22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

NUMERICAL METHODS IN PROCESSES OF DESIGN AND OPERATION IN PNEUMATIC CONVEYING SYSTEMS

G. Borsuk*, S. Pochwała*, J. Wydrych*

Abstract: *During design and operation of large dust boilers systems one of the main problems is to provide the required distribution of the air-dust mixture to individual burners. Further, the higher concentration of particles in certain areas of the flow can cause uncontrolled erosion wear of these fragments. For boilers with burners in the corners, just behind the outlet of the mill four-path separator is built-in, whose task is even distribution of air-dust mixture. For numerical analysis Psi-CELL method was used to determine velocity distributions and for calculating particle trajectories Lagrangian method. Numerical calculations of the air-pulverized coal mixture flow through a pipeline with built-in elbow and a four- path separator were prepared. The result of the study showed when a small modification of the test system - by installing the threshold scattering - can reduce dust segregation intensity in the section downstream the elbow. It is also shown that the method adopted to calculate the system allows optimization of the flow for other very complex geometries.*

Keywords: Pneumatic conveying, two-phase flow, CFD, particle concentration distribution.

1. Introduction

During the design and operation of large power boilers systems there are many problems that impede the optimal operation of these systems. One of the main problems is to provide the required separation of a gas-particle mixture to each burner (Wydrych J., 2010, Xiliang C. et al, 2012). This problem is important not only because of the limitation of losses incomplete combustion, but also because of the life of parts of the combustion installation and nitrogen oxide emissions. In the case of boilers with corner burners, downstream to the outlet form the mill there is a four-path separator, where it should be uniform gas-particle mixture distribution.

2. Methods

The presence of particles in the gas volume has an effect on gas velocity and this effect depends on the particle concentration (Taylor T., 1998). For modeling the movement of diluted gas-particle mixture method in which the individual particles are considered as material moving points in space with the interaction with the gas and the walls is used (Liang C. et al, 2014). The Lagrangian method provides good quality of results for the volume fraction of particles less than 12% (Lain et al. 2012). Because of the potential movement analysis of the polidisperse gas-particle mixture PSICell method were used (Crowe C. et al. 1977). Neglecting the phase changes and assuming that both phases are microscipically incompressible, and the flow is isothermic and stationary, the gas motion can be described in the uniform, generalized conservative form, isolating convection, diffusion and source components. In a consequence we obtain

$$\frac{\partial(\rho\phi)}{\partial t}+\frac{\partial(\rho U_i\phi)}{\partial x_i}=\frac{\partial}{\partial x_i}\left(\Gamma_\phi\frac{\partial\phi}{\partial x_i}\right)+S_\phi+S_{\phi p} \tag{1}$$

where ϕ is a generalized dependent variable, Γ_ϕ is the coefficient of diffusion transport, and the source term S_ϕ contains all the remaining components of the differential equations (except for convection and

* Grzegorz Borsuk, PhD., Sławomir Pochwała, PhD., Jacek Wydrych PhD.:Opole University of Technology, Department of Thermal Engineering and Industrial Facilities, ul. Mikołajczyka 5, 45-271 Opole, g.borsuk@po.opole.pl

diffusion ones). The coefficients Γ_ϕ i S_ϕ are dependent on the variable ϕ. In the PSICell method it is assumed that particles of the disintegrated phase are the sources of mass, momentum and energy occurring as additional components $S_{\phi p}$ in equations of the continuous (gaseous) phase.

The system of equations is accompanied by suitable boundary and initial conditions. This system of partial differential equations is non-linear. Particular equations are coupled, so they have to be solved with special numerical techniques. The particle trajectory should be known during calculation of the mentioned source components. The particle trajectory is calculated according to its equation of motion (Lain et al. 2012). If the phase density difference is large, the equation of particle motion can be written as

$$m_p \frac{du_p}{dt} = \frac{3}{4} C_D \frac{\rho m_P}{\rho_p dp} u \left| u - u_p \right| (u - u_p) + g \qquad (2)$$

where m_P is mass of the particle, and C_D is the aerodynamic drag coefficient. Special attention should be paid to the case when the particle collides with the wall. In such a case, components of the particle velocity vector after the collision are calculated from equations included normal and tangential coefficients of restitution. These coefficients are heavily depend on the particle impact angle, material properties of the particles and the walls as well as wall surface smoothness and particle shape.

3. Results

Analyzed flow system shown in Fig. 1. a) is an outlet straight section of the pipeline from the mill with the elbow.

a) b)

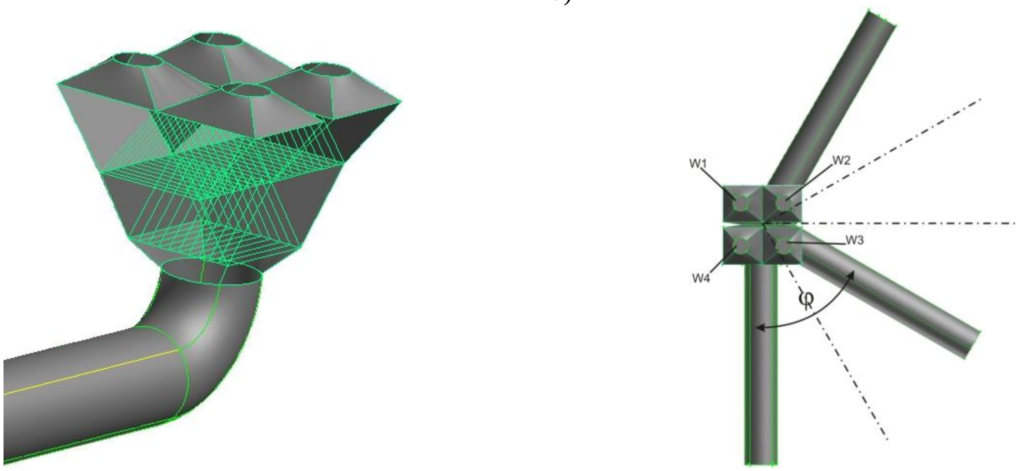


Fig.1. a) General view of four-part seperator with the elbow,
b) The tested system „ four-path separator" for different inlet locations.

Directly downstream the elbow there is a four-path separator. There were velocity and concentration measurements in the cross-sections upstream and downstream the elbow, as well as the fractional particle analysis. Measurements and numerical research were realized with an average load for the mill RP1043x ie. 40 t/h and the air flow of 70000 Nm^3/h. Based on the mathematical algorithm a series of numerical calculations were implemented, using FLUENT (Ansys Package). As a result of calculation obtained concentration of solid phase, as shown in Fig. 2.

To improve the flow conditions in the separator a special diffusion element was built. The purpose of the construction was to change the direction of gas flow and the particle concentration downstream the elbow. During the numerical calculations it was found that installing this element have an effect on the particle concentration change in the cross-section in the pipe downstream the elbow. It was determined that the diffusion element should be located in the area where is a high concentration of particles, i.e. in the final section of the elbow. As a result of particle collision with diffusion element formed mass distribution homogenize in the pipe downstream this element. On the basis of completed series of calculations it was found that the optimum ratio of diffusion element height h to the radius of bend R is 0.29. Moreover element placed in the elbow under an angle β=13,5° relatively best equalize the distribution of particle concentration upstream the separator.

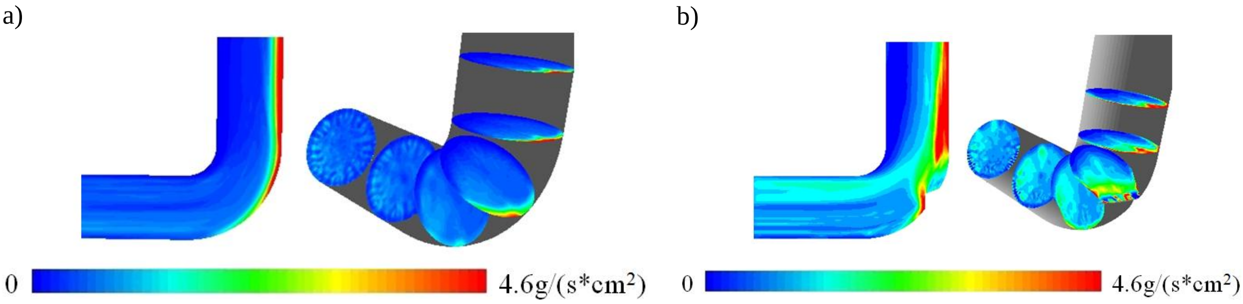


Fig. 2. Paricle concentration distribution in axis plane and selected cross-sections for the geometry a) without, b) with diffusion element

Further part of this paper was to evaluate the effect of the supplying pipe configuration to the four-path separator on the particle distribution uniformity downstream the separator. It was made an attempt to assess the effect of the configuration for six different settings of the entry section to the separator, at different velocities as well as particle diameters. In the calculation domain considered the complex internal structure of the separator, which is schematically shown in Fig. 1a. Setting the inlet compared to the position of the four-path separator is shown in Fig. 1b. The results was prepared for different inlet angles φ. The inlet plane illustrated as being vertical was marked as set of 0°, and further setting the set inlet of 30°, 60°, 90°, 120° and 150°. Fig. 1b shows a flow system in a top view with symbols of outlet cross-sections. The calculation results for trajectories of the particles delivered to the system from the point inlets of the system 90° and 150° are presented in Fig. 3.

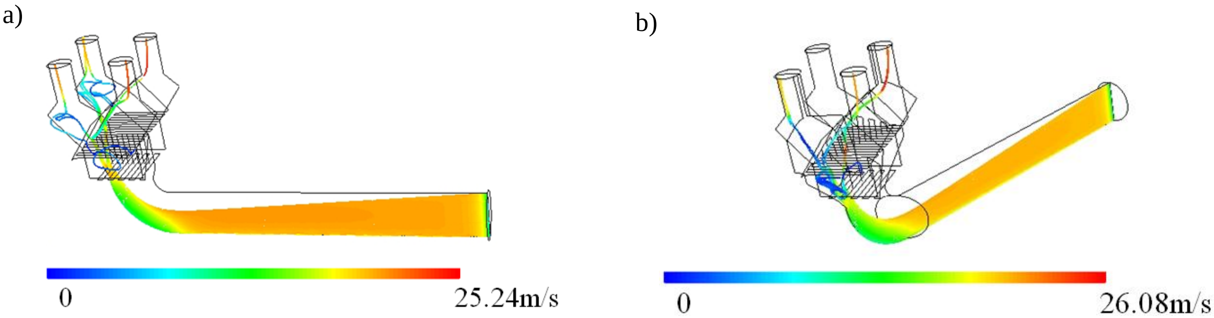


Fig. 3. Trajectories of the particles 100μm for the inlet velocities 25m/s for the system.
a) φ=90°, b) φ=150° *(color indicates particle velocity)*

The tests concerned dispersed coal particles of 5, 10, 25, 50 and 100 μm. The calculations were performed for the stationary flow with the interfacial coupling. At the inlet to the calculation area, three stationary velocity distributions of the gaseous phase were assumed (25, 30 and 35 m/s).

Assuming that uniform separation (25% of particles for each outlet) provides the best service conditions of the boiler installation, at the next stage deviations of the calculated separations from the expected were estimated according to the following relation:

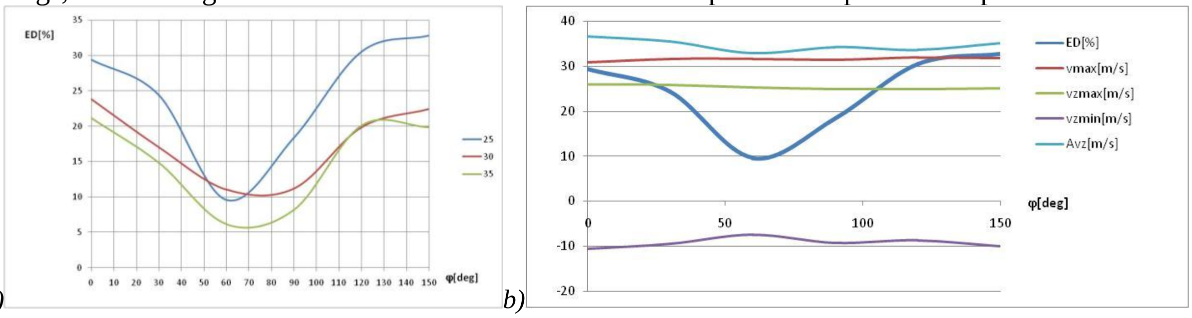
$$ED = \frac{D-25}{25}\cdot 100 \tag{2}$$

where *D* is the calculated separation, and *ED* deviation of separation from the expected value.

Analysis of calculated distribution deviations demonstrate that the increasing of inlet velocity of gas-particle mixture increases the uniformity of the particle distribution to the respective outlets, especially for systems with the angle of the inlet in relation to the separator within the range of 50-100°. For lower velocity to improve the uniformity of the distribution is at an angle φ approx. 90°.

The presented results allowed to formulate the sets of moduli of the averaged deviations from all the outlets for whole the polidysperse mixture. From these sets was built chart presented in Fig. 4, where changes of these moduli related to changes of velocity and angle of inlet location φ was compared.

Application of the smallest inlet velocity to the system causes occurrence of the largest non-uniformities in dust distribution to the outlets. At this velocity, the angle φ=60° is the optimum inlet angle in relation to the separator. Increase of the inlet velocity to 30 m/s causes a change of the optimum inlet angle to 80°. At the highest tested inlet velocity 35 m/s, the optimum inlet angle reduces to 70°. Such results testify strong influence of the inlet system on effectiveness of particle separation by the four-path separator. Moreover, we can find that particular inlet locations are optimum for the given service loadings, and a change of these conditions can cause a worse separation of particles to particular outlets.



a) *b)*

Fig. 4. a) Modulus of the averaged deviation for all the outlets
b) Changes of deviations, extreme velocities and velocity amplitudes versus the inlet location angle φ

The further part of analysis includes an attempt of a relation between deviations of particle separation from the expected values and gas velocities for different inlet-separators systems determination. Fig. 4a shows changes of separation deviations, maximum gas velocities, maximum, minimum and component vertical gas velocities caused by changes of locations of the inlet angle φ.

The data presented in Fig. 4b allowed to determine correlations between them, and calculated correlation coefficients allow to state that there are not important relations between the maximum moduli v_{max} and vertical component v_{zmax} gas velocities and separation deviations. On the other side, high convergence between the minimum values v_{zmin} and amplitudes A_{vz} of vertical velocity components with separation deviations from the expected values can be seen.

4. Conclusions

Completed numerical calculations lead to the conclusion that placing the diffusion element significantly affects the concentration of dust in the cross-section of the pipe downstream the elbow and very important for diffusion element localization. Measurements of concentration before and after installing the diffusion element made explained the desirability of the building. It is advisable to conduct further numerical calculations carried out mainly for optimization of diffusion element shape.

Regarding the elbow and four-path separator analysis leads to the conclusion that due to the method used, it is possible to define the geometry of the four-path separator, which ensure optimum distribution of particles into selected outlet sections. It has been found that the use of minimum inlet velocity for the system affects the occurrence of nonuniformity in the largest section of particle outlets. Changing the inlet velocity influences the optimum angle of the inlet. These results indicate a major impact on the efficiency of the inlet particle separation by the four-path separator.

References

Crowe Clayton T., Stock David E. & Sharma M.P., (1977) The particle-sources-in cell /PSI-CELL/ model for gas-droplet flows. Journal of Fluid Engineering No. 99, pp. 325-332.

Lain S. & Sommerfeld M. (2012) Numerical calculation of pneumatic conveying in horizontal channels and pipes: Detailed analysis of conveying behavior. International Journal of Multiphase Flow, No. 39, pp. 105–120.

Liang C., et al, (2014) Comparison of pressure drops through different bends in dense-phase pneumatic conveying system at high pressure. Experimental Thermal and Fluid Science, No. 57, pp. 11-19.

Schuh M.J., Schuler C.A. & Humphrey J.A.C., (1989) Numerical calculation of particle laden gas flows past tubes. AIChE Journal, No. 35, 3, pp. 466-480.

Sommerfeld M. & Huber N., (1999) Experimental analysis and modelling of particle–wall collisions. International Journal of Multiphase Flow, No. 25, 6,7, pp. 1457–1489.

Taylor T., (1998) Specific energy consumption and particle attrition in pneumatic conveying. Power Technology, No. 95, pp. 1-6.

Wydrych J., (2010) Comparative analysis of the methods of simulation of flow in boiler dust systems. Chemical and Process Engineering, No. 31, 4, pp. 603-623.

Xiliang C., et al, (2012) Investigations of pulverized coal pneumatic conveying using CO2 and air. Powder Technology, No. 219, pp. 135–142..