# MODELING OF PRESSURE LOSS IN A VERTICAL PNEUMATIC CONVEYING UNIT WITH AN ACCELERATION SECTION

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## Abstract

Reducing energy consumption for pneumatic conveying of various bulk materials is an important scientific problem. The use of suction pneumatic conveying units with a material acceleration section can reduce energy consumption compared to units using material pipelines with a constant diameter. The purpose of this work was to conduct modeling and analysis of pressure losses in a suction pneumatic conveying unit with constant and variable diameters of the material pipeline and to derive a formula for calculating the air velocity in the material product acceleration section.

Modeling of pressure losses in a suction vertical pneumatic conveying unit was carried out on the basis of calculated relations used for calculating pneumatic conveying units with a constant diameter of the material pipeline.

Studies have shown that for a suction pneumatic conveying unit with a constant diameter, the total pressure loss was 4097.2 Pa, and for a pneumatic conveying unit with an acceleration section, it was 3474.9 Pa. The reduction in total pressure loss is achieved by reducing the air velocity in the main material pipeline.

Analysis of total pressure losses in a suction pneumatic conveying unit with a wheat grain dispersal section showed that pressure losses decreased by 15% compared to pressure losses in a unit with a constant diameter. The reduction in total pressure losses is achieved by reducing the air velocity in the main material pipeline.

The analysis has established that at the same air speeds (24 m/s) the total pressure losses in the unit with a grain acceleration section will be higher than in the unit with a constant diameter of the material pipeline. The main condition for reducing the total pressure losses in installations with grain acceleration sections is reduced air velocities compared to installations with constant diameters of material pipelines.

A formula has been derived that allows calculating the air velocity in the material dispersion area depending on the air velocity in the main area and the diameters of the material pipeline in the material dispersion area and the main area.

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# МОДЕЛЮВАННЯ ВТРАТ ТИСКУ У ВЕРТИКАЛЬНІЙ ПНЕВМОТРАНСПОРТНІЙ УСТАНОВЦІ З РОЗГІННОЮ ДІЛЯНКОЮ

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*Встановлено, що для всмоктуючої пневмотранспортної установки із постійним діаметром отримано загальні втрати тиску 4097,2 Па, а для пневмотранспортної установки з ділянкою розгону — 3474,9 Па. Аналіз загальних втрат тиску у всмоктуючій пневмотранспортній установці з ділянкою розгону зерна пшениці показав, що втрати тиску зменшились на 15% порівняно з втратами тиску в установці з постійним діаметром. Зниження загальних втрат тиску забезпечується за рахунок зниження швидкості повітря в основному матеріалопроводі.*

***Ключові слова:*** *пневмотранспортування, пшениця, швидкість повітря, ділянка розгону, втрати тиску.*

**Statement of the problem.** Reducing energy consumption during pneumatic transportation of grain and other grain products is an important scientific problem in the field of grain processing [1, 3, 7]. One of the ways to reduce energy consumption during pneumatic transportation of grain and other bulk grain products is to create a material pipeline with variable diameters. Such units have been created and are successfully used in some grain processing plants for transporting grain products at high concentrations, but they belong to the pumping aerosol transport units [4, 18, 20].

**Literature review.** A significant number of scientific works have been devoted to the study of various aspects of the operation of pneumatic conveying systems. The vast majority of works are focused on the study of bend configurations [2, 6, 26] or on the study of transportation modes in horizontal and vertical planes at low and high air velocities and different product concentrations [8, 15, 24—29]. In order to reduce pressure losses in the transportation of bulk materials, new types of feeders were studied and optimization of pressure losses in the transportation of materials was carried out [7, 19—23]. Analysis of the above works showed that these scientific works studied pumping systems of pneumatic conveying and did not touch on suction systems of pneumatic conveying, which are widely used in grain processing enterprises both in Ukraine and widely in the world [4, 13, 22]. Researchers did not conduct studies on changing the diameters of material pipelines for suction pneumatic conveying systems [16, 17].

Some flour mills use suction pneumatic conveying units with different diameters of the material pipeline along the length [5]. However, the efficiency of such units remains unknown. The pressure losses for pneumatic conveying of grain products remain unknown in comparison with units that have a constant diameter of the material pipeline along the length. Some works indicate that the use of a product acceleration section and a decrease in air velocity in the material pipeline allows reducing energy consumption for grain products conveying in pumping pneumatic transporting units [4, 5].

However, for vertical material pipelines there are limits of air velocity in the material pipeline below which the material pipeline becomes clogged and the product stops being transported. Dmytruk Y. A. investigated the limits of blockage and showed that the air velocity in the material pipeline during the transportation of wheat grain is within 13.7...15.0 m/s. He also established that blockage occurs at the site of grain introduction into the material pipeline [5]. At the same time, high air velocities lead to increased air consumption and high energy consumption for material transportation [11, 14].

Based on the analysis, it was hypothesized that the use of a material acceleration section and a reduction in air velocity in the main section of the material pipeline would reduce energy consumption for transportation in vertical suction units.

**Research purpose.** The purpose of this work was to simulate pressure losses in a suction vertical pneumatic conveying unit with a constant diameter of the material pipeline and a suction vertical pneumatic conveying unit with a grain acceleration section, as well as to analyze pressure losses in both systems.

**Materials and methods.** The simulation was carried out for two types of suction pneumatic conveying units for wheat grain. The first unit (Fig. 1, a) had a material pipeline with a fixed diameter, which was $D = 125$ mm. The second unit (Fig. 1, b) had a material pipeline consisting of two sections. The first section was an acceleration section with a diameter of $D_a = 90$ mm, the second section had a diameter of $D = 125$ mm. The accepted diameters of material pipelines are often used in pneumatic conveying units at flour mills.

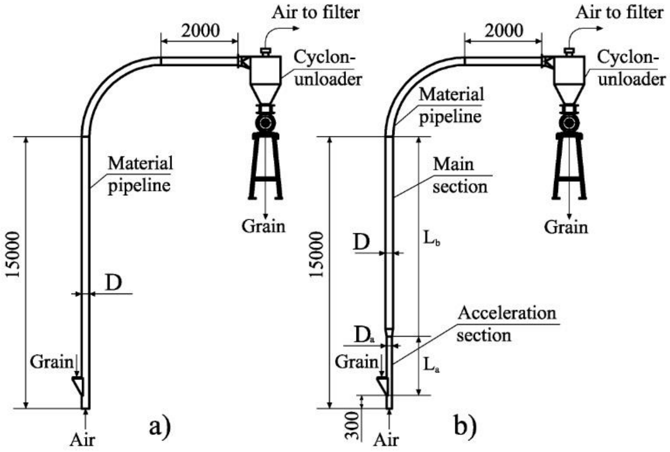

**Figure 1. Pneumatic conveying unit:** a — with a constant diameter of the material pipeline; b — with a variable diameter of the material pipeline; $L_a$ — length of the acceleration section; $L_b$ — length of the main section; $D$ — diameter of the material pipeline of the main section; $D_a$ — diameter of the material pipeline of the grain acceleration section

The total length of the straight vertical section was taken for both options to be 15 m, as shown in Fig. 1. The length of the acceleration section (Fig. 1, b) was taken to be $L_a = 1.0$ m. The distance from the edge of the material pipeline of the grain acceleration section to the feeder was 0.3 m. The length of the grain acceleration section is taken arbitrarily, but in the future it is necessary to develop a method for determining the optimal length of the section.

The radius of the bend rounding r was taken to be 10 diameters, i. e. $r = 10D$.

To simulate pressure losses in a pneumatic conveying unit, wheat grain was taken. The hanging velocity $V_h$, m/s for wheat grain was taken as $V_h = 9.8$ m/s. The productivity of the pneumatic conveying unit was calculated at 50 t/24 hours or 0.58 kg/s.

Pressure losses during pneumatic grain transportation consist of the following components [12]:

$$H_0 = H_f + \sum H_g + \sum H_e + \sum H_V + H_c, \tag{1}$$

where $H_f$ is pressure losses in a feeder, Pa; $\Sigma H_g$ is sum of pressure losses in horizontal sections, Pa; $\Sigma H_e$ is sum of pressure losses in the bend which includes pressure losses on product acceleration after the bend, Pa; $\Sigma H_v$ is sum of pressure losses in vertical sections of the material pipeline, Pa; $H_c$ is pressure losses in the cyclone-unloader, Pa.

The pressure losses in the feeder are determined by the formula [5]:

$$\mathrm{H}_d = \xi_d \frac{\rho V_d^2}{2}, \tag{2}$$

where $\xi_d$ is coefficient that depends on the type of the feeder; $V_d$ is air velocity in the feeder, m/s; $\rho$ is air density, kg/m$^3$.

At the normal environmental conditions, the air density for calculations is assumed to be 1.2 kg/m$^3$. The air velocity $V_d$ was assumed to be equal to the air velocity in the material dispersion area.

The value of the coefficient $\xi d$ was taken equal to 0.7.

Air velocity $V$ (m/s) in the material pipeline was calculated by formula [4, 5]:

$$V = K_r\,(10.5 + 0.57V_h), \tag{3}$$

where $K_r$ is reserve ratio; $V_h$ is hovering velocity, m/s.

Pressure losses in the vertical section of the material pipeline with a constant diameter $Hmp$ (Pa) were calculated using the formula [5]:

$$H_{mp} = H_c + H_m = 0.013L\frac{V^{1.75}}{D^{1.25}} + G\left(1.59\frac{W}{D^2} + 12{,}5\frac{L}{WD^2} + 0.00535\frac{LW}{D^3}\right), \tag{4}$$

where $H_c$ is pressure losses when moving clean air, Pa; $H_m$ is pressure losses when moving wheat grain, Pa; $G$ is bulk material consumption (the load), kg/s; $W$ is average particle velocity of bulk material, m/s; $L$ is length of a straight vertical section of the material pipeline, m; $V$ is air velocity in the vertical section, m/s; $D$ is diameter of vertical section of material pipeline, m.

The average velocity of the material pipeline particles was calculated using the formula [5]:

$$W = 0.18\frac{G^{0.067} \times L^{0.25} \times V}{D^{0.317} \times V_h^{0.2}}. \tag{5}$$

When modeling pressure losses in a material pipeline with a product acceleration section, the ratio $1{,}59W/D^2$ was taken into account only in the acceleration section. In the main section, this product was not taken into account due to the fact that the air velocity decreases in the main section due to the increase in the diameter of the material pipeline.

In the product acceleration section, the air velocity increase was assumed to be no more than 30 m/s. The formula for calculating the air velocity $V_a$ in the acceleration section will be derived in the "Results and Discussion" and used for the next modeling.

The pressure loss in the band was calculated using the formula [5]:

$$H_e = H_c(1 + K_e\mu) + \beta K_p\frac{\rho V^2}{2}\mu, \tag{6}$$

where $H_c$ is pressure losses in the bend when clean air moves, Pa; $K_e$ is resistance coefficient when moving the product in the bend; $\mu$ — grain weight concentration, kg/kg; $\beta$, $K_p$ are experimental coefficients; ρ is air density, $\rho$ = 1,2 kg/m$^3$.

The second ratio in formula 6 takes into account the recovery of velocity after the bend (acceleration). It was not taken into account for the horizontal section of the material pipeline because it is taken into account when calculating the pressure losses in the bend.

Pressure losses during the movement of clean air in the bend and horizontal section of the material pipeline were calculated using the formula [12]:

$$H_c = 0.013L\frac{V^{1.75}}{D^{1.25}}, \tag{7}$$

where $L$ is bend length or horizontal section, m.

The deployed length of the bend $L$ is calculated by the formula [16]:

$$L_e = \pi \alpha r/180, \tag{8}$$

where $\alpha$ is central angle of the bend, degree; $r$ is radius of the bend, m.

The coefficient $K_e$ was defined as [5]:

$$K_e = \frac{BD}{V^{1.25}\left(\frac{r}{D}\right)^m}, \tag{9}$$

where $B$, $m$ are experimental coefficients that depend on product which conveying and from the direction of movement (Table 1); $D$ is the diameter of material pipeline, m; $r$ is the bend radius, m.

*Table 1.* **Coefficients *B, m, E***

| Bend direction | Coefficient | Grain | | Coarse products | | Soft products | |
|---|---|---|---|---|---|---|---|
| | $m$ | $B$ | $E$ | $B$ | $E$ | $B$ | $E$ |
| From vertical to horizontal direction | 0.23 | 550 | 1.20 | 450 | 1.32 | 320 | 1.41 |
| From horizontal to vertical direction | 0.15 | 620 | 0.91 | 500 | 0.99 | 400 | 1.15 |
| In horizontal plane | 0.18 | 590 | 1.01 | 480 | 1.15 | 370 | 1.24 |

Coarse products included grain, waste of various categories, crushed grain, products of I, II, III and IV break systems, 1, 2, 3 reducing and 1 and 2 grinding systems, coarse grain, products of processing of grain of cereal crops. All other milled products, finished products, meal, bran, corn germ were classified as soft products [5].

The weight concentration of the aeromixture μ was calculated by the formula [12, 16]:

$$\mu = \frac{G}{\rho Q}, \tag{10}$$

where $G$ is the bulk material consumption (load), kg/s; $Q$ is air flow rate, m3/s; $\rho$ is air density, kg/m$^3$.

$\beta$ coefficient was taken depending on the radius of the bend and the direction of the material flow from Table 2.

*Table 2.* **$\beta$ coefficient [5]**

| Grinding product | Ratio $r/D$ | Material pipeline length after the bend, m | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1.1...2.0 | 2.1...3.0 | 3.1...4.0 | 4.1...5.0 | 5.1...6.0 | 6.1...7.0 | >7.0 |
| Horisontal material pipeline | | | | | | | | |
| Coarse products | 5.0...9.9 | 0.30 | 0.51 | 0.73 | 0.85 | 0.91 | 0.96 | 1.00 |
| | 10...25 | 0.30 | 0.56 | 0.75 | 0.88 | 0.95 | 1.00 | 1.00 |
| Soft products | 5.0...9.9 | 0.25 | 0.45 | 0.63 | 0.75 | 0.84 | 0.92 | 0.97 |
| | 10...25 | 0.28 | 0.48 | 0.65 | 0.80 | 0.87 | 0.95 | 1.00 |
| Vertical material pipeline | | | | | | | | |
| Coarse products | 5.0...9.9 | 0.35 | 0.60 | 0.78 | 0.90 | 0.96 | 1.00 | 1.00 |
| | 10...25 | 0.40 | 0.70 | 0.82 | 0.95 | 1.00 | 1.00 | 1.00 |
| Soft products | 5.0...9.9 | 0.30 | 0.52 | 0.70 | 0.85 | 0.92 | 0.97 | 1.00 |
| | 10...25 | 0.33 | 0.57 | 0.75 | 0.89 | 0.95 | 1.00 | 1.00 |

$K_p$ coefficient was calculated by following [5]:

$$K_p = E\left(\frac{r}{D}\right)^{-m}, \tag{11}$$

where $E$, $m$ are the coefficients which were choosen from the Table 1; $D$ is the material pipeline diameter, m; $r$ is the bend radius, m.

Pressure losses in the horizontal section of the material pipeline were determined by the formula [5]:

$$H_{hm} = H_c(1 + K_{hm}\mu), \tag{12}$$

where $K_{hm}$ is experimental coefficient.

$K_{hm}$ coefficient was definied by the formula [16]:

$$K_{hm} = \frac{A_{hm}D}{V^{1.25}}, \tag{13}$$

where $A_{hm}$ is coefficient which for grain is equal to $A_{hm} = 150$, for the other coarse grain products is $A_{hm} = 135$, for the soft products is $A_{hm} = 110$.

Pressure losses in the cyclone-unloader were calculated using the formula [16]:

$$H_{cu} = \xi_{cu}\frac{\rho V_{in}^2}{2}, \tag{14}$$

where $\xi_{cu}$ is resistance coefficient of a cyclone-unloader; $V_{in}$ is air velocity in the inlet of the cyclone-unloader, m/s; $\rho$ is air density, kg/m$^3$.

The resistance coefficient of the cyclone-unloader was taken $\xi_{cu} = 5$.

The air velocity in the inlet of the cyclone-unloader was calculated using the formula [16]:

$$V_{in} = \frac{4Q}{3.14D_{cu}^2}, \tag{15}$$

where $D_{cu}$ is the diameter of the inlet pipe of the cyclone-unloader, m.

To simulate pressure losses in pneumatic conveying units, MS Excel software was used, thus creating a digital twin of a suction pneumatic conveying unit [10].

**Research results.** To calculate the pressure loss in the product acceleration section, it is necessary to know the air velocity in this area. The air velocity in this area cannot be specified, due to the fact that there is a relationship between these velocities due to the air flow rate in the pneumatic conveying unit. However, there is no formula in the literature that would allow calculating the air velocity in the material acceleration section. In order to carry out further modeling of pressure losses in the units, we will derive a formula that connects the air velocity in the material acceleration section with the air velocity in the main area.

The air flow in a pipe calculated as the product of the air velocity in the material pipeline and the cross-sectional area of this material pipeline [16]:

$$Q = VF, \tag{16}$$

where $Q$ is air flow rate, m$^3$/s; $V$ is air velocity in material pipeline, m/s; $F$ is cross-sectional area of the pipe, m$^2$.

Then in each section of the material pipeline (Fig. 2) the air flow rate will be respectively:

$$Q_1 = V_1 F_1; \tag{17}$$

$$Q_2 = V_2 F_2. \tag{18}$$

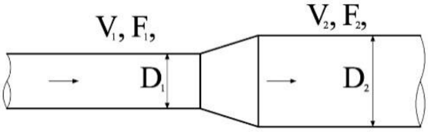

**Figure 2. Airflow continuity diagram**

The cross-sectional area of the material pipeline is calculated as [12]:

$$F = \frac{\pi D^2}{4}, \tag{19}$$

where $D$ is the diameter of material pipeline, m.

Substitute formula 19 into formulas 17 and 18 [16]:

$$Q_1 = V_1\frac{\pi D_1^2}{4}; \tag{20}$$

$$Q_2 = V_2 \frac{\pi D_2^2}{4}. \tag{21}$$

From the law of continuity of air flow, it is known that the air flow rate in a material pipeline of different cross-section is a constant value:

$$Q_1 = Q_2 = const. \tag{22}$$

Substitute formulas 20 and 21 into formula 22:

$$V_1 \frac{\pi D_1^2}{4} = V_2 \frac{\pi D_2^2}{4} = const. \tag{23}$$

From formula 23 we derive the dependence of the air velocity in the material acceleration section on the air velocity in the main section and the diameters of the sections:

$$V_1 = V_2 \frac{\pi D_2^2}{4} \times \frac{4}{\pi D_1^2} = V_2 \frac{D_2^2}{D_1^2}. \tag{24}$$

Thus the air velocity $V_a$ in the acceleration section is calculated by the formula:

$$V_a = V_{mp} \frac{D_{mp}^2}{D_a^2}, \tag{25}$$

where $V_{mp}$ is air velocity in the main section, m/s; $D_{mp}$ is the diameter of the main section of the material pipeline, m; $D_a$ is the diameter of material pipeline of the acceleration section, m.

To use formula 25, it is necessary to know the air velocity in the main section, the diameter of the material pipeline of the main section and the diameter of the material pipeline of the acceleration section.

Let's determine the pressure losses in individual sections of a pneumatic conveying unit with a constant diameter of the material pipeline.

The air velocity in the material pipeline is calculated from formula 3. The reserve coefficient for wheat grain is taken as 1.5 for the purpose of reliable grain transportation:

$$V = 1.5(10.5 + 0.57 \times 9.8) = 24.1\ \frac{m}{s}.$$

Air flow rate:

$$Q = 24.1 \frac{3.14 \times 0.125^2}{4} = 0.296 \ \text{ or } \ 1065.4 \frac{m^3}{hour}.$$

Weight concentration of the aeromixture:

$$\mu = \frac{0.58}{1.2 \times 0.296} = 1.63\ \frac{kg}{kg}.$$

The average velocity of the product particles according to formula 5:

$$W = 0.18 \frac{0.58^{0.067} \times 14.7^{0.25} \times 24.1}{0.125^{0.317} 9.8^{0.2}} = 10.0\ \frac{m}{s}.$$

1. Pressure losses in the feeder:

$$H_d = 0.7 \frac{1.2 \times 24.1^2}{2} = 244.5 \text{ Pa}.$$

2. Pressure losses in the vertical part of a material pipeline with a constant diameter:

$$H_{\text{mp}} = 0.013 \frac{14.7 \times 24.1^{1.75}}{0.125^{1.25}} + 0.58\left(1.59 \frac{10.0}{0.125^2} + 12.5 \frac{14.7}{10.0 \times 0.125^2} + 0.00535 \frac{14.7 \times 10.0}{0.125^3}\right) = 2178.5 \text{ Pa}$$

The pressure loss in the vertical section to the feeder with a length of 0.3 m in according to formula 7:

$$H_{\text{mp}}^{\text{c}} = 0.013 \frac{0.3 \times 24.1^{1.75}}{0.125^{1.25}} = 13.8 \text{ Pa}.$$

3. Pressure losses in the bend taking into account the velocity recovery after the bend according to formula 6:

$$H_{\mathrm{e}} = 0.013 \times \frac{3.14 \times 90 \times 1}{180} \times \frac{24.1^{1.75}}{0.125^{1.25}} \left( 1 + \frac{550 \times 0.125}{24.1^{1.25} \times \left(\frac{1}{0.125}\right)^{0.23}} \times 1.63 \right)$$

$$+0.3 \times 1.32 \times \left(\frac{1}{0.125}\right)^{-0.23} \times \frac{1.2 \times 24.1^2}{2} \times 1.63 = 305.5 \text{ Pa}$$

4. Pressure losses in a horizontal material pipeline after the bend according to formula 12:

$$H_{\mathrm{hm}} = 0.013 \times 2 \times \frac{24.1^{1.75}}{0.125^{1.25}} \left(1 + \frac{150 \times 0.125}{24.1^{1.25}} \times 1.63\right) = 144.4 \text{ Pa.}$$

5. The pressure losses in the cyclone-unloader according to formula 15:

$$H_{\mathrm{cu}} = 5 \times \frac{1.2 \times \left(\frac{4 \times 0.296}{3.14 \times 0.137^2}\right)^2}{2} = 1210.5 \text{ Pa.}$$

6. Total pressure losses in a suction pneumatic conveying unit according to formula 1:

$$H_0 = 244.5 + 2178.5 + 13.8 + 305.5 + 1210.5 = 4097.2 \text{ Pa.}$$

Let us determine the pressure losses in individual sections of a pneumatic conveying unit with a grain acceleration section.

The air velocity in the material pipeline is calculated using formula 3, but the reserve coefficient was increased by only 10% and its value was accepted 1.1.

$$V = 1.1(10.5 + 0.57 \times 9.8) = 17.7 \ \frac{m}{s}.$$

The air velocity in the acceleration section is determined from formula 25:

$$V_a = 17.7 \frac{0.125^2}{0.1^2} = 27.6 \ \frac{m}{s}.$$

Air flow rate is:

$$Q = 17.7 \frac{3.14 \times 0.125^2}{4} = 0.217 \frac{m^3}{s} \ \text{ or } \ 781.3 \frac{m^3}{hour}.$$

Weight concentration of the aeromixture according to formula 10:

$$\mu = \frac{0.58}{1.2 \times 0.296} = 2.22 \ \frac{kg}{kg}.$$

Average velocity of product particles in the main section:

$$W = 0.18 \frac{0.58^{0.067} \times 14.7^{0.25} \times 17.7}{0.125^{0.317} 9.8^{0.2}} = 7.3 \ \frac{m}{s}.$$

Average velocity of product particles in the grain acceleration section:

$$W_a = 0.18 \frac{0.58^{0.067} \times 0.7^{0.25} \times 27.6}{0.1^{0.317} 9.8^{0.2}} = 5.8 \ \frac{m}{s}.$$

1. Pressure losses in the feeder:

$$H_d = 0.7 \frac{1.2 \times 27.6^2}{2} = 321.1 \text{ Pa.}$$

2. Pressure losses in the product dispersion section are determined in the same way as in the main section:

$$H_{ap} = 0.013 \frac{0.7 \times 27.6^{1.75}}{0.1^{1.25}} + 0.58 \left(1.59 \frac{5.8}{0.1^2} + 12.5 \frac{0.7}{5.8 \times 0.1^2} + 0.00535 \frac{0.7 \times 5.8}{0.1^3}\right) = 685 \text{ Pa.}$$

Pressure losses in the vertical section to the feeder with a length of 0.3 m:

$$H_{mp}^{c} = 0.013 \frac{0.3 \times 27.6^{1.75}}{0.1^{1.25}} = 23.1 \text{ Pa.}$$

3. Pressure losses in the vertical part of the material pipeline with a constant diameter after the acceleration section and before the bend with a length of 14.0 m:

$$H_{mp} = 0.013 \frac{14.0 \times 17.7^{1.75}}{0.125^{1.25}} + 0.58 \left(1.59 \frac{7.3}{0.125^2} + 12.5 \frac{14.0}{7.3 \times 0.125^2} + 0.00535 \frac{14 \times 7.3}{0.125^3}\right)$$

$$= 1426 \text{ Pa.}$$

4. Pressure losses in the bend, taking into account the velocity recovery after it:

$$H_e = 0.013 \times \frac{3.14 \times 90 \times 1}{180} \times \frac{17.7^{1.75}}{0.125^{1.25}} \left( 1 + \frac{550 \times 0.125}{17.7^{1.25} \times \left(\frac{1}{0.125}\right)^{0.23}} \times 2.22 \right)$$

$$+0.3 \times 1.32 \times \left(\frac{1}{0.125}\right)^{-0.23} \times \frac{1.2 \times 17.7^2}{2} \times 2.22 = 253.8 \text{ Pa.}$$

5. Pressure losses in the horizontal part of the material pipeline:

$$H_{hm} = 0.013 \times 2 \times \frac{17.7^{1.75}}{0.125^{1.25}} \left(1 + \frac{150 \times 0.125}{17.7^{1.25}} \times 2.22\right) = 114.7 \text{ Pa.}$$

6. Pressure losses in the cyclone-unloader:

$$H_{cu} = 5 \times \frac{1.2 \times \left(\frac{4 \times 0.217}{3.14 \times 0.137^2}\right)^2}{2} = 651 \text{ Pa.}$$

7. Total pressure losses in a suction pneumatic conveying unit with a grain dispersal section:

$$H_0 = 321.1 + 685 + 23.1 + 1426 + 253.8 + 114.7 + 651 = 3474.9 \text{ Pa.}$$

The conducted study showed that the pressure losses in the unit with a constant diameter of the material pipeline are greater than the pressure losses in the unit with a material acceleration section. The increased pressure losses are due to the fact that the air velocity in the unit with a constant diameter of the material pipeline is greater than the air velocity in the unit with a grain acceleration section.

At first glance, it may seem a mistake to think that to reduce pressure losses in a pneumatic conveying unit with a constant diameter, it is enough to reduce the air velocity in the material pipeline. If the air velocity in the material pipeline of a pneumatic conveying unit with a constant diameter is reduced, this will lead to a decrease in the air velocity at the moment of contact of the air and the material. In turn, this will lead to the formation of regular blockages in the material pipeline. High air velocity in a unit with a constant diameter of the material pipeline is necessary to prevent blockages and ensure reliable transportation of grain at the moment of its capture by air.

Using the material acceleration section allows you to reduce the air velocity in the main part of the material pipeline without creating conditions for blockages in the material pipeline at the stage of feeding grain into the material pipeline, because the grain has already received kinetic energy in the acceleration section. Reduced air consumption allows for lower pressure losses during transportation due to lower air velocities.

Using the modeling technique presented in Section 2, pressure losses were simulated for conditions of equal air velocities (Fig. 3). If the air velocities in the main sections of the material pipelines are the same, then the pressure losses in the unit with a grain acceleration section will be greater than the pressure losses in the unit with a constant diameter of the material pipeline. The product acceleration section creates increased pressure losses, which must be compensated by reducing the air velocities in the main section. The main condition for reducing the total pressure losses in the unit with an acceleration section is a reduced air velocity compared to the unit with a constant diameter of the material pipeline.

The air velocity in the acceleration section should be sufficient to avoid blockages in the material pipeline. The optimal value of the air velocity in the acceleration section requires further research. Dmytruk E. A. recommended using an air velocity in the acceleration section of 30 m/s [5]. In the main section of the material pipeline, the product can be transported with lower air velocities (16...18 m/s). This is explained by the fact that the product, which has already received kinetic energy in the acceleration section, is transported with velocities lower than required at the time of its loading into the material pipeline.

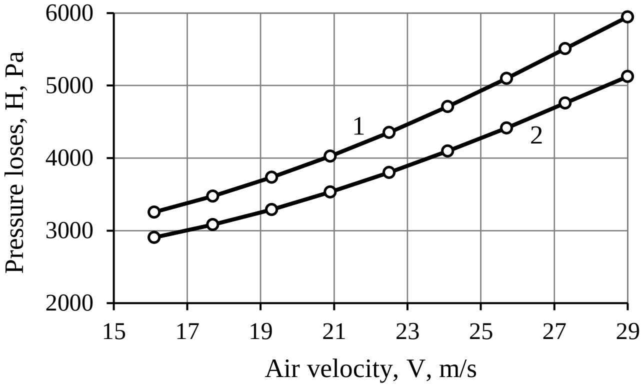

**Figure 3. Comparison of pressure losses of two pneumatic conveying units:** 1 — unit with a material pipeline acceleration section; 2 — unit with constant material pipe diameter

Comparison of pressure loss data (Table 3) in the units shows that pressure losses in the unit with a material acceleration section are 15 % less than when using a material pipeline with a constant diameter. In all elements of the unit with a grain acceleration section, pressure losses are reduced except for the feeder, where pressure losses increased by 31%. From the data in table 3, it can be seen that with a decrease in air consumption, the weight concentration of grain increased by 36%.

*Table 3.* **Comparative analysis of pressure losses in the studied units**

| Element of pneumatic conveying system | Type of the unit | | Absolute deviation, Δ | Relative deviation, % |
|---|---|---|---|---|
| | constant diameter of material pipeline | material pipeline with the acceleration section | | |
| Air velocity, m/s: | | | | |
| in the acceleration section | — | 27.6 | — | — |
| in the main section | 24.1 | 17.7 | 6.4 | –26 |
| Air flow rate, m$^3$/hour | 1065.4 | 781.3 | 284.1 | 26 |
| Weight concentration of the aeromixture, kg/kg | 1.63 | 2.22 | 0.59 | +36 |
| Average particle velocity, m/s: | | | | |
| in the acceleration section | — | 5.8 | — | — |
| in the main vertical section | 10.1 | 7.3 | 2.8 | –28 |
| Feeder, Pa | 244.5 | 321,1 | 76.6 | +31 |
| Pressure losses in the acceleration section, Pa | — | 708.1 | | |
| Pressure losses in the vertical material pipeline, Pa | 2192.3 | 1426 | 766.3 | –35 |
| Pressure losses in the bend, Pa | 305.5 | 253,8 | 51.7 | –17 |

*Продовження таблиці 3*

| | | | | |
|---|---|---|---|---|
| Pressure point in the horizontal section, Pa | 144.4 | 114,7 | 29.7 | –20 |
| Pressure losses in the cyclone-unloader, Pa | 1210.5 | 651 | 559.5 | –46 |
| Total pressure losses, Pa | 4097.2 | 3474.9 | 622.3 | –15 |

The obtained results of research on modeling pressure losses in the pneumatic conveying unit can be used for any bulk food products. The idea of using the acceleration section in suction pneumatic conveying units is not new. The main difference of this study from known technical solutions in the modes of pneumatic conveying of bulk products. In the main section of the material pipeline, it is proposed to reduce the air velocity and to prevent blockage in the section of material acceleration, it is proposed to increase the air velocity to 28...30 m/s. The result of changing the modes of pneumatic transport of the product is a reduction in pressure loss throughout the entire unit.

**Conclusion.** The conducted research showed the prospects of using grain acceleration sections in suction vertical pneumatic conveying units. A formula was derived that connects the air velocity in the acceleration section and the main part of the material pipeline and the diameters of the sections. The research found that pressure losses in the unit with a grain acceleration section are 15% lower than in a unit with the constant diameter of the material pipeline, provided that the air velocity in the main section of the material pipeline is reduced. Pressure losses in the unit with a material acceleration section were 3474.9 Pa. Pressure losses in the unit with the constant diameter were 4097.2 Pa.

In the future, it is necessary to experimentally confirm the adopted reduced air velocities in the main section. It is also necessary to develop a method for calculating the length of the grain acceleration section.

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