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ANALYSIS OF THE EROSIVE WEAR MODELING RESULTS OF THE PNEUMATIC CONVEYING SYSTEMS

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Abstract: *This paper attempts a qualitative and quantitative comparison of the calculation results of multiphase flow gas - solid particles in a flow system with built-in bend. The movement of the gas phase and particle trajectories are described by Euler and Lagrange models respectively. Simulation tests were performed for several different inlet conditions, in order to determine their impact on results. The study allowed us to identify the model of Euler-Lagrange as useful for this type of flows, and the formulation of a number of important conclusions. The paper presents the possibility of applied mathematical models to predict the erosive wear of flow system with built-in elbow. The emphasis of the work was put on qualitative comparison the effect of inlet conditions on the change of the gas velocity field and the concentration of particulate matter. These elements made it possible to locate areas of increased wear as well as the degree of wear.*

Keywords: Erosive wear, CFD, Euler-Lagrange method.

1. Introduction

Operating of pneumatic conveying systems brings many problems. Uncontrolled particle segregation or local erosion of the system components are only some of them. Problems of pneumatic transport system designing are the subject of a many types of research (Borsuk et al., 2006; Liang et al., 2014; Olszowski et al., 2007; Taylor, 1998 and Wydrych, 2010). However, current methods for the design of pneumatic conveying systems did not allow for a proper assessment of the erosive wear. The paper presents a method that allows to evaluate the aerodynamics and erosion as a function of inlet conditions in the test flow system. The movement of the gas phase and particles was described by Euler and Lagrange models respectively, which was extended by the turbulence model equation. Numerical calculations were performed for the two particle diameters. The results of numerical calculations are compared with the results of experimental installation shown in Fig. 1a. It is a part of a pipeline of circular cross section with a built-in elbow. The system is made of pipes with the diameter $\phi D = 76$ mm. In the measuring section was made research material loss due to wear erosion. During the numerical calculations length of the inlet section was changed and amounted to 100, 500 or 1000 mm. Outlet section has a length of 600 mm.

Bending angle measuring section in the shape of the elbow is 90°, while the bending radius $R = 1.5\cdot D = 114$ mm. In the illustrated arrangement gas - mixture flow was tested with the following molecular characteristics. The air density $\rho = 1.2$ kg/m^3, and a dynamic viscosity $\mu = 1.8\cdot10^{-5}$ Pa·s provided a cross-sectional view of the inlet velocity of 23.0 m/s, which corresponds $1.17\cdot10^5$ Reynolds number. At the same time, the inlet section supplied with particles of quartz sand from 6200 inlet points. Particles with diameters of 150 and 300 μm have the same velocity as air at the inlet, and the density was 2650 kg/m^3. Sand particles with a hardness of HV 9.8, were applied in an amount of 0.033 kg/kg of air. The flow system was stainless steel 316, wherein the density of 7990 kg/m^3, the hardness HV is 1.83, and the BH is 178.9.

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2. Methods

A mathematical model consisting equations of the gas phase and particles motion was formulated in order to realize numerical calculations. Motion of the gas is described by Euler method while the movement of particles by Lagrange. In order to correctly analyze motion poly-dispersed mixture gas - solid particles, in this paper, the method of PSI-Cell was used (Source Particle in Cell) (Wydrych, 2010), (Fidaros et al., 2007). Bitter model was selected for calculation of the erosive losses (Bitter, 1963), with attention to the smallest differences in the numerical calculations results of measurements. In the Bitter model, erosion was classified in two categories, i.e. shearing and deformation. Generally, shear and deformation are used simultaneously and they are independent, so the total amount of the wall material, which is removed, can be written as the sum of these two mechanisms. In this section, the equations were solved using a commercial package ANSYS Fluent (Fluent Inc., 2015).

3. Analysis of the results

The Fig. 1.a shows the flow system with built-in elbow, in which numerical calculations was realized. Detailed calculation carried out for the system in three different configurations at the inlet section, for three different lengths of inlet: 100, 500 and 1000 mm. Tests were conducted for two different diameters of the dust particles, i.e.: 150 and 300 μm. In addition, the calculation of particle trajectories was made without turbulent fluctuations in the motion of particles and taking account of these fluctuations. The result is series of 12 data set, which take into account changes in the above factors and in the rest of the work will be determined in a symbolic way. For example, the inlet length of 100 mm, a particle diameter 150 μm without taking into account the fluctuation is applied to symbol - 100_d150, and for the inlet of length 500 mm, particle diameter, included fluctuations in the calculations 300μm - 500_d300_rnd.

a) b)

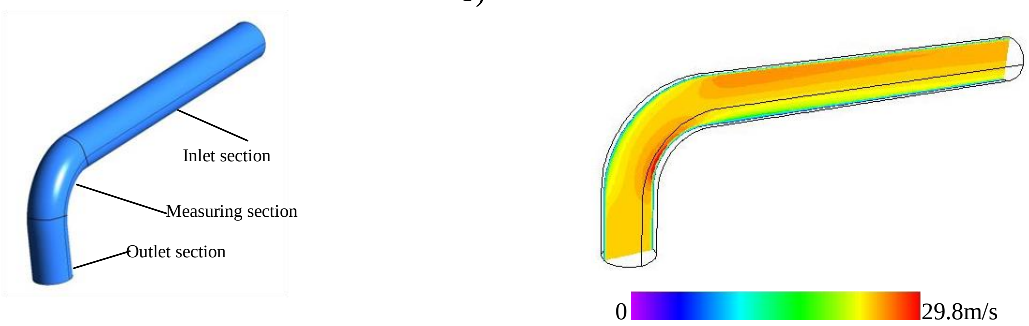

Fig. 1: Experimental set (a) and distribution of module gas velocity (b) for the set 100_d150.

At the inlet to the system were set uniform velocity distributions and particle concentration. The calculations were made for the velocity of 23 m/s, and the concentration of particles 0.033 kg/kg gas. The results of calculation of the velocity field in the selected cross-section of the flow system are shown in Fig. 1b.

a) b)

Fig. 2: Trajectories of particles (a) and distribution of the concentration of the solid phase (b) for the set 100_d150.

Velocity distributions for all lengths of the inlet confirm that movement of the gas phase in the presence of particulate matter in the areas of the elbows occurs primarily close to internal arcs. Extending intake causes major gas recirculation zones downstream the elbow and reducing the effective cross-section of the outlet. This may induce of increased resistance of the mixture motion. The Fig. 2a presents exemplary trajectories of the particles supplied to the inlet section arranged in one plane. Analysis of particle trajectories shows that particles at inlet section change their trajectories as a result of turbulent fluctuations only slightly, while the particles at the outlet section with turbulent fluctuations spread over a larger area and at shorter distance occupy the entire cross-section of the outlet. Concentration of the solid phase was calculated based on specific locations of the solid particles, as shown in Fig. 2b.

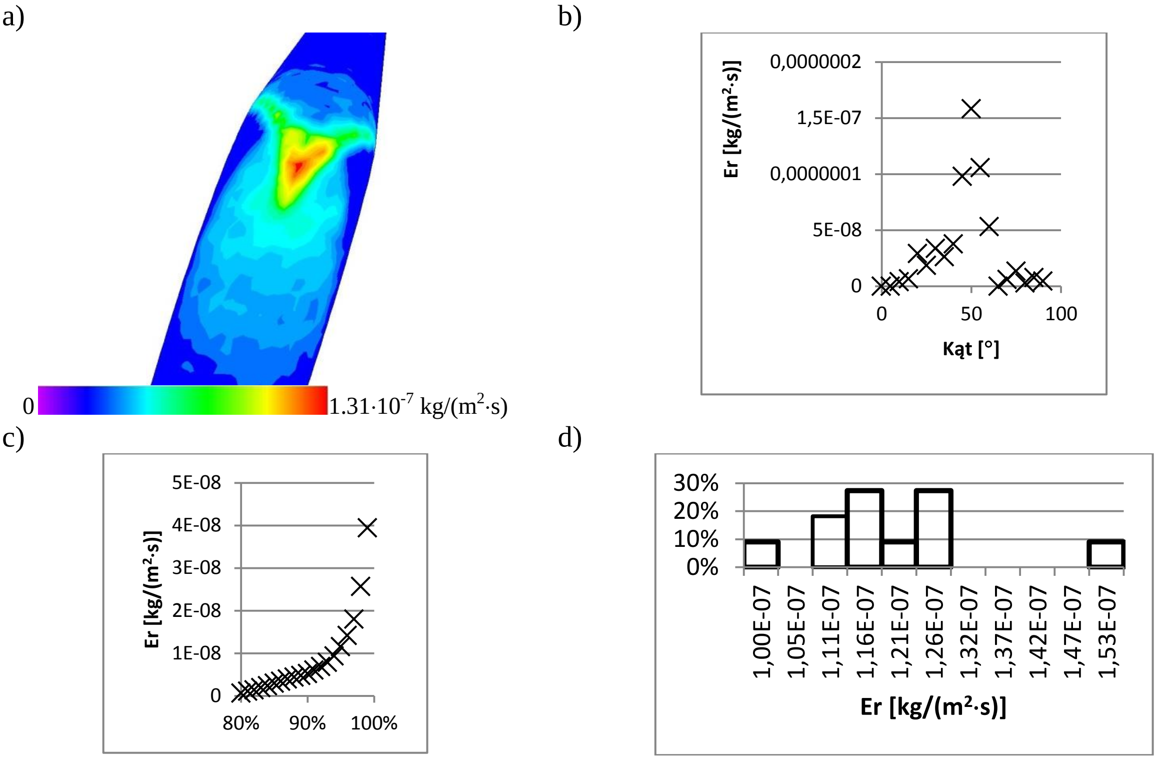

Fig. 3: A set of analytical data for the 1000_d150 a) distribution of consumption erosion; b) dependence of the consumption of the angular position of the measuring point, c) graph percentile consumption, d) histogram of the percentage of consumption zones.

The presence of the elbow significantly distorts the distribution of concentration in the elbow and downstream the elbow. Clearly, the uniform concentration distribution in the inlet section is deformed by the centrifugal force as an effect of the elbow, to form the external increase of solid particles concentration. In contrast, there are no notable changes in the concentration distributions for tested systems. Because of the mixture movement which composition comprises solid particles of sand will gradually wear the wall. High wear zones are located in areas of the elbow which results from the rejection of the particles by centrifugal force. The Fig. 3 presents sets of results to analyze the wear-life of the erosion caused by the presence of particles in the conveying mixture. Data analysis leads to the conclusion that the area of the greatest erosion is located on a small area of the external elbow arch. Percentiles charts and histograms provide information, which shows that this area is less than 1 % of the entire surface of the tested element. Graphs b) and c) allow to conclude that the inclusion in the calculation of the random fluctuations of particles reduces the maximum consumption and at the same time increasing the area of the occurrence of erosion. Furthermore, the results shown in Fig. 3b were compared with the experimental results. Measurements were carried out for the erosive loss of elbow, for which detailed data were available regarding the time and operating conditions. Experimental data for the test system were taken from the literature (Vieira et al., 2016). The results of calculations apply only to the outer curve of the elbow in the measuring section. Elbow in this section has been divided into 18 parts angle φ per 5 °. For each measuring point, losses of erosion were calculated using ANSYS FLUENT (Fluent, 2015). The Fig. 4 shows the comparison of the numerical calculations results with experimental. Analysis of erosive wear distribution on the surface of the elbow received by experiment and calculation shows that the developed method of modeling erosive wear gives qualitatively similar results for a given element. Areas of greatest wear were correctly predicted by model 100_d150_rnd for angle 50 °. However, in the area of the whole range of computational model it was the most effective 1000_d300.

This demonstrates the significant influence on the length of the inlet section calculation results erosive wear.

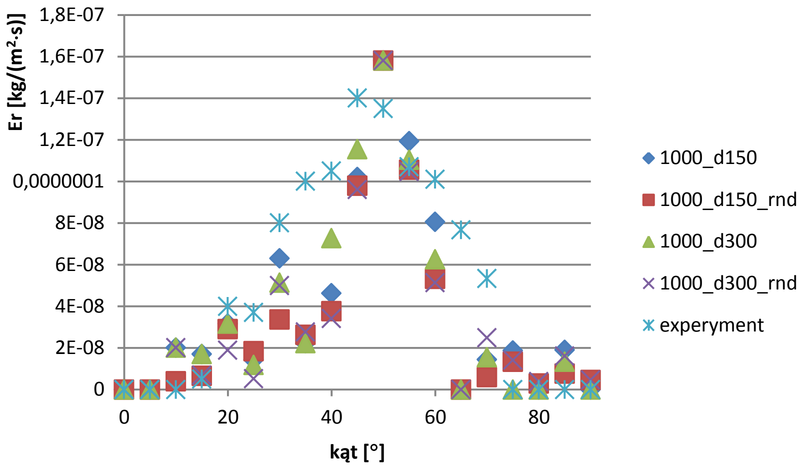

Fig. 4: Influence of the angular position of the measuring point on errors of erosive wear.

4. Conclusions

The analysis leads to the conclusion that the method used for the prediction of erosive wear get correct results for considered installations. The observed discrepancies between the results of the calculations and the results of the measurements can be related to:

- lack of full information about the operating conditions of the analyzed system in the long term,
- simplifications accepted at the stage of formulating a mathematical model,
- assumption of sphericity of the particles.

Nevertheless, authors observed qualitative compliance the results of calculations with the measurements of erosion losses. Examination of the data leads to the conclusion that the area of greatest consumption is located on the side of the outer curve of the elbow in a small area occupying less than 1 % of the entire surface of the test element. Considering random fluctuations of the particle in calculations, results a reduction of maximum erosive wear, and simultaneously increasing the area of the erosion occurrence. A significant effect studies is that in complex systems flow erosion process was conditioned by the aerodynamics of movement mixture of gas - solids.

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