$; $B = kE\mathrm{Le}/\left(\overline{|w|}\sqrt{\zeta_0}\right)$.

Thus, the problem is reduced to solving a system of differential equations (27) with boundary conditions (7) - (12). The solution of the first equation of the system (27) has the form:

$$u = C_1 e^{a_1 x} + C_2 e^{a_2 x} + v - k_1 - k_2 x, \quad k_1 = \left(2A(b_1 - k_2) - b_2\right)/B;\ k_2 = 2b_2 A/B, \quad a_{1,2} = A \pm \sqrt{A^2 + B} \quad (28)$$

$$C_1 = \left(m_2 - m_1 e^{a_2}\right)/\left(e^{a_1} - e^{a_2}\right);\ C_2 = \left(m_1 e^{a_1} - m_2\right)/\left(e^{a_1} - e^{a_2}\right);\ m_1 = u_n - n + k_1;\ m_2 = u_k - 1 + k_1 + k_2.$$

Using equation (25) with (28), we obtain the following relation: $p_{\omega} - p_u = \overline{|w|}\sqrt{\zeta_0}\left(C_1 a_1 e^{a_1 x} + C_2 a_2 e^{a_2 x} + b_1 + b_2 x - k_2\right)/E$, allowing us on the basis of the first equations of boundary conditions for pressures of (11) and (12) to form a system of equations:

$$\left.\begin{aligned} &\zeta_{\omega n}(u_n - z)^2/r^2 + \zeta_{un}u_n^2 = \overline{|w|}\sqrt{\zeta_0}\left(C_1 a_1 + C a_2 + b_1 - k_2\right)/E; \\ &\zeta_{\omega k}(u_k - z)^2/r^2 + \zeta_{uk}u_k^2 = -\overline{|w|}\sqrt{\zeta_0}\left(C_1 a_1 e^{a_1} + C a_2 e^{a_2} + b_1 - k_2 + b_2\right)/E. \end{aligned}\right\} \quad (29)$$

For closing of the resulting system of two equations with three unidentified, u_n, u_k and z we use the second differential equation of the system (27). Integrating this equation over the entire length of the channel, we obtain the following relationship $p_{\omega}(1) - p_{\omega}(0) + 4\left(\bar{u} - z\right)(u_k - u_n)/r^2 = 0$, which with the second equation of the boundary conditions for the pressures of (11) and (12), and using (13) and (14), provides a third equation closing the system (29):

$$p_y + \zeta_n^* z^2 + 4\left(\bar{u} - z\right)(u_k - u_n)/r^2 = \zeta_{\omega k}(u_k - z)^2/r^2 + \zeta_{\omega n}(u_n - z)^2/r^2 = 0; \quad (30)$$

To solve the system (30) and (29) is necessary to find averaged velocity of ejected air ($\bar{u}$) recycled ($\bar{\omega}$) and flows through the perforation holes $\overline{|w|}$.

To determine the average velocity of ejected air is necessary to carry out integration with the second equation of "simplified" system (26) over the entire length of the chute.

Now we have: $p_u(1) - p_u(0) + 4\bar{u}(u_k - u_n) = \mathrm{Le}(\bar{v} - \bar{u})^2/\bar{v}$ or taking into account the boundary conditions for pressures $\zeta_{uk}u_k^2 + \zeta_{un}u_n^2 + \zeta_n^* z^2 + p_y + 4\bar{u}(u_k - u_n) = \mathrm{Le}(\bar{v} - \bar{u})^2/\bar{v}$, where we find the following relationship:

$$z = \sqrt{\left(k\mathrm{Le}\left(\bar{v} - \bar{u}\right) - F_y\right)/\zeta_n^*},\ \ F_y = \zeta_{uk}u_k^2 + \zeta_{un}u_n^2 + p_y + 4\bar{u}(u_k - u_n). \quad (31)$$

Suppose as a first approximation $\bar{u} = u_c, \bar{\omega} = \omega_c$, where u_c и ω_c determined by the equations (22) after solving (21) with respect to parameter z_c. Averaging of the absolute magnitude of the overflow velocity $\overline{|w|}$ is performed by of the quantity of this value at the three points along the length of the chute. Considering that the velocity w is alternating, we can write

$\overline{|w|} \approx (|w(0)|+|w(1)|)/3$, where with the boundary conditions (8) и (10), (11) и (12), and also considering the (2): $|w(0)| = \sqrt{\left(\zeta_{\omega n}\left((u_n - z)/r\right)^2 + \zeta_{un}u_n^2\right)/\zeta_0}$; $|w(1)| = \sqrt{\left(\zeta_{\omega k}\left((u_k - z)/r\right)^2 + \zeta_{uk}u_k^2\right)/\zeta_0}$.

For solving the system (29) with the substitution of (31) as a first approximation the average speed $\bar{u}$ was assumed average of the ejected air velocity at the three points. (if $x=0; x=x_m$ and $x=1$) $\bar{u}=(u_n+u_m+u_k)/3$, $u_m \approx u_c$. After determining u_n and u_k the average velocity was determined by according to the formula $\bar{u}_r = \bar{v} + C_1(e^{a_1}-1)/a_1 + C_2(e^{a_2}-1)/a_2 - k_1 - 0.5k_2$, obtained by integrating the function (28) within the range $0 \le x \le 1$. Then, after comparing of these quantities with necessarity to implement the following approximation with $\bar{u} \approx \bar{u}_r$.

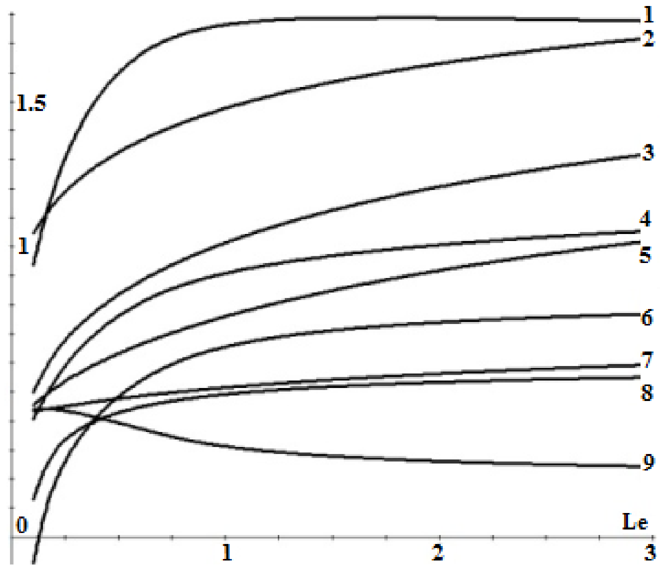

Figure 5 Changing of Ejected air in costs in one circulation ring Q_1, Q_{u1} with two Q_2 Q_{u2}, absence Q_0, Q_{u0}, depending on the number of ejection Le:
1 - $q_2 = Q_{u2}/Q_1$; 2 - $q_0 = Q_{u0}/Q_1$; 3 - Q_{u1}; 4 - Q_{u2}; 5 - Q_{u0}; 6 - $R_{z2} = (Q_{u2} - Q_2)/Q_{u2}$; 7 - Q_1; 8 - $R_{z1} = (Q_{u1} - Q_1)/Q_{u1}$; 9 - Q_2

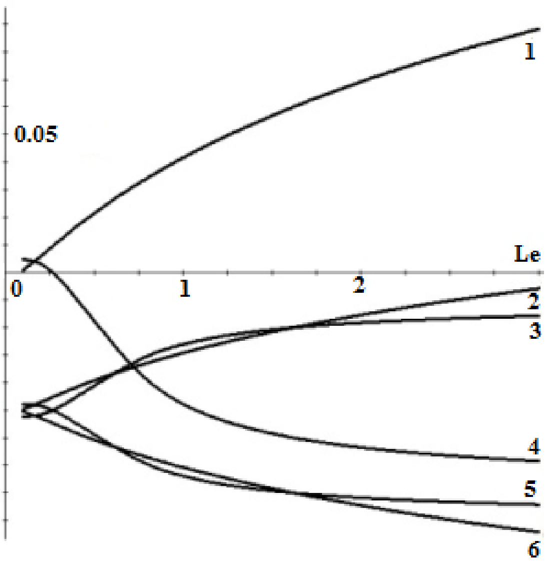

Figure 6: Changing the static overpressure of air in the upper ($p_{1(1)}$, $p_{1(2)}$) and the lower covering ($p_{2(1)}$, $p_{2(2)}$) in the presence of one or two rings in circulation depending on the Le:
1 - $\Delta p_{21(1)} = p_{2(1)} - p_{1(1)}$; 2 - $p_{2(1)}$; 3 - $p_{1(2)}$;
4 - $\Delta p_{21(2)} = p_{2(2)} - p_{1(2)}$; 5 - $p_{2(2)}$; 6 - $p_{1(1)}$

The results of research for a specific example of reloading unit (if ρ=1.2kg/m^3; ε=0.25; $\zeta_0 = \zeta_1 = \zeta_p = 2.4$; $\zeta_{un} = 0.5$; $\zeta_{uk} = 1.0$; $\zeta_u = \zeta_\omega = 1.5$; $\zeta_{\omega n} = \zeta_{\omega k} = 0.75$; $f_1 = f_p = S_u = S_\omega = 0.3\text{m}^2$; $n = 0.3$; $v_k = 10\text{m/s}$; $P_3 = -6\text{Pa}$; $P_y = -0.1$; $\zeta_1^* = \zeta_p^* = 2.4$; $\zeta_n^* = 4.8$) are showed that the presence of two recirculating rings (external transit relative bypass chamber upstream - 1st ring and the internal upward airflow in the bypass chamber, flows through openings in the chamber walls into the chute at the top and flowing out of the bottom of the the gutter - 2nd ring), return air flow increases and the flow rate of injected air (transit portion of the air flow in the channel relative to the top of the cover - cover trench-bottom) of the receiving chamber to the lower injected cover decreases (fig.5). It is easy to notice by comparing the graphs of the recycle ratio R_{z1}, R_{z2}, and costs of forced air Q_1 и Q_2. With an increase in capacity of the flow ejecting granular materials, i.e. with the growth of number Le, this difference becomes more noticeable. If $\mathrm{Le}=0.6$ in the absence of forced air bypass function as flow in an absolute expression has made $Q_0=0.66\,\mathrm{m^3/s}$, the presence of only the one ring this recycling rate has dropped to $Q_1=0.49\,\mathrm{m^3/s}$ (at 26%) and at presence of two rings - up to $Q_2=0.37$ $\mathrm{m^3/s}$ (decreased to 1.78 times). These quantities as $\mathrm{Le}=3$ accordingly constitute $Q_0=1.03$ $\mathrm{m^3/s}$, $Q_1=0.6$ $\mathrm{m^3/s}$ (42% less); $Q_2=0.24$ $\mathrm{m^3/s}$ (is less than 4.29 times in comparison with the quantity Q_0).

Reduced costs forced air Q_1 and exhaust air Q_a due to increased back pressures under cover (fig.6) by increasing Le. There is an increase the value of the vacuum in the upper cover $p_{1(1)}$, reduces vacuum in the receiving chamber of the lower cover $p_{2(1)}$, which stimulates an increase of recirculating air consumption in the growth of $\Delta p_{21(1)}$.

For the case of of the two rings there is an increase recirculation of recycle of air through the intensification of overflow of air through the perforations when the number of ejection Le grows.

Despite the increase in negative pressure in the inlet chamber $p_{2(2)}$ and the associated reduction in backpressure $\Delta p_{21(2)}$ increases the value of recycling. This is due to the increased capacity of the flow ejecting Loaded material with an increase in the parameter Le.

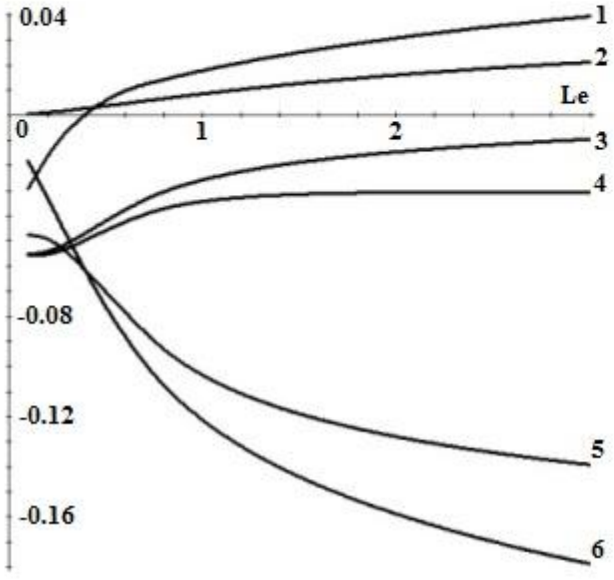

Figure 7: Change of static overpressure of air at the ends of chute $p_u(0)$ (curve 4), - at the entrance air ejection chute $p_u(1)$ (curve 1) - at its outlet from the chute, at the ends of the bypass chamber $p_\omega(0)$ (curve 3) - at the output of return air from the camera to the upper cover $p_\omega(1)$ (curve 5) - at the entrance cover as well as the difference between these pressures $\delta p(0)=p_\omega(0)-p_u(0)$ (curve 2) and $\delta p(1)=p_\omega(1)-p_u(1)$ (curve 6) depending on the number Le

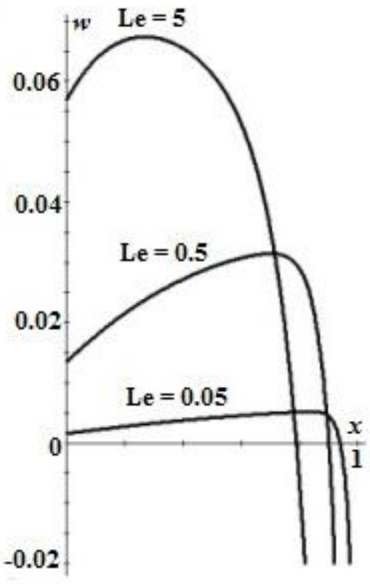

Figure 9 Change of dimensionless velocity of the overflow of recirculating air bypass chamber through the perforations on height chute

There is an increase of pressure incremental redundancy (fig.7) in the trough and the bypass chamber, increase the absolute value of the pressure difference and thereby increase the flow of recycled air.

With increasing the number Le grow both longitudinal velocities, and recirculating ejected air (fig.8), and velocity overflowing of air (fig.9).

Significant role in reducing the amount of injected air belongs sealing top cover (increased p1) and reducing the area of the gap between the conveyor belt and the walls of the receiving chamber (rising p_2).

5 CONCLUSIONS

Consumption injected into the ejected suction air Q_1 cover can be considerably reduced by arranging the double air circulation on external ring (with end openings bypass chamber) and the inner ring, which ensures flow of air through the perforations along the length of the trough.

The device is combined with the camera's transit exchange of air between the top suction cover and receiving chamber of the lower suction cover (fig.1) increases the energy-saving effect.

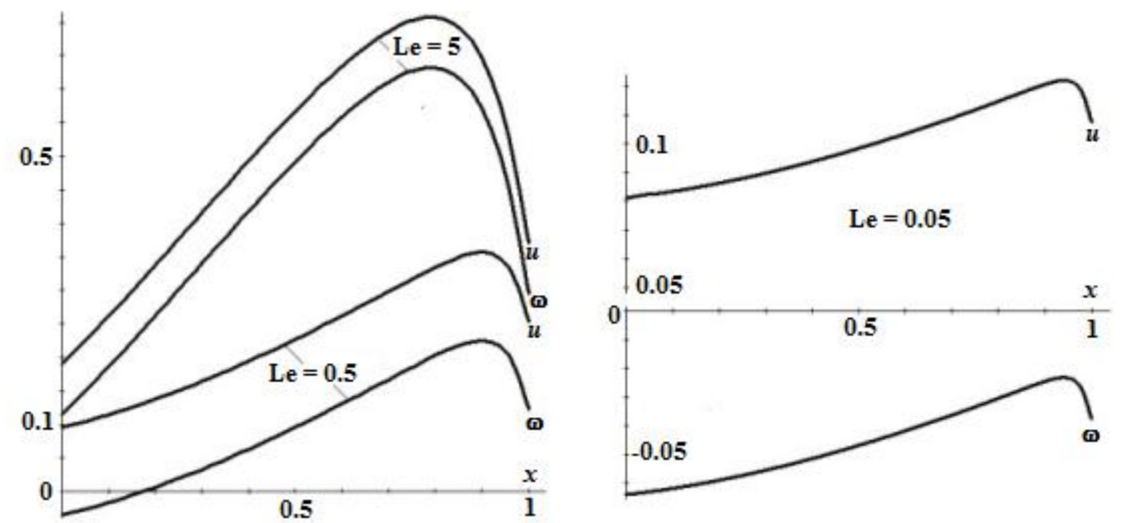

Figure 8: Changing the dimensionless velocities of ejected air in chute (u) and recycled ascending flow bypass air chamber ((ω)) drop range adjustment overloaded granular material particles.

For a specific example, when there is a small capacity of ejecting flow of granular materials, even single inner ring recirculation, forced air flow was reduced to 1.35 times as compared with overloading of the same material flow in the chute with impermeable walls and the absence bypass chamber, and when the double ring recycling - 1.78 times.

And with larger numbers of ejection effect of reducing the consumption Q_1 is even higher. Thus, if $\mathrm{Le}=3$ and the circulation of the outer ring the same consumption with the same comparison (with Q_{u0}) has been reduced to 1.72 times, and with two rings - to 4.29-times.

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