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Complex modeling of technological processes in pneumatic mixers for production of dry construction mixtures

T N Orekhova[1], O A Nosov[1], V S Prokopenko[1], A E Kachaev[2]

[1] Belgorod state technological University V. G. Shukhov, 46, Kostyukova St., Belgorod, 308012 Russia
[2] OOO «Resurrection plant «Mashinostroitel»», 1, Garage St., Voskresensk, 140200, Russia

E-mail: vlad.prokopenko1@ yandex.ru.ru

Abstract. The improvement of the design of the pneumatic mixers aimed at the possibility of obtaining homogeneous disperse systems, while the resource and energy saving issues play an important role in the conditions of enterprises that use this type of equipment in their technological chain, is described in the article.

1. Introduction

At the present stage of the development of dry construction mixtures technologies in Russia, an important role in their production is played by the possibility of using efficient technological units. The specificity of production of dry mixes provides flexibility of technological operations in view of ensuring their wide range, as well as the quality of products in comparison with the existing variety of analogues.

Advances in the field of building materials science, concerning the composition of dry construction mixes, determine the main directions for improving the technique and technology of homogenization of their dispersed components. In this case, product homogeneity is the main characteristic of the required quality of modern construction mixtures [1].

2. Materials and methods

Depending on the type of construction mix, for example, such as light (heat-insulating), heavy (finishing plasters), extra-heavy (mixes for pouring floor screeds), etc., it is necessary to select a mixing equipment that would satisfy production technology. For example, for light insulating mixes it is advisable to use continuous mixers [2, 3, 4]. The main advantages of the pneumatic mixer developed design can be called the production of a homogeneous product with a high degree of uniformity, as well as the possibility of producing mixtures in a continuous cycle.

3. Mathematical model of vortex flow in pneumatic mixers

In the construction of pneumatic mixers [2, 3], the main mixing of the dispersed components of the mix occurs by the axial moving in the homogenization chamber of two-phase flow, which, under the action of the air introduced from the periphery of the chamber, begins to curl into the vortex (Fig.1). Theoretical studies of the motion of a vortex flow of a two-phase medium in a pneumatic mixer make it possible to adequately assess the nature of the process of homogenization, to determine the design parameters of the aggregate and its effective operating conditions for examples of different compositions of construction mixes. That is why such studies are very relevant and indicative.

When the components of the mixture get from the accelerating unit to the homogenization chamber, the two-phase flow decelerates (Fig. 1). In this place, particularly large particles (250 μm or more) can fall out of the stream and settle in the so-called "stagnant" zones of horizontal mixers [2]. To eliminate the "stagnant" zones [2] of the homogenization chamber, a peripheral tangential air blowing is provided in the design of the air mixer, which begins to involve particles entering the chamber after the accelerating unit into the vortex flow. Certainly, a process of mixing occurs already at the stage of transporting the mix in the accelerating unit; however, vortex mixing is the main process of more efficient mixing, and its mathematical description is more relevant.

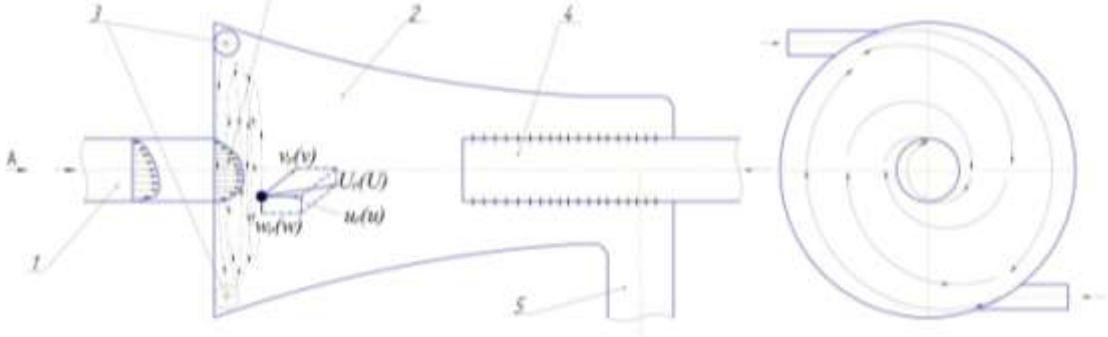

Figure 1. A scheme of the vortex motion of a two-phase flow in a homogenization chamber:
1 - transportation of the components of the mixture over the accelerating unit; 2 - homogenization chamber; 3 - tangential air blowing; 4 - unit for aeration and disaggregation of the mixture; 5 - discharge fitting.

In the rotating air stream, the forces of gravity F_g act on the particle of the material being ground; aerodynamic resistance of medium (air) F_a; force due to the change in the pressure of the medium over the surface of particle F_p; side asymmetric flow around rotating particle $F\omega$.

The equation of equilibrium of the forces acting on the particle in the vortex flow of the homogenization chamber can be represented as:

$$\frac{dU_p}{dt} = \frac{(U - U_p)}{\tau} - gradp + g + 2U\frac{dU_p}{dr_1}, \quad (1)$$

where U, U_p is the absolute velocity of the carrier phase and the particles in the vortex stream, respectively, m/s; r_1 is the initial radius of the homogenization chamber, m; g - acceleration of gravity, m/s^2; p is the pressure of the carrier medium (air) per particle of material, Pa, taking into account the geometric parameters of the homogenization chamber. It is calculated by the formula:

$$p = p_{p.y} + \frac{\rho U}{2}\left[1 + \left(\frac{L_1 \cdot l_1}{2\pi r_1^2} + \cdots + \frac{L_\kappa \cdot l_\kappa}{2\pi r_\kappa^2}\right)\right], \quad (2)$$

where $p_{\text{p.y}}$ - the pressure created in the disperse unit of the pneumatic mixer, Pa; L_1- initial length of the homogenization chamber, $L_1 = 0$, m; L_k - the final value of the length of the homogenization chamber, m; l_1 and l_k - initial and final vortex swirl lengths, m; r_1^2 is the initial radius of the homogenization chamber decreasing to r_k^2, m.

The absolute velocity of the carrier phase and the particle is determined from the expression:

$$U(U_p) = \sqrt{[v(v_p)]^2 + [w(w_p)]^2 + [u(u_p)]^2}, \quad (3)$$

For determining the velocity field of a particle with a force that takes into account its rotation, we neglect it due to the smallness of its magnitude. Let us suppose that the radial, tangential and axial velocities of the air movement and the particles of the material being ground are determined by the distance from the rotation axis and time intervals without collisions with the walls of the

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homogenization chamber and other intensifying devices that can be located in it, as, for example, in [3,4].

Theoretically, the particle motion in the vortex flow of the centrifugal field of the homogenization chamber can be represented by a system of equations:

$$\begin{gathered}\frac{dv}{dt}=\frac{\left(v-v_p\right)}{\tau}-\frac{1}{\rho_p}\frac{\partial p}{\partial r_1}+\frac{w_p^2}{r_1},\\ \frac{dw}{dt}=\frac{\left(w-w_p\right)}{\tau}+\frac{v_p\cdot w_p}{r_1},\\ \frac{du}{dt}=\frac{\left(u-u_p\right)}{\tau}-\frac{1}{\rho_p}\frac{\partial p}{\partial z}+g,\end{gathered}\tag{4}$$

where v_p, w_p, u_p are the radial, circumferential and axial velocities of the particle motion in the vortex flow of the homogenization chamber, m / s; v, w, u - the same for the carrier phase (air), m/s; z is the vertical coordinate of the particle position in the vortex, m.

To average the velocities of the particles and the carrier phase, the system of dimensionless quantities is used ($\bar{\lambda}=\frac{1}{\tau}$):

$$\begin{gathered}\frac{d\bar{v}}{d\bar{t}}=\bar{\lambda}\left(\bar{v}-\bar{v}_p\right)-\frac{1}{\rho_p}\frac{\partial p}{\partial r_1}+\frac{\bar{w}_p^2}{\bar{r}},\\ \frac{d\bar{w}}{d\bar{t}}=\bar{\lambda}\left(\bar{w}-\bar{w}_p\right)+\frac{\bar{v}_p\cdot\bar{w}_p}{\bar{r}},\\ \frac{d\bar{u}}{d\bar{t}}=\bar{\lambda}\left(\bar{u}-\bar{u}_p\right)-\frac{1}{\rho_p}\frac{\partial p}{\partial z}+Fr,)\\ \frac{d\bar{r}}{d\bar{t}}=\bar{v}_p,\qquad \bar{w}_p=\frac{\bar{r}d\varphi}{dt},\quad \bar{u}_p=\frac{dz}{dt}.\end{gathered}\tag{5}$$

The initial conditions for solving system (4):

$$\left\{t=0;r=1;\ \varphi=0;z=0;v_p=1;w_p=1;u_p=0\right\}.$$

The components of the velocity field of the carrier phase (air) in the vortex flow will be determined by the formulas:

- radial:

$$\bar{v}=\frac{t\left[\rho_p\left(\bar{w}_p^2-\bar{\lambda}\bar{v}_p\bar{r}\right)-p\right]}{\bar{r}\rho_p\left(1-\bar{\lambda}t\right)},\tag{6}$$

- peripheral:

$$\bar{w}=\frac{\bar{w}_p t\left[\left(\bar{v}_p\ -\bar{\lambda}\bar{r}\right)-p\right]}{\bar{r}\left(1-\bar{\lambda}t\right)},\tag{7}$$

- axis:

$$\bar{u}=\frac{t\left(\bar{\lambda}\bar{v}_p+\frac{p}{\rho_p z}\right)}{\left(1-\bar{\lambda}t\right)}.\tag{8}$$

According to expressions (6 - 8), the velocities of particles in the vortex flow can also be calculated using the specified characteristics of the carrier phase.

Analysis of the obtained expressions allows us to conclude that the peripherial and radial velocities of the material particles in the vortex flow moving from the periphery to the center (unloading) of the homogenization chamber have maximum values: at r = 0.3-0.15 m, the corresponding particle velocities of the material are in the range from 90 to 113 m/s. It is obvious that the use of equations for estimating the relative velocities of particle motion in a laminar flow, rather than in a vortex flow, which are traditionally used in calculations, leads to significant errors.

The aerodynamics of a two-phase flow in an accelerating unit of a pneumatic mixer can be described by various solutions of expressions based on the Navier-Stokes or Newton equations. Thus, for example, the speed parameters of a two-phase flow can be determined by numerical simulation of the following system of equations:

$$\begin{cases} \text{axis } z: & \rho \dfrac{\partial \mathrm{w_z}}{\partial \mathrm{t}} = -\dfrac{\partial P}{\partial \mathrm{z}} - \rho g + \mu \left(\dfrac{\partial^2 w_z}{\partial x^2} + \dfrac{\partial^2 w_z}{\partial \mathrm{y}^2} + \dfrac{\partial^2 w_z}{\partial \mathrm{z}^2} \right) \\ \text{axis } x: & \rho \dfrac{\partial \mathrm{w_x}}{\partial \mathrm{t}} = -\dfrac{\partial P}{\partial x} - \rho g + \mu \left(\dfrac{\partial^2 w_x}{\partial x^2} + \dfrac{\partial^2 w_x}{\partial \mathrm{y}^2} + \dfrac{\partial^2 w_x}{\partial \mathrm{z}^2} \right) \\ \text{axis } y: & \rho \dfrac{\partial \mathrm{w_y}}{\partial \mathrm{t}} = -\dfrac{\partial P}{\partial y} - \rho g + \mu \left(\dfrac{\partial^2 w_y}{\partial x^2} + \dfrac{\partial^2 w_y}{\partial \mathrm{y}^2} + \dfrac{\partial^2 w_y}{\partial \mathrm{z}^2} \right), \end{cases} \tag{9}$$

where ρ is the density of particles of the solid phase, kg/m^3; $\mathrm{w_z}, \mathrm{w_x}\ \mathrm{w_y}$ - components of the absolute velocity of particles in the stream, m/s^2; P is the pressure created in the flow during the movement of the solid phase, Pa; g-acceleration of gravity, m/s^2; t-time, s; x, y, z are the Cartesian coordinates accepted in the calculation (geometric parameters of the air mixer), m; μ is the dynamic viscosity of the two-phase flow, m^2/s.

The nature of the quantities entering into equation (9) determines the specificity of the motion of particles in the volume of the energy carrier. A systematic approach to the differentiated description of the individual indices of equations (9) makes it possible to determine the optimum dimensions of the mixing chamber.

This mathematical model of the dynamics of a two-phase flow in a mixing chamber of a pneumatic mixer is confirmed by computer simulation of technological processes in it. The dynamics of the two-phase flow in the accelerating unit (Figure 3) allows mixing components only by 10-15% of the required homogeneity coefficient. Consequently, it is expedient to use an axial turbulent flow to convert it into a vortex flow. So the design of the air mixer [3, 4] has a rotary distributor with a dissecting cone that converts the axial flow into a radial flow for further intensification in the jets of the vortex flow resulting from the additional supply of energy from the periphery of the mixing chamber. In this zone, the following high-speed mode is observed (Figure 2). The average speed in the acceleration node is 62 m/s, which is sufficient for effective acceleration of the mix and is small for the destruction of particles in its cylindrical volume. The average speed in the zone of basic mixing is 32 m/s.

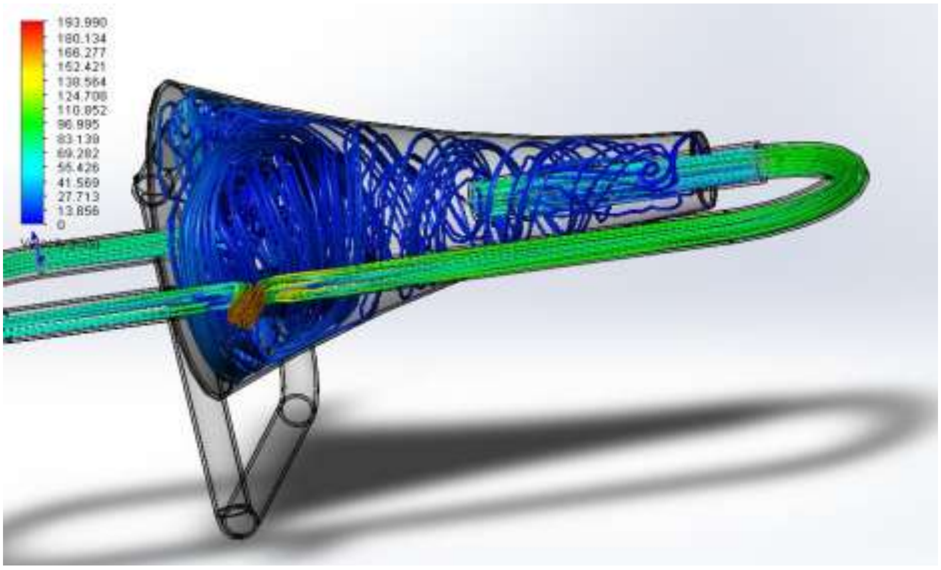

Figure 2. Dynamics of the motion of two-phase flow in the zone of basic mixing.

At the same time, the flow of particles in the air of their radial is transformed into a counterflow vortex flow. Stationary vortex motion of particles in the energy carrier flow is observed, the velocity components of the particles can be determined in accordance with equations (6-8).

The relative volume of the mixing chamber, formed by the ridiculous existence of the zones of the main and vortex mixing, makes it possible to maintain the particle components separately, thereby uniformly distributing the particles of the individual components in this relative volume due to the complex dynamic effect of the ejector (Figure 3).

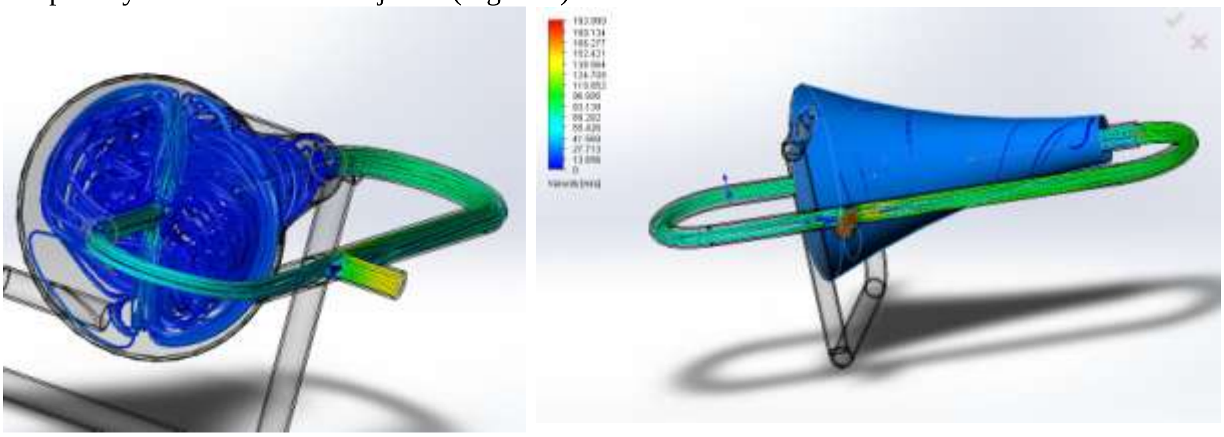

Figure 3. Distribution of two-phase flow in the volume of the mixing chamber.

The pneumatic mixer has an energy supply unit near the discharge nozzle for fluidization of the mixture near the discharge nozzle, reverse flows are formed in the mixing chamber of the unit. This phenomenon has a positive effect on the quality of the mix since it increases the residence time of its relative volume in the vortex mixing zone. However, it should be noted that the reverse flows adversely affect the performance of the unit, reducing its overall rate by 5-8%.

For determining the technological modes of operation of pneumatic mixers in all their designs is very important to take into account the fact that the particle velocities depend on the speeds of the carrier phase. It is important that the process of particle grinding does not pass inside the mixing chamber. To do this, it is necessary to carry out aerodynamic calculations and scientific studies of currents in mixing chambers of similar units, often resorting to the capabilities of modern software products that allow estimating the speed parameters of two-phase flows in different sections of the mixing chambers.

The condition of nondestruction of particles during their homogenization in the mixing chamber of the pneumatic mixers of the designed structures can be represented as:

$$[\sigma_{dyn}]<0,7[\sigma]_p, \quad (5)$$

where $[\sigma_{dyn}]$ - the stresses in the particles during motion and their mutual collision in the energy carrier flow, Pa; $[\sigma]_p$ - stress in the particles, necessary for their destruction, Pa. Coefficient 0.7 is used in view of the fact that at large values of it, in accordance with the Griffiths theory, cracks begin to form in the particles, which precede further destruction of the particles at smaller values of quantity $[\sigma]_p$.

4. Conclusion

With the help of mathematical and computer modeling of aerodynamic features of mixing chambers of pneumatic mixers, optimal speed regimes for the motion of two-phase flows in them have been established. Areas influencing the quality and nature of the motion of particles of various components in an excess of energy carrier are determined. A criterion is established according to which the mode of motion of the mixture in the mixing chamber can be chosen from the condition that the individual particles of its components are not destroyed. The optimal speed regime of the two-phase flow in each zone of the mixing chamber is established on the basis of a complex approach to modeling the processes of homogenization of dispersed components of mixtures. Numerical methods for solving equations (6-8) are adequate to the results of computer simulation in the FlowSimulationSolidWorks 2016 software package.

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References
[1] Uvarov V A, Klyuev S V, Orekhova T N, Klyuev A V, Sheremet E O and Durachenko A V 2014 The counterflow mixer for receiving the disperse reinforced composines *Research Journal of Applied Scieneces* **12** 1211-1215
[2] Orekhova T N 2011 Opredelenie proizvoditel'nosti pnevmosmesitelya suhih stroitel'nyhsmesej s uchyotom analiza ustrojstv smesitel'nyh agregatov *Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V.G. SHuhova* **3** 65-68
[3] Uvarov V A, SHaptala V G, SHaptala V V and Ovchinnikov D A 2013 Novoe napravlenie mekhanoaktivacii cementa *Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V.G. SHuhova* **3** 68-73
[4] Uvarov V A, SHarapov R R and Harlamov E V 2016 Obosnovanie krivoj razdeleniya vozdushnogo separatora *Mekhanizaciya stroitel'stva* **9** 13-15
[5] Korneev V I, Zozulya P V, 2010 *Construction materials* (Moscow: RIF «Strojmaterialy»)
[6] Loskut'ev YU A, Maksimov V M, Veselovskij V V 1986 *Mekhanicheskoe oborudovanie* (Moscow: Mashinostroenie)
[7] Krasnov N F 1976 *Osnovy teorii. Aehrodinamika profilya i kryla* (Moscow: Vysshaya shkola)
[8] Agarkov A M, SHarapov R R and Prokopenko V S 2016 Analiz gidravlicheskogo soprotivleniya koncentratora *Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V.G. SHuhova* **3** 87-90
[9] Sharapov R R, Prokopenko V S 2013 Modeling of the separation process in dynamic separators *World Applied Sciences Journal* **3** 536-542
[10] Uvarov V A, Karpachev D V 2003 Tekhnologiya dlya suhogo obogashcheniya i polucheniya vysokokachestvennyh pigmentov s ispol'zovaniem protivotochnyh strujnyh mel'nic *Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V.G. SHuhova* **6** 392