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A NUMERICAL ANALYSIS OF THE FLOW THROUGH THE ELBOW IN THE BOILER PULVERIZED COAL SYSTEM

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Abstract: *Use of large power boilers requires appropriate distribution of the air - coal particle mixture to particular burners. The tests of gas and coal distribution show the problem of their non-uniformity under different working conditions of the system. In the paper multi-phase flow models were presented in the installation with elbow. In the work three methods: Euler-Euler, Euler-Lagrange and E-L with modification were compared with results of experiment. This work shows that the Euler-Euler model seems to be more useful for the considered flows.*

Keywords: CFD, Pneumatic conveying systems.

1. Introduction

In the pneumatic conveying systems in power boilers, the solid particle separation in some areas is a significant problem. Diversification of concentration and uncontrolled segregation of particles of such systems take place in many cases. As a consequence, diversification of propagation, disturbances of the combustion process and accelerated erosion of the installation elements may occur (Dobrowolski et al., 2007, El-Behery et al., 2009, Miller et al., 2009). Moreover in the large power boilers, the required distribution of the air-coal mixture to particular burners must be obtained. This problem is very significant because of limitation of incomplete combustion losses, furnace elements durability and NO_x emission. This paper presents numerical calculations of the air-coal dust mixture flow through the pipeline with the built-in elbow. The results of calculations for gas and particle separation show the problem of non-uniformity of their distribution. It follows that particle distributions to particular outlets are non-uniform and vary under different working conditions of the installation (Rajniak et al., 2008, Spedding et al., 2007, Woods et al., 2008). The calculations were performed in order to qualitative and quantitative comparison of the results for two methods of simulation: the Euler-Lagrange and the Euler-Euler. The Euler-Lagrange model is usually applied for tests of the multiphase gas-solid particle mixture flow. It provides good quality of the results for volume fractions of solid particles not exceeding 12%. From the analyzes of elements as elbows, distributors or cyclone separators it appears that in some of theirs area the limit value 12% is exceeded (Jaworski et al., 2002). This work shows that the Euler-Euler model seems to be more useful for the considered flows (Wydrych, 2010).

2. Methods

Presence of the particles in the gas stream influences the gas motion, and this influence depends on the particle diameters and concentration. In the simplest case, the mixture motion can be described by introduction of the substitute density to the equations of motion. In simulation of motion of the gas-particles mixture, two approaches are applied (Fokeer et al., 2004):

- particles are treated as the material points displacing in the space, and their interactions with gas and the walls are taken into account (the Lagrange method) (Laín et al., 2012),
- the particle phase is replaced by the fictitious fluid with suitably defined physical properties (the Euler method).

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Neglecting the phase changes and assuming that both phases are incompressible, and the flow is isothermal and stationary, the gas motion can be described in the uniform, generalized conservative form (Dobrowolski et al., 2007), containing 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.

In order to calculate turbulence k-ε model was used with assumption that the flow was fully turbulent, and the effects of molecular viscosity were negligible (Kuan et al., 2007). The turbulence kinetic energy, k, and its rate of dissipation ε, are obtained from the following transport equations:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{2}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \tag{3}$$

The particle trajectory is calculated according to its motion equation. If the phase density difference is very large, the equation of particle motion can be written as (Laín et al., 2012):

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

where m_P is mass of the particle and C_D is the aerodynamic drag coefficient.

In the case of simulation of multiphase gas-solid flows, while processes similar to fluidization, the heterogeneous Euler-Euler model (the Euler model) is applied. In the case of the Euler model, the equations of mass and momentum conservation are similar to the equations for the one phase model (Doods et al. 2011). If there is no mass exchange between the considered phases, the equation of motion and continuity for phase "k" have a form:

$$\frac{\partial(\alpha_k\rho_k u_k)}{\partial t}+\nabla\cdot(\alpha_k\rho_k u_k u_k)=-\alpha_k\nabla p+\nabla\cdot(\alpha_k T_k)+\alpha_k\rho_k g+\alpha_k\rho_k(F_k+F_s) \tag{5}$$

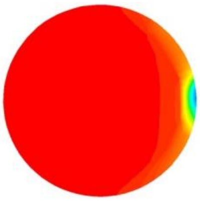
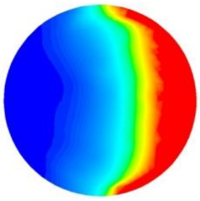
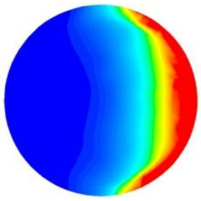
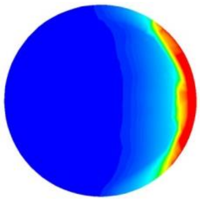
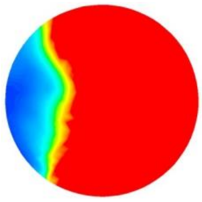
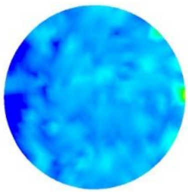
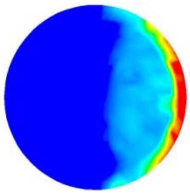
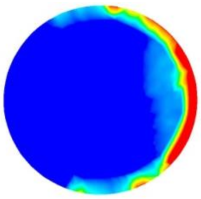
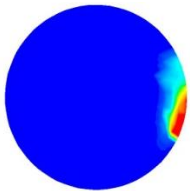
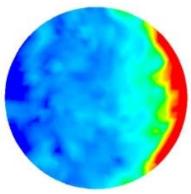
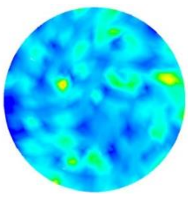
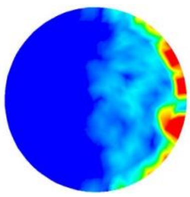
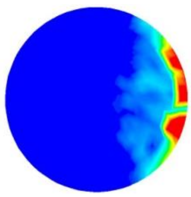
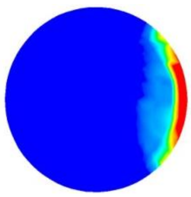
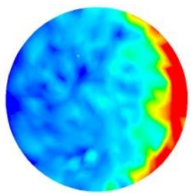
$$\frac{\partial(\alpha_k\rho_k)}{\partial t}+\nabla\cdot(\alpha_k\rho_k u_k)=0 \tag{6}$$

The FLUENT program was applied for numerical calculations. It allows to solve the systems of equations of mass, gas momentum and the solid phase transport completed with the turbulence model equations. Calculations were made according to the Euler-Lagrange method (the **EL** method) and the Euler-Euler method (the **EE** method). Moreover calculations were made also with use Euler-Lagrange method completed by particle turbulence effect and particle shape effect (the **ELpl** method).

3. Results and Discussion

In order to make calculations, the continuous flow systems with elbow were replaced by the calculation areas including non-structural calculation meshes. Disintegrated coal particles for diameters d_k: 15, 90, 125, 200 μm were tested. The inlet velocity was at level 30 m/s and diameter of the pipe was 1,2 m. In the case of the Euler-Lagrange model, when convergence of the velocity field solution is obtained and presence of solid particles and coupling between the phases are taken to calculations, trajectories of motion of the coal dust particles of density 1300 kg/m^3 was calculated. From analysis of the trajectories it appears that the particles with small diameters move along the paths corresponding to streamlines of the gaseous phase. The particles with larger diameters move along to the paths often forming a "cord". This is a reason of local increase of concentration (Borsuk et al., 2006, Fokeer et al., 2004, Wydrych, 2010). This effect can cause increase of non-uniformity of the solid phase concentration right after the elbow. The centrifugal force causes that bigger solid particle fractions are rejected to the external surfaces of the arcs, and next they move as "the cords" of particles. This effect is undesirable because particles segregation causes excessive wear of surfaces of the installation elements in some areas. From comparison of the results obtained with different methods it appears that the EL and ELpl models show greater particle concentration at the lesser area than the EE model. This difference is a result of including collisions between the particles of all the phases into the EE model. In the EL and ELpl models it is neglected.

Tab. 1: Distributions of concentration for particles 15, 90, 125, 200μm in diameters and for all types of particle obtained with the EE, EL and ELpl methods.

	15	**90**	**125**	**200**	**All**
EE					
EL					
EL pl					

The calculations performed with the Euler-Lagrange (EL, ELpl) and Euler-Euler (EE) methods allowed to determine distributions of the disintegrated phase in the outlet section after the tested elbow. In both methods, the uniform distribution of velocity was assumed at the inlet section. In the EE method, an uniform distribution of particle volume fraction at the level 0.9654 % was assumed at the inlet section. Tab. 1 contains distributions of dust particles 15, 90, 125 and 200 μm in diameters at the outlet after the elbow obtained with the EE, EL and ELpl methods. Maximum results in the table was truncated to 0.3% for EE method and to 1 g/(cm^2·s) for EL and ELpl methods. In the presented pictures inner part of elbow is located on left side of circles.

Measurements of the velocity distributions and concentration of dust in the measuring section after the elbow were performed in order to determine the real flow conditions. The measurements were performed in the working conditions (Dobrowolski et al., 2004). The coal-particle samples in the section before the

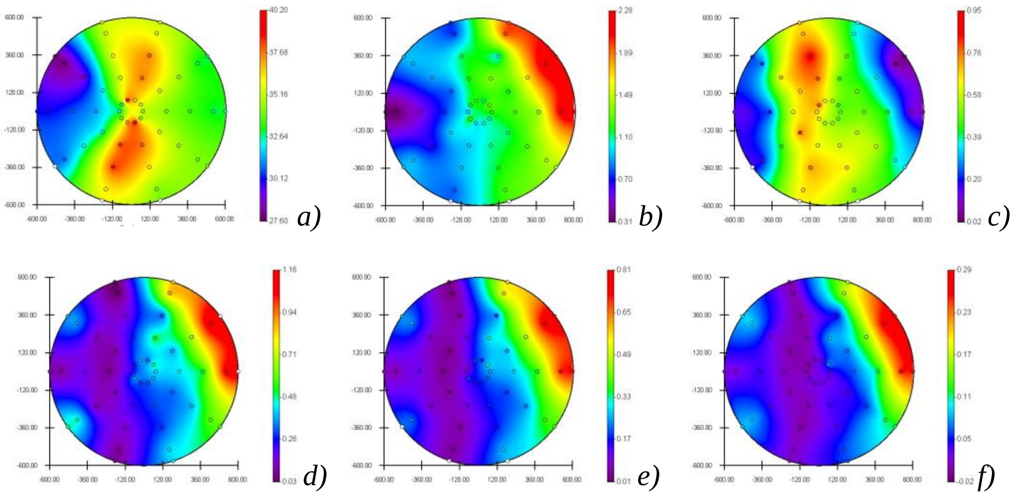


Fig. 1: Distributions of: a) Velocity in [m/s] and concentration in [g/s] for the particles; b) All diameters; c) 15, d) 90, e) 125 and f) 200 μm obtained with experiment.

separator were drawn with the device for isokinetic suction. Velocity and concentration distributions are similarly to obtained by other researchers. After comparison particle concentration distribution obtained with experiment and calculations, it appears that particles form "rope" after the elbows. It is especially evident for large diameter particles.

4. Conclusions

Comparison results let conclude that Euler-Euler is the best method to calculation of gas-particle flow in set with elbow. Differences between EE and EL methods are result of interparticle collisions included only in Euler-Euler method. Adding this mechanism to Euler-Lagrange method may improve efficiency of particles concentration distribution estimation. The EE method gives more uniform results of concentration calculations for all the tested particle fractions. Comparison reciprocal correlation for distribution of particle's concentration from experiment with EE, EL and ELpl methods shows that for particles 15μm from experiment occurrence negative correlation for bigger particles from calculations. This phenomenon is a result of filling volumes by large particles, which cause crowding-out effect for smaller particles. Authors suggest to introduce a new definition "**anti-cord**".

The observed quantitative differences between theory and experiment can result from the assumed simplifications and three-dimensionality of the flow in the tested system. It limits the applicability range of the methods used for the measurements of solid particles velocity and concentration. In such situations, the results obtained according to the Euler-Lagrange model are incorrect, and the error is a result of application of an incorrect method of calculations. In the case of volume fractions of solid particles in gas exceeding 12%, the Euler-Euler method (so-called Euler methods) seems to be more useful, and this method is recommended to the further investigations.

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