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MODELING THE MOTION OF PARTICLES IN THE PNEUMATIC TRANSPORT MILLS

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Summary. The modeling of coal particles motion in the curvilinear streams of the pneumatic transport mills was done. The trajectories of particles motion and their velocities in the moment of impact at the angle pipes dash elements of pneumatic transport mills were calculated.

Key words: modeling, milling, curvilinear stream, pneumatic transport, coal powder processing.

INTRODUCTION

Presently in many processes coal burning powder coal is widely used. On most Ukrainian thermal power-stations anthracitic and carbonaceous powder culm is mainly used. Coal flaring effectiveness depends on its milling fineness that determines additional expenses of energy in coal powder processing systems [Turushin 2010].

One of effective thin milling methods is impact of solid particles at a hard balk. This method can be realized by the air stream acceleration of particle and their impact at the angle pipes dash elements of pneumatic transport mills [Turushin 2009]. This device is intended for coal powder processing systems and allows to combine the milling process and pneumatic transport of coal, intended for flaring in the burners.

Among the number of basic construction and technological parameters, that bear influence on coal milling efficiency of the developed device, are the particle size and its velocity at the moment of impact at dash element and the angle of attack. The angle of attack depends on the trajectory of particle motion in the angle pipe. Thus, mathematical description of two phase flow is required with the use of CAM programs and computing systems.

The last years researches in the examined problem area [Hughes 1986, Tritton 1988, Hauke 1994, Hoekstra 1999, Hauke 2001, Soulaïmani 2001, Coulson 2002, Syomin 2004, Syomin 2009, Dmitrienko 2009], are mostly devoted to the motion of curvilinear streams in cyclone and separator devices, vortex and cyclone burners, vortex mixers and etc. Issues, related to the motion of coal particles in the acute-angles of pneumatic pipes, are practically not examined by researchers. A necessity for such research arose up due to the study of material milling regularities in the process of pneumatic transport.

Development of mathematical model of coal particles motion in the angle pipes with taking the construction and technological device parameters into consideration will allow to determine the influence of basic factors on the milling process. Modeling results can be used in development of engineering methods of basic parameters calculation for pneumatic transport mills.

MODEL AND GOVERNING EQUATIONS

For the effective milling of coal in pneumatic transport mills, the angle pipes are used with the turn angle δ from 60 to 90^0 [Lenich 2011]. Schematically the construction of the angle pipe is presented on a fig. 1. A section of angle pipe is a square. The internal edge is rounded, the external is acute-angled. The dash element *1* is set leveled with the external wall of the angle pipe to impact and mill the particles of material.

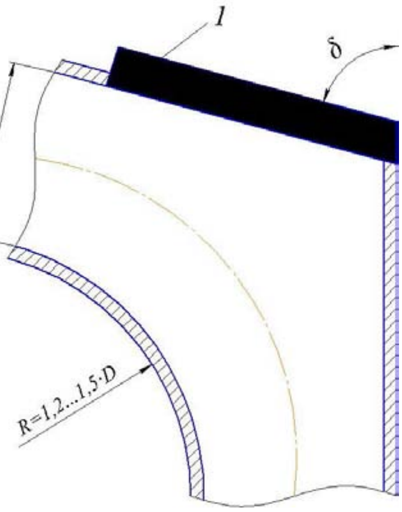


Fig. 1. The construction of angle pipe of pneumatic transport mill

The specific features of pneumatic transport mills application in the industrial systems of coal powder processing are large Reynolds numbers with pressures or Mach numbers, for which the motion of working environment is developed turbulent.

Depending on the number of particles, there are streams with a low and high concentration and superconcentrated streams. At a low concentration, the motion of two phase stream is determined by hydraulic description of liquid motion. This results in the necessity of hydrodynamic modeling of single phase swirling flow in the angle pipe of pneumatic transport mill with the use of the detailed models.

Supposition that a liquid is a continuous environment makes consideration of molecules ensembles unnecessary and allows to use the Navier-Stokes equations of motion. Equations of motion take into account that physical properties of liquid remain unchanged, and external forces field is absent. Our application describes the isothermal flow where the energy conservation equation is decoupled from the system.

The Navier-Stokes equations solved by default in all single-phase flow interfaces are the compressible formulation of the conservation of mass and momentum [Batchelor 1967, Bruus 2008]:

$$\frac{\partial \rho}{\partial t}+\nabla\cdot(\rho\mathbf{u})=0\,; \qquad (1)$$

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\rho\mathbf{u}\cdot\nabla\mathbf{u}=-\nabla p+\nabla\cdot\left(\mu\left(\nabla\mathbf{u}+(\nabla\mathbf{u})^T\right)-\frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}\right)+\mathbf{F}\,, \qquad (2)$$

where: ρ is the density, kg/m^3;

$\boldsymbol{u}$ is the velocity vector, m/s;

p is pressure, Pa;

$\mathbf{F}$ is the volume force vector, N/m^3;

T is the absolute temperature, K;

μ is the dynamic viscosity, Pa·s;

$\mathbf{I}$ is the single diagonal tensor.

Particle tracing was done assuming that the impact of the particles on the flow field is negligible. It was then possible to first compute the flow field, then, as an analysis step, calculate the motion of particles. The motion of a particle is defined by Newton's second law [Coulson 2002]

$$m\frac{d^2\mathbf{x}}{dt^2}=\mathbf{F}_p\left(t,\,\mathbf{x},\,\frac{d\mathbf{x}}{dt}\right), \qquad (3)$$

where: $\mathbf{x}$ is the position of the particle, m;

m is the particle mass, kg;

$\mathbf{F}_p$ is the sum of all forces acting on the particle, N.

Examples of forces acting on a particle in a fluid are the drag force, the buoyancy force, and the gravity force. The drag force represents the force that a fluid exerts on a particle due to a difference in velocity between the fluid and the particle. It includes the viscous drag, the added mass, and the Basset history term. Several empirical expressions have been suggested for the drag force. One of those is the one proposed by Khan and Richardson [Coulson 2002]. That expression is valid for spherical particles for a wide range of particle Reynolds numbers. The Reynolds particle number is defined as

$$\mathrm{Re}_p=\frac{|\mathbf{u}-\mathbf{u}_p|d_p\rho}{\mu}, \qquad (4)$$

where: $\mathbf{u}_p$ is the particle velocity, m/s;

d_p is the particle diameter, m.

The empirical expression for the drag force according to Khan and Richardson is

$$\mathbf{F}_p=\pi\frac{d_p^2}{4}\rho|\mathbf{u}-\mathbf{u}_p|(\mathbf{u}-\mathbf{u}_p)\left[1{,}84\mathrm{Re}_p^{-0{,}31}+0{,}293\mathrm{Re}_p^{0{,}06}\right]^{3{,}45} \qquad (5)$$

As practice shows, the most optimal is two-parametric «$k-\varepsilon$» model of turbulence, based on the balancing of generation averaging streams of turbulent energy dissipation in every point [Armfield 1986, Aksenov 1996, Syomin 2004].

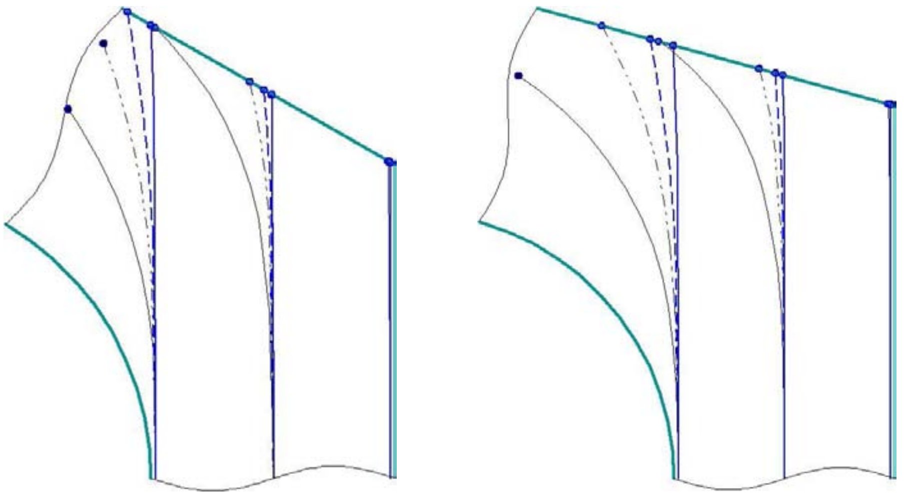
As a resulted system of differential equations is elliptic it is necessary to set boundary conditions for entire computational domain. For simplicity of task and programmatic realization we apply universal «hard» boundary conditions which allow to compute the flow field. On the walls the velocity is set to zero, as a result of liquid adhesion to the walls $u_w = 0$; in the angle pipe inlet section the velocity of flow is set to u_{in} as a result of experimental researches; in the angle pipe outlet section static pressure is $p_{out} = 0$.

A number of software products is now developed for the numeral simulation of liquid and gas flows. One of such products is a “Comsol Multiphysics”.

RESULTS

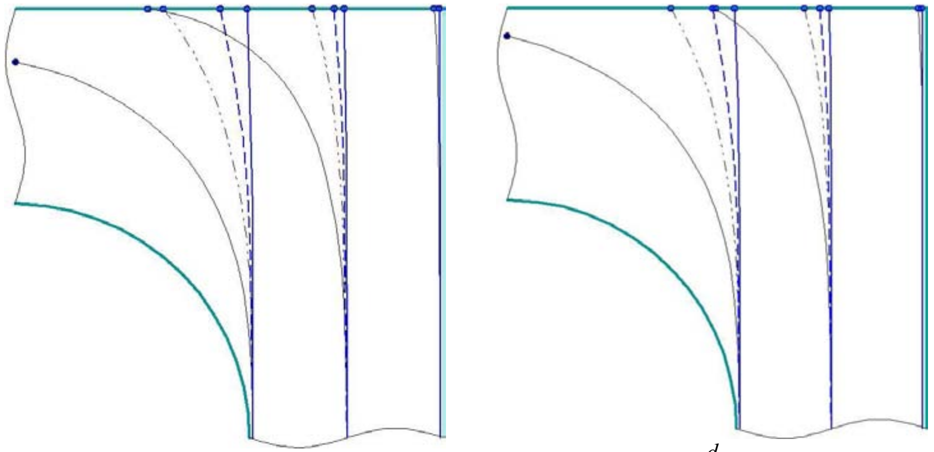
The numerical modeling of particles motion in the angle pipes of pneumatic transport mills was carried out in the software package «Comsol Multiphysics 4.2».

The angle pipes with transversal section dimensions 50×50 mm, turn angle δ = 60, 75 and 90^0 and velocities on the inlet u_{in} = 50, 70 and 90 m/s were examined. The anthracite particles as a solid phase with the density ρ_p = 1700 kg/m^3 were taken. The sizes of particles were d_p = 20, 50, 100 and 400 µm. The trajectories of particles motion are presented on a fig. 2.



a
$\delta = 60^0$; u_{in} = 70 m/s

b
$\delta = 75^0$; u_{in} = 70 m/s



c
$\delta = 90^0$; u_{in} = 50 m/s

d
$\delta = 90^0$; u_{in} = 90 m/s

Fig. 2. Particle trajectories:

——————— d_p = 20 µм; - · - · - · - d_p = 50 µм;
– – – – – – d_p = 100 µм; ——————— d_p = 400 µм

It's obvious from a fig. 2, that particles with $d_p \leq 20$ μm near the internal wall of the angle pipe and in the centerline of it move along the flow line and their trajectories are curved. As a result, these particles impact at the dash elements tangentially or leave the angle pipe with the flow without impact.

Particles with sizes $d_p \geq 100$ μm practically don't change the straightforward trajectories because of their greater mass and amount of kinetic energy. Angle of attack for such particles $\alpha = 90^0-\delta$.

Near the external wall, all particles impact at the dash elements without curving of trajectory, because of small curvature of flow line.

In the moment of impact at the dash elements the particles positions on a fig. 2 are marked with points, the positions of particles with $d_p = 20$ μm (near the internal wall) that leave the angle pipes were also marked. For each of these points the absolute velocities of particles u_{imp} were calculated. Decrease of particles velocities in the moment of impact is characterized by relative velocity $\bar{U} = u_{imp} / u_{in}$. Dependency of relative velocity $\bar{U}$ on the turn angle δ of the angle pipes for $u_{in} = 70$ m/s is presented on a fig. 3.

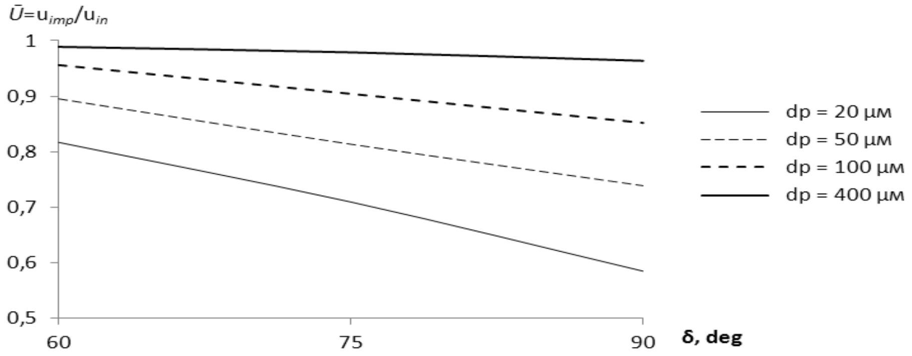


Fig. 3. The diagram of dependency $\bar{U} = f(\delta)$ for $u_{in} = 70$ m/s

As we can see from fig. 3, with the increase of turn angle δ of angle pipes the relative velocities of particles $\bar{U}$ in the moment of impact decrease. Thus the greater size of particle, the greater relative velocity $\bar{U}$ of its motion. For the particles with sizes $d_p = 100$ μм $\bar{U}$ is 0,85…0,96; for $d_p = 400$ μм – $\bar{U} = 0,96…0,99$. For the particles with greater sizes $\bar{U} \rightarrow 1$, that well conforms to the results, obtained by other authors [Kesova 1991, Varaksin 2003].

CONCLUSIONS

1. The character of anthracite particles motion in the angle pipe is determined by turn angle of the angle pipe, flow velocity and sizes of particles.

2. There is a maximum size of anthracite particle $d_p = 100$ μм, greater than which the trajectory of particle is near to the straight line regardless of the angle pipe configuration and flow velocity.

3. Anthracite particles with $d_p > 400$ μм don't change the direction of motion in the angle pipes, their velocities in the moment of impact at the dash elements are roughly equal to the flow velocity.

4. The obtained modeling results show that this construction is possible to apply practically at velocities and particles sizes which are used in pneumatic transport systems.

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МОДЕЛИРОВАНИЕ ДВИЖЕНИЯ ЧАСТИЦ УГЛЯ В ПНЕВМОТРАНСПОРТНОЙ ИЗМЕЛЬЧАЮЩЕЙ УСТАНОВКЕ

Дмитрий Дмитриенко, Сергей Ленич

Аннотация. Проведено моделирование движения частиц антрацита в криволинейных потоках пневмотранспортных измельчающих установок. Определены траектории движения и скорость частиц в момент удара об отбойные элементы колен пневмотранспортных измельчающих установок.

Ключевые слова: моделирование, измельчение, криволинейный поток, пневмотранспорт, пылеприготовление.