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METHODOLOGICAL BASES FOR CALCULATION OF THE ASPIRATION VENTILATION SYSTEMS

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Abstract.

Disperse materials are typically used in the production of construction products. A specific role in the production of porous thermal insulation materials is plaid by low-tonnage technological complexes, using traditional materials such as concrete block, and various man-made materials with low-bulk density. From an environmental and economic point of view, fine polydisperse materials shall be charged into technological equipment by closed transports (pneumatic), as well as shelters and aspiration systems for localization of dusting sources of a technological complex. Power indicators of the performance of the aspiration systems are pressure losses at a particular point, as well as the energy flow coming into the shelter. For the calculations, the discrete method of particles motion in the air duct and in the shelter was proposed. We have considered the forces acting on the particles in the moving two-phase flow. We have developed the pressure loss calculation method for each fraction, and then summation over all fractions. We have proposed the efficiency calculation method for dust collecting in the filter material subject to a disperse composition of dust and fraction-wise efficiency of the fabric.

Keywords. Two-phase systems, pneumatic transport, aspiration, shelter, air duct aerodynamic calculation, pressure losses.

Introduction. Large-scale tasks to increase the housing stock in the Russian Federation calls for the development of the protecting structures with high thermo-technical performance. The most widely used in the construction are various insulating concretes such as gas-filled (foam concrete, aerated concrete), and based on lightweight fillers (expanded clay concrete, perlite concrete, polystyrene, etc.). A special role in the production of thermal insulation materials is plaid by low-tonnage technological complexes (LTTC), using both traditional materials such as expanded clay, and materials obtained by heat treatment of the extruded granules (polystyrene), as well as extruded natural materials (perlite) and various man-made materials (fiberized paperboard), etc. [1-3].

The analysis of technological processes of LTTC showed that the production of porous composite materials uses various polydisperse finely grinded materials (perlite, polystyrene, cement, fiberized paperboard, etc.), which requires using, from an environmental and economic point of view, the closed types of transport (pneumatic). Calculation methods for pipelines for such materials are insufficiently developed to this time. Processes of cement charging into LTTC silo bunker require using the special local ventilation systems [4].

The above factors determine the relevance of this paper.

Main part. The main energy indicators, largely determining the efficiency of the unit and the systems in general, are pressure losses in the pipeline in a particular area.

The main feature of pneumatic transport systems in the production of thermal insulation materials is the use of materials with low density (ρ_M<500 kg/m^3) and, as a consequence, low concentrations (μ <0.5 mg/kg). On the other hand, using the pipelines with small diameters (d <100-150 mm) in the systems poses a number of requirements for the calculation of such systems.

It is the consideration of two-phase low-concentration flows during bulk materials transportation in the channels allowed us adequately describe the process and to develop on the basis of analytical and experimental studies an engineering calculation method for air ejection volumes in conjunction with the movement of the bulk material (the inverse problem with respect to the pneumatic transport).

On the other hand, the transport process of the fillers in the LTTC has significant differences from the previously studied processes occurring during particulate material ejection in the closed channels.

Methods for solving the main problem of pneumatic transportation - determination of pressure losses - is mostly based on the estimated equations, including experimental factors, which functions are not defined, and the numerical values are different in different authors. This can be explained by the complexity of the physical phenomena occurring during pneumatic transportation, the difficulty of analytical calculation, the difference in experimental techniques, various physical properties of the particles, and other reasons [4].

Based on the above, the calculations of the pressure loss in pneumatic transportation pipelines in the production of thermal insulation materials must be preceded by experimental measurements on the specially created units or similarly operating systems. Of course, this approach is unacceptable in modern conditions.

All studies devoted to the aerodynamics of the two-phase pneumatic conveying flow can be divided into two groups.

The first group includes studies where two-phase flow is considered as a continuous medium. These studies determine the pressure loss in general, without considering the mechanism of movement of the particles and the factors that influence the pressure loss in the flow. We shall particularly note the work by I. Gasterstadt. According to the author, the pressure losses in the two-phase pipeline are determined based on the experimental factor (later called Gasterstadt coefficient) *K* [5]:

$$\Delta H_{2\phi} = \Delta H_0 (1 + K\mu), \qquad (1)$$

where ΔH_0 - pressure losses for clean air;

ΔH_{2ph} - pressure losses in the two-phase pipeline;

K - experimental coefficient;

μ - weight concentration of the material in the pipeline, kg/kg.

The author conducted 38 experiments with wheat in horizontal pipes with diameter of 89 and 95 mm. The limited conditions of Gasterstadt's experiments and their small number made it impossible to generalize the *K* value by a calculation formula, but this method has become widely used for the calculation of pneumatic transportation of other materials. Many researchers, using the equation, have directed their efforts at finding the *K*value for the various materials and conditions of pneumatic transportation. At the same time, the *K* value depends on many factors and varies within a wide range (from 0.2 to 2.5 and above). Recommended *K* values by different authors for certain materials may differ significantly from each other.

In recent years, BSTU named after V.G. Shukhov has successfully conducted works on the analytical determination of the pressure loss. The obtained results were based on the works by Saks S.E., Schwab V.A., and Mednikov E.P. [6].

In this case, a solid body may consist of several components with different physical parameters that allow with a sufficient degree of engineering precision calculating the pressure loss (and hence energy loss in the system) without the preliminary construction of the experimental unit. At the same time, the difference in the actual and analytical pressure losses does not exceed 15-20%.

In developing calculation methods for the pressure loss in the pipelines performed in BSTU named after V.G. Shukhov, a discrete method or the method of trajectories [7] was used. The pressure loss calculation is performed discretely for each fraction, followed by the summation of all the fractions (superposition method). It should be noted that the methods of calculation based on analytical solutions of the trajectories of particle motion have several advantages over empirical methods such as the use of empirical methods in conditions different from the conditions of their production, and require an appropriate justification of their adequacy.

At the same time, currently there is no available analytical calculation methods for the LTTC pipelines, in particular, under pneumatic transportation of materials such as perlite, polystyrene, fiberized paperboard, grinded cement.

Analysis of studies of the pneumatic transportation processes has shown that the existing methods for calculating the pressure loss during transportation of two-phase flows (especially in the construction materials industry) are based mainly on the generalization of the experimental data and obtaining of empirical relations, which can be used in those cases, when the initial system parameters correspond to the experimental data. According to our calculations, when transporting the LTTC porous materials, the weight concentrations of the materials (such as perlite, polystyrene, fiberized paperboard) do not exceed 5-7 (μ <5-7). This fact confirms appropriateness of using the results of research carried out in BSTU named after V.G. Shukhov, aimed at the analytical calculation of the pressure losses in the pipelines of the vacuum dust cleaning systems.

Considering the movement of low-concentration aerosols, we used the principle of superposition - a separate consideration of the carrier phase (gas) motion, and individual fractions of material with subsequent summation of pressure losses in the transportation of all phases.

The following assumptions were made during the development of a mathematical model of the material transfer in pipelines:

1. All particles of the polydisperse material are affected by a particular mechanism of pressure loss, while larger particles (d> 0.15 mm) are characterized by an abrupt movement, and small particles (d <0.15 mm; ρ_M> 1000 kg/m^3) - by pulsation movement.

2. The influence of material particles on the kinematic structure of the air flow is significant. The gas velocity diagram in a horizontal pipeline is asymmetrical and permanent, regardless of the changing particle concentration in the pipeline (μ).

$$V = V_{cp}\left(1-\frac{r}{R}\right)^{a} e^{\pm\beta\cdot r/R}, \qquad (2)$$

where V_{av} - output air velocity; R - pipe radius; r - distance from the pipe axis; a and β – parameters depending on V_{av} (the value is taken for the upper and lower half of the pipe, respectively).

3. Particle collisions with each other is neglected.

4. We believe that the energy consumption for transportation of the material consist of the consumption for transportation of the individual particles of energy.

Thus, the total pressure loss *H* in the flow in a stabilized area is:

$$H = H_1 + H_2 + H_3, \tag{3}$$

where H_1– pressure loss for the restoration of the linear and angular velocities of the particles after hitting the pipe wall;

H_2 - pressure loss for overcoming of the shear stresses of the clean air on the pipe wall;

H_3 - pressure losses for pulsation of particles due to the developed airflow turbulence.

Assumptions 1 and 2 are true for the flows with a small weight concentration (μ <5-7), which takes place in the LTTC pipelines. In this case, the particles move at a relatively great distance from each other (more than 10 particle diameters) and their collision probability is small.

Since we consider the motion of a weakly concentrated flows and can ignore the interaction of particles with each other, it is evident that the energy consumption for transportation of dispersed materials will be summarized.

Implementation of the proposed approach requires solving the equation of motion of particles of the suspended in the flow material under a certain field of carrier phase velocities. The velocity field can be obtained on the basis of existing empirical relationships for the distribution of the flow velocities along the channel cross section.

A model of discrete particle motion in the gas flow was obtained as [8]:

$$m\frac{d\overline{U}}{dt} = \sum \overline{F_i}, \tag{4}$$

where *m* - particle mass; *U* - particle velocity vector;

$$\sum \overline{F_i} = \overline{F_c} + \overline{F_м} + \overline{F}_s + \overline{m}g, \tag{5}$$

where $\sum \overline{F_i}$ - the sum of forces affecting the particle.

Intense rotation of the particles, as well as the presence of significant gas velocity gradients in the wall regions requires to consider the equation describing the change in angular velocity of the particles:

$$\overline{J}\frac{d\overline{\omega}}{dt} = \overline{M}, \tag{6}$$

where $\overline{J} = 0,1 \cdot md^2$ - particle inertia moment;

$\overline{M} = -\pi\eta d^3(\overline{\omega} - \overline{\omega}\text{g})$ - the moment of the aerodynamic interaction forces of a rotating particle with the gaseous medium;

$\overline{\omega}$ - angular rotation velocity of a particle;

$\overline{\omega}\text{g}$ - instantaneous angular rotation velocity of the gas at a given point.

Given the above, the mathematical model of the particle motion in a gas stream takes the form:

$$\begin{cases} \dfrac{d\overline{r}}{dt} = \overline{U} \\ \dfrac{d\overline{U}}{dt} = -\dfrac{C_d \,\text{Re}}{24\tau}(\overline{U} - \overline{V}) + \overline{g} + \overline{a}_{м} + \overline{a}_{s}, \\ \dfrac{d\overline{\omega}}{dt} = -\dfrac{10}{3\tau}(\overline{\omega} - \overline{\omega}\text{g}) \end{cases} \quad (7)$$

where $\overline{a}_{м} = \frac{3}{4} \cdot \frac{\rho_r}{\rho_\tau} \cdot \overline{\omega}_x(\overline{U} - \overline{V})$ - Magnus force acceleration,

$\overline{a}_s = \frac{3,2}{\pi}\sqrt{\frac{\rho_r}{\rho_\tau \cdot \tau(\overline{\omega g})}}(\overline{U} - \overline{V})$ - Saffman force acceleration,

$\text{Re} = \frac{d\rho_\tau}{\eta}\left|\overline{U} - \overline{V}\right|$ - Reynolds number for a particle,

C_d- aerodynamic drag factor.

As a result of the numerical solution, the researches of BSTU named after V.G. Shukhov developed an analytical calculation method for pressure loss for a variety of material particles, for each specific fraction of a polydisperse material. i.e., H_1 [9]. To determine H_2 we used Darcy-Weisbach formula:

$$H_2 = \lambda \frac{\rho_в \cdot V_в^2 \cdot l}{2D}, \quad (8)$$

where the drag factor λ was determined by formula:

$$\lambda = \frac{0,3164}{\text{Re}_D^{\;0,25}}, \quad (9)$$

$$\text{Re}_D = \frac{D \cdot V_в}{\nu}. \quad (10)$$

For particles smaller than d <0.15 mm, for determining H_3:

$$H_3 = \sum_{n=1}^{n} \frac{3}{2} \frac{(V_p')^2 \cdot V_в \cdot \rho_в \cdot f \cdot \mu}{U_{cp}{}^2} l, \quad (11)$$

where V_p' - the root mean square of the particle pulsation velocity equal to $V_p' = \overline{\theta} \cdot \overline{V'}$,

f - average pulsation frequency ($f = 10V_v$)

μ - material concentration in the flow, kg/kg.

The numerical values show that even when d = 150 μm (when ρ = 2550 kg/m^3) the value H_3 is practically negligible.

The given method of analytical determination of pressure loss can only be used for horizontal pipelines.

To calculate the efficiency of fabric used as a filter material it is necessary to know the fraction-wise efficiency of the fabric and a disperse composition of dust entering the aspiration system [10]:

$$\dot{\eta} = 0,01 \sum Ni \cdot \eta_{фi}, \quad (12)$$

where *Ni* - a particulate composition determined by the above method;

η - fractional efficiency used in a fabric system, taken from reference books. Dust concentration after filtration can be determined as:

$$A_{выброс} = A \cdot (1 - \dot{\eta}) / 100, \quad (13)$$

where *A* - concentration at the inlet of the aspiration system, mg/m^3.

At the same time, in our opinion, the concentration of emissions $A_{emission}$ should be compared with the maximum permissible concentration A_{MPC} rather than with maximum permissible emissions A_{MPE}, as the dependencies used herein do not adequately reflect the processes in nature. It seems to us that values of $A_{emission}$should not exceed 30 mg/m^3 (taking into account the fact that the LTTC is usually located near residential areas, as well as in accordance with European standards).

The time between regeneration (*Δt*) can be calculated based on a dust layer thickness *Δh*, which significantly increases the fabric resistance.

Then, knowing the concentration *A* and airflow Q_{asp} we can calculate the amount of dust entering the filter:

$$G_1 = A \cdot Q_{асп}. \quad (14)$$

Therefore, we can also determine the time *Δt*, required for the dust layer to become equal to *Δh*:

$$G_1 = F_{ф} \cdot \Delta h \cdot Q_{м} / \Delta t, \tag{15}$$

$$\Delta t = F_{ф} \cdot \Delta h \cdot \rho_{м} / \mathrm{G}_1 . \tag{16}$$

Economic effectiveness of the conducted research can be assessed both when using the results of the developed techniques for the calculation of the LTTC pipelines and when using the complex production in general, in particular, LLC "LTTC Recycle". The introduction of the developed techniques for the calculation of pipelines in the project practice of increases labor productivity of the engineers by 25-30%.

Analysis of the existing analytical methods for the calculation of pipelines for bulk materials showed that the LTTC conditions require correcting the existing analytical methods.

We should also note that the disperse materials are widely used for the production of granulated products for various purposes. The choice of method and tools for their compaction means is done based on physical and mechanical properties of the raw materials and the finished product requirements [11-14].

Conclusion. The developed physical model of pneumatic transportation process in the horizontal and vertical pipelines more fully, in our view, takes into account the factors of energy consumption by the flow. These factors include: energy loss for the impact of particles on the wall and change in their angular rotation and linear, particles weighing and lifting, the energy loss for the chaotic relocation of the fine particles by turbulent vortices; and loss in the clean air flows.

The ability to use the analytical method for the calculation of the pressure loss in relation to LTTC materials requires conducting both special experimental and analytical studies. Experimental studies were carried out using an industrial unit of LLC LTTC "Recycle".

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References

1. Sevostianov V.S., Makridin A.A., Sevostianov M.V., Shinkarev L.I., 2011. Engineering and technology of integrated recycling of the cellulose and paper waste. Problems of construction, engineering, landscaping and ecology: International scientific-practical conference, pp: 152-156.

2. Glagolev S.N., Sevostianov V.S., Iliina T.N., Uralskii V.I., 2010. Technological modules for integrated processing of man-made materials. Chemical and Petroleum Engineering, 9: 43-45.
3. Glagolev S.N., Sevostianov V.S., Gridchin A.M., Trubaev P.A., Sevostianov M.V., Koshchukov A.V., 2015. Thermal analysis of the technological line for extrusion of man-made fiber materials. Bulletin of Belgorod State Technological University named after V.G. Shukhov, 2: 78- 83.
4. Logachev I.N., Logachev K.I., 2005. Aerodynamic fundamentals of aspiration. St. Petersburg: Khimizdat, p: 658.
5. Gasterstadt I., 1927. Pneumatic transport. L.: Northwest industrial bureau, p: 119.
6. Mednikov E.P., 1981. The turbulent transportation and deposition of aerosols. M.: Nauka, p: 174.
7. Minko V.A., Logachev I.N., Logachev K.I., 2006. Dedusting ventilation. V.1. Belgorod: Publishing House of BSTU, p: 460.
8. Shaptala V.T., Feoktistov Iu.A., Feoktistov A.Iu., 2001. Numerical simulation of transport process of fine materials in the pipelines of vacuum dust cleaning systems. Proceedings of the All-Russian Conference "Energy and resource saving. Alternative and renewable energy sources", pp: 137-139.
9. Shaptala V.T., Feoktistov Iu.A., Feoktistov A.Iu., 2002. The calculation of the pressure loss during movement of dusty flows in the pneumatic pipelines. Proceedings of NSABU, 1(16): 72-75.
10. Minko V.A., Logachev I.N., Logachev K.I., et al.; ed. V.A. Minko, 2010. Dedusting ventilation. V.2. Belgorod: Publishing House of BSTU, p: 568.
11. Sevost'yanov M.V., T.N. Il'ina, V.S. Sevost'yanov, V.A. Uvarov, 2013. Mechanical Compaction Process Models of Materials and Their Instrumentation Software. World Applied Sciences Journal, 25(12): 1770-1775.
12. Il'ina T.N., 2013. Classification of Fine Materials and Recommendations for Sintering . Chemical and Petroleum Engineering. Vol. 49. Nos. 3-4: 229-232.
13. Sevostyanov M.V., T.N. Il'ina, W. S. Sevostyanov , D.A. Emelyanov, 2014. Methodological Principles of Agglomeration Processes Improvement in Technologies of Disperse Materials Processing. Research Journal of Applied Sciences 9 (11): 738-744.
14. Sevostyanov M.V., T.N. Il'ina, W.S. Sevostyanov, D.A. Emelyanov, 2015. About the Role of Surface Phenomena in the Processes of Processing of the Dispersed Materials. Research Journal of Applied Sciences, 10: 684-689.