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M. M. Chaltsev

Automobile Transport and Highway Engineering Institute of Donetsk National Technical University

VORTEX TWO PHASE FLOW RESEARCH WHILE BULK MATERIAL CONVEYING

The mathematical model of the vortex two phase gas-solid flow in a cylindrical pipe is engineered. The model can be adapted for bulk materials pneumatic conveying parameters design.

Recently researchers have been particularly concerned about vorticity while pneumatic conveying. Due to the rotation there is the aerodynamic effect causing the increased pressure of the air at the pipe walls. The wearing is reduced due to it. The task of the present work is in theoretical determining of qualitative and quantitative indicators of the above mentioned aerodynamic effect and vorticity impact on the conveying parameters. The mathematical model of the vortex two phase flow motion at the feeder outlet to the conveying line has been developed for the purpose. Different vortex devices ensuring the transported mixture reciprocating motion can be used as a feeder. The most reliable and simple one is a vortex ejector given in figure 1. The air vorticity in this tangential device is achieved by means of the tangential nozzle and the bulk material supply from the tank is carried out through the axial inlet.

The analytical experimental model of the vortex flow motion in a circular pipe, based on the vertical and axial velocity components approximation has been suggested for solving the set problem. The whole flow was divided into three areas to simplify the modeling process:

1. Wall adjacent flow area $\left(R-\delta<r\le R\right)$;
2. Main flow area $\left(r_{mf}<r\le R-\delta\right)$ where the axial component has the maximum value;
3. Back near-axial flow area $\left(r\le r_{bf}\right)$.

Where: R – pipe inner radius, r_{mf} – zero velocity radius, r – reference radius, δ – shear layer thickness [1]

$$\delta=0,37\left(\frac{w_\infty x}{\nu}\right)^{-1/5}.$$

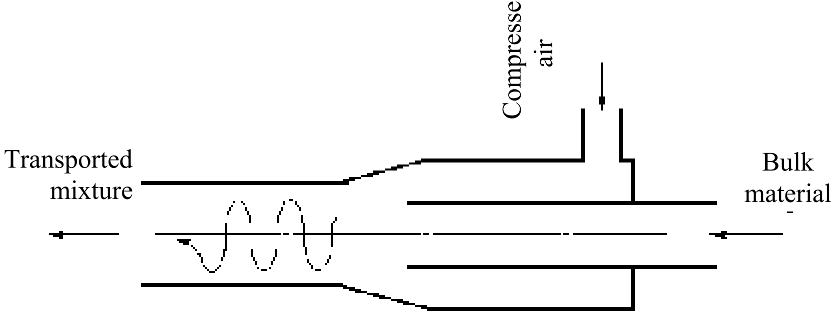

Figure 1 – Vortex ejector scheme

According to the works of different authors ([2], [3]), the kinematic similarity of the vortex flow in a pipe is determined by the dimensionless parameter Φ_*, which characterizes the ratio of the angular momentum M to the axial momentum K_1 in a random section to the scale of the pipeline L linear dimension:

$$\Phi_* = M \big/ K_1 L \cdot$$

The parameter Φ_* initial value is determined as the ratio of the air angular momentum incoming into the tangential nozzle to the bulk material angular momentum designed in the same section. For each pipeline section the reverse flow area radius can be determined by means of the evaluated Φ_*

$$\frac{r_{bf}}{R} = 0,3\left(\Phi_* - 0,24\right)^{0,72}.$$

The main flow area, ($r_{mf} < r \le R - \delta$):

The vortical velocity profile is determined by the Schlichting formula

$$\frac{u}{u_*} = \left(\frac{2\eta}{1+\eta^2}\right)^k,$$

where the parameter $\eta = \dfrac{r}{r_{\varphi m}}$,

$r_{\varphi m}$ – the maximum vortical velocity radius is determined by

$$\frac{r_{\varphi m}}{R} = 0,51\Phi_*^{0,41};$$

the vortical velocity maximum value $\dfrac{u_*}{W_m} = 2,04\Phi_*^{1,09}$.

2. The axial velocity profile is determined by the formula

$$w = \frac{u}{\Phi_*}\frac{r}{R}.$$

The wall-adjacent flow area, ($R - \delta < r \le R$):

1. The axial velocity profile is determined by the formula

$$\frac{w}{w_*} = \left(\frac{R-r}{r}\right)^n,$$

where the exponent is determined by the expression $\dfrac{n}{n_0} = \left[1 + 0,78\left(\Phi_* - 0,07\right)\right]^{0,7}$.

2. The vortical velocity profile is determined by

$$u = w\frac{\Phi_*}{r}R.$$

The back flow area, ($r \le r_{bf}$):

1. The axial velocity profile

$$\frac{w}{w_0} = 1 - \frac{r^2}{r_{bf}^2}.$$

2. The vortical velocity profile is determined by analogy with the previous item.

The radial velocity in all the three areas is determined by the continuity equation

$$\frac{\partial v}{\partial r}+\frac{v}{r}+\frac{\partial w}{\partial x}=0.$$

We will add the differential equation of motion for a solid particle in the vortex air flow

$$\frac{dV}{dt}-\frac{U^2}{r}=F\left(v-V\right)-\frac{1}{\rho_s}\frac{\partial p}{\partial r}-g\cos\varphi;$$

$$\frac{dU}{dt}+\frac{UV}{r}=F\left(u-U\right)+g\sin\phi;$$

$$\frac{dW}{dt}=F\left(w-W\right)-\frac{1}{\rho_s}\frac{\partial p}{\partial x},$$

where $U,\ V,\ W$ – solid circular, radial and axial velocity components;
F – jet force impacting the solid particle from the air flow;
ρ_s – solid particle density.

$$F=\frac{3}{4}k\ C\frac{\rho}{\rho_s}\frac{1}{a}\left|\vec{u}-\vec{U}\right|,$$

where the aerodynamic resistance coefficient is

$$C=\frac{24}{\mathrm{Re}}+\frac{4,4}{\sqrt{\mathrm{Re}}}+0,32$$

a – solid diameter;
Re – Reynolds effective number.
The coefficient, considering the deviation of the solid shape from spherical

$$k=\left(0,843\lg\frac{1}{0,065f}\right)^{-1},\ \text{at } \mathrm{Re}<0,05;$$

$$k=12,4-11,4f^{-1},\ \text{at}\ \ 2\cdot10^3<\mathrm{Re}<2\cdot10^5.$$

The pressure drop throughout the radius and movement will be determined having expressed in partial derivatives from the Navier–Stokes equation

$$\frac{\partial p}{\partial r}=-\rho\left(v\frac{\partial v}{\partial r}+w\frac{\partial v}{\partial x}-\frac{u^2}{r}\right);$$

$$\frac{\partial p}{\partial x}=-\rho\left(v\frac{\partial w}{\partial r}+w\frac{\partial w}{\partial x}\right).$$

The model was numerically computed by the Runge–Kutta method. The design dependences of the two phase vortex flow velocity and pressure change were obtained. The design trajectories of the solids motion through the pipeline boost area depending on the dimensionless time for the particles different diameters are given below as illustrations (figure 2). The figure one refers to the particle diameter 40 micron, 2 – 30 micron.

As seen from the given diagram the trajectory of the bigger and thus the higher mass particles being of relatively higher inertness is flatter than that of the smaller particles. But due to the higher inetrnes the particles boosting takes more time andfor a long time they remain under the vorticity impact tending to concentrate the particles at the pipeline axis. In general there is the tendency to the vortex flow solid phase displacement to its axis in the pipeline beginning at the boost moment. Further on with the vorticity decaying the particles start falling on the walls (figure 3).

Thus the assumption of the air "barrier layer" at the pipeline wall, protecting it from increased wear, is proved.

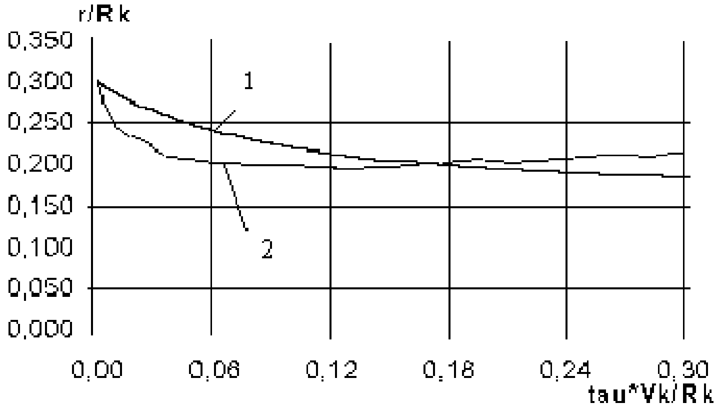

Figure 2 – Solids trajectory

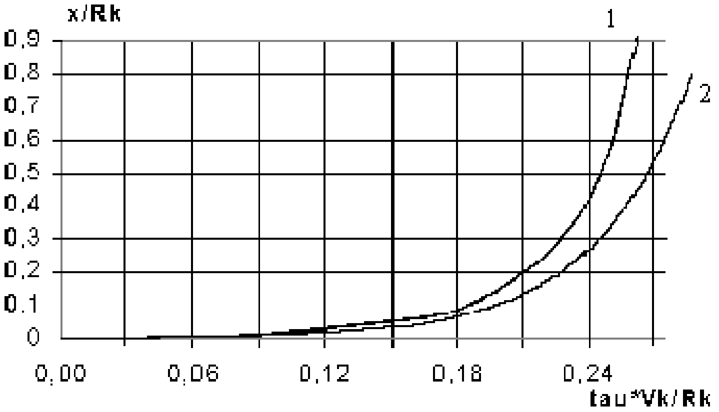

Figure 3 – The coordinate of the solid falling on the pipeline wall

The mathematical model describing the solids motion in the air vortex flow in a circular pipe is given and can be used for the parameters design of bulk materials pneumatic conveying by means of compressed air vortex flow. At that the solid phase limit volume concentration shall not exceed 2%. For example for ashes, removed from coal thermal power plant electrical filters, it is 40 kg of the bulk material per 1 kg of air.

Bibliography

1. Шлихтинг Г. Теория пограничного слоя / Г. Шлихтинг. – М.: Наука, 1984. – 712 с.

Shlikhting G. Teoriya pogranichnogo sloya (The Shear Layer Theory) / G. Shlikhting. – M.: Nauka, 1984. – 712 s.

2. Халатов А. А. Теория и практика закрученных потоков / А. А. Халатов. – К.: Наукова думка, 1989. – 192 с.

Khalatov A. A. Teoriya i praktika zakruchennykh potokov (Vortex FlowsTheory and Practice) / A. A. Khalatov – K.: Naukova dumka, 1989. – 192 s.

3. Щукин В. К. Теплообмен, массообмен и гидродинамика закрученных потоков в осесимметричных каналах / В. К. Щукин, А. А. Халатов. – М.: Машиностроение, 1982. – 200 с.

Shchukin V. K., Khalatov A. A. Teploobmen, massoobmen i gidrodinamika zakruchennykh potokov v osesimmetrichnykh kanalakh (Vortex Flows Heat Exchange, Mass Transfer and Hydrodynamics in Axially Symmetric Paths) / V. K. Shchukin, A. A. Khalatov. – M.: Mashinostroyeniye, 1982. – 200 s.

4. Лойцянский Л. Г. Механика жидкостей и газов / Л. Г. Лойцянский. – М.: Наука, 1987. – 840 с.

Loytsyanskiy L. G. Mekhanika zhidkostey i gazov (Fluids and Gases Mechanics) / L. G. Loytsyanskiy. – M.: Nauka, 1987. – 840 s.