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Application of porous media flow model for the regenerator fluidised bed simulation

Zastosowanie modelu przepływu przez warstwę porowatą jako symulacje przepływu przez złoże fluidalne

Abstract

Modeling a flow thorough a fluidized bed is a complicated, time-consuming and power-demanding task. However, in some cases such a flow could be simplified as a porous media flow, when we treat it as a fixed bed. This publication presents a comparison between free flow and porous media flow in order to assess the effect on the surface layer erosion.

Keywords: Porous media flow, regenerator flow, fluidized bed

Streszczenie

Modelowanie przepływu przez złoże fluidyzacyjne jest zadaniem skomplikowanym, bardzo czasochłonnym oraz wymagającym dostępu do bardzo dużych mocy obliczeniowych. W niektórych jednak przypadkach modelowanie tego typu przepływu można uprościć do przepływu przez warstwę porowatą, tak jakby złoże miało postać stałą. W artykule przedstawiono porównanie przepływów bez złoża oraz ze złożem stałym w celu oszacowania wpływu na erozję warstwy wierzchniej.

Słowa kluczowe: Przepływ porowaty, regenerator, złoże fluidyzacyjne

Nomenclature
ν – velocity
μ – viscosity
γ – flow porosity

1. Introduction

The fluidized bed is one of the commonly used technologies for combustion, regeneration or cement production, which is a floating mixture of gas and solid particles. Solid particles have usually abrasive properties, especially with high flow velocity near walls. The shape of inner elements influences velocity field near walls. The velocity field is a crucial factor for the determination of erosion threat. The simulation of the fluidized bed requires really high computational effort, exceeding the possibilities of standard computers and software. Therefore, the idea to substitute fluidized bed by the porous flow was proposed in this investigation.

1.1. Internal lining erosion issues

Fluidized bed vessels are often built of steel with internal lining especially chosen to reduce vessel temperature and abrasive action of particles. There are several companies which specialize in different types of lining. Some of them are designed for thermal insulation, others for erosion reduction. It is important to select a proper kind of lining since erosion resistant linings have higher conductivities. Internal erosion may, in the most dangerous cases, formulate "gas paths" inside the lining up to the vessel shell. In this case particles directly hit the steel causing erosion and possible cracks. Therefore, it is extremely important for safety reasons to avoid this effect. One of the forecasting tools which can be used is the simulation of internal vessel fluidized bed flow. With the results of simulation, the most dangerous places can be determined. Then the internal shape may be modified or a proper anti abrasive lining applied. The solution of a fluidized bed is usually too complicated for the reactor/regenerator vessels. In this paper, the porous bed flow model is proposed as a tool for inner flow simulation. This provides reasonable computational effort giving the answers for modifications. The results have been checked up against a real regenerator case, where the erosion occurred near the hatch.

1.2. Fluidized bed modeling

In the hydrodynamic model of a fluidized bed, relations between phases and mass and heat transfer phenomena are used to describe the motion, distribution and relation between gas and solids. Several cases of fluidized beds can be analyzed:

- Fixed bed with determined packed bed height – where the gas velocity is low and the bed is static,

- Bed with minimum fluidization – where the beginning of the fluidization of the particle bed can be observed,
- Bubbling bed – where the flow starts to be unstable,
- Bed with minimal solid fraction treated rather as a pneumatic transport with minimal solid fraction [1].

The fluidized bed is also characterized by the relation between pressure drop and gas velocity. In the pneumatic transport of solid particles, pressure drop decreases when gas velocity is higher than particles velocities. In the fixed bed, pressure drop increases when gas velocity increases. Therefore, for the fixed bed, the calculation of pressure loss is similar to porous volume flow. The so called packed-beds are mostly used in heterogeneous catalytic reactors [2].

In fluidized bed modeling, four different regimes are used to determine particles characteristics. This regimes were described by Geldard [3] and they are related to particles dimensions.

The minimum fluidization condition is determined by physical properties, where pressure drop, porosity, gas velocity and bed expansion are defined. These characteristics allow for the determination of particle diameter and velocity, which influence heat and mass transfer between phases. These phenomena are related mostly to the contact between different phases [1]. Depending on the calculation aim, numerical simulations of the fluidized bed can be based on different approaches. Sometimes basic equations like mass, energy and momentum conservation equations must be coupled with additional sources which describe the hydrodynamic model of phases interaction or another appropriate model. In the literature, many different approaches are presented. In this investigation, porous media flow is used to observe how much the flow thorough a fixed bed influences the lining layer abrasion. In the literature there are several models of porous media flow and its influence on different flow parameters like pressure drop, heat transfer etc. [4, 5].

2. Numerical model

Several models can be used for the fluidized bed simulation. For the specific problem which is the lining layer abrasion, porous media flow will be used to define the influence of flow parameters on the layer abrasion scale. In this paper, the results obtained in FLUENT/ANSYS simulation are presented.

2.1. Porous media flow

The "porous" region in a model determines empirically additional flow resistance in the volume. It means that the porous media model adds a momentum source term to the governing momentum equations. This term is composed of two parts: an inertial loss term and a viscous loss term [6]:

$$S_i = -\left(\sum_{j=1}^{3} -\left(D_{ij}\right) D_{ij} \mu v_j + \sum_{j=1}^{3} C_{ij} \frac{1}{2} \rho |\upsilon| \upsilon_j \right) \tag{1}$$

where:

$|\upsilon|$ – velocity magnitude,
D – viscous loss term predefined matrix,
C – inertial loss term predefined matrix.

This approach creates a pressure drop in the porous cell, which is proportional to the fluid velocity in the cell. In the case of simple homogeneous media, it takes the following form:

$$S_i = -\left(\frac{\mu}{\alpha} v_i + C_2 \frac{1}{2} \rho |\upsilon| \upsilon_j \right) \tag{2}$$

where:

α – permeability.

For the power law model, different equations are used to define the velocity magnitude, but the authors do not consider this approach in this case.

In the laminar flows through porous media, pressure drop is proportional to velocity, but constant C_2 from the equation (2) is equal to zero. This gives us a pressure drop equation which is equal to the first part of the equation (2). The same constant for the turbulent flows is used as a pressure loss coefficient per length through the flow direction. In the FLUENT/ANSYS software, the porous medium, by default, has no influence on the turbulence generation and dissipation rates. The user can introduce the turbulence suppression if they consider it necessary.

While modeling the porous flow as a viscous flow, effective viscosity is introduced in the momentum equations as:

$$\mu_e = \mu_r \mu \tag{3}$$

Where μ_r is the relative viscosity which can be calculated in the FLUENT/ANSYS using one of implemented sub models:

Breugem Correlation:

$$\mu_r \begin{cases} \frac{1}{2}\left(\gamma - \frac{3}{7}\right) & \text{when} \quad \lambda \geq \frac{3}{7} \\ 0 & \text{when} \quad \lambda < \frac{3}{7} \end{cases} \tag{4}$$

Brinkman Correction:

$$\mu_r = 1 - 2.5(1-\gamma) \tag{5}$$

or Einstein Formula:

$$\mu_r = 1 + 2.5(1-\gamma) \tag{6}$$

To calculate thermal dependencies between porous medium and fluid, effective thermal conductivity must be defined. In the FLUENT/ANSYS software, effective thermal conductivity in the porous medium is computed as the volume average of the solid and fluid conductivity:

$$k_{eff} = \gamma k_f + (1-\gamma)k_S \tag{7}$$

where:

k_S – thermal conductivity of solid,

k_f – thermal conductivity of fluid.

Further in this paper, the possibility of using the porous media flow model to assess fixed bed flow influence on the internal lining erosion is presented.

2.2. Geometry and mesh

To achieve the expected results from numerical simulations, a simplified regenerator model geometry was created. It is a simple volume without additional elements (like cyclones, pipes etc.). Internal lining erosion occurs especially near different cavities, corners etc. In most cases such a cavity constitutes a cylinder volume which is a part of a hatch structure. Geometry used in this investigations is presented in Fig. 1. It is 16 meters high with the radius equal to 3.5 m.

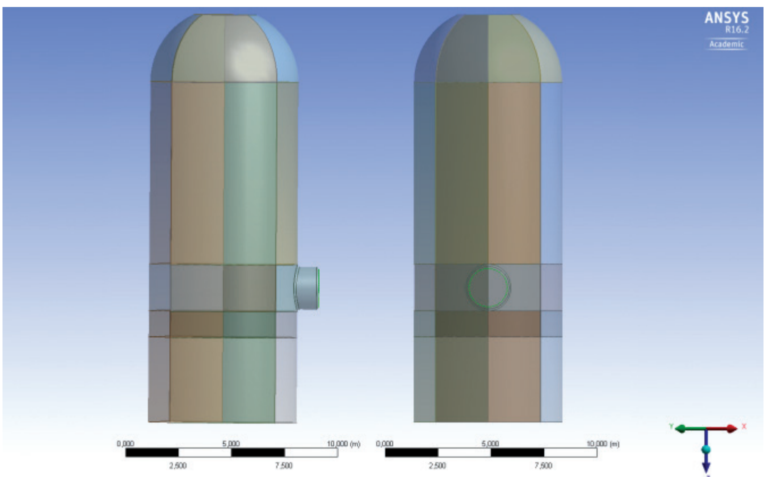

Fig. 1. Regenerator geometry – side and front view

The mesh generated for presented geometry should be as fine as possible. The presented approach has to be simple, fast and done in the simplest commercial tool like FLUENT/ANSYS. Therefore, also the grid has to be done in this software. Unfortunately, Ansys Mesher in the 6.2.version has a problem with defining fine hexagonal mesh with the boundary layer in the presented volume when there is an additional cavity. In this case, the fine mesh was defined in the model heights below and above the hatch. The tetrahedral mesh was created for the hatch heights. The fine mesh for the cylinder volume is presented in detail in Fig. 2 and details of the mesh near hatch are presented in Fig. 3.

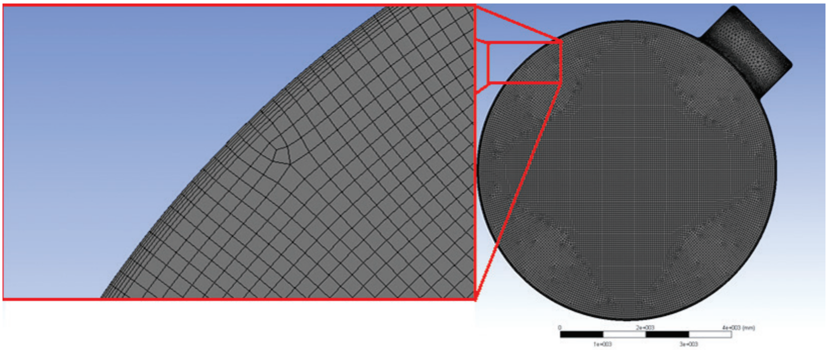

Fig. 2. Mesh with details (Bottom view)

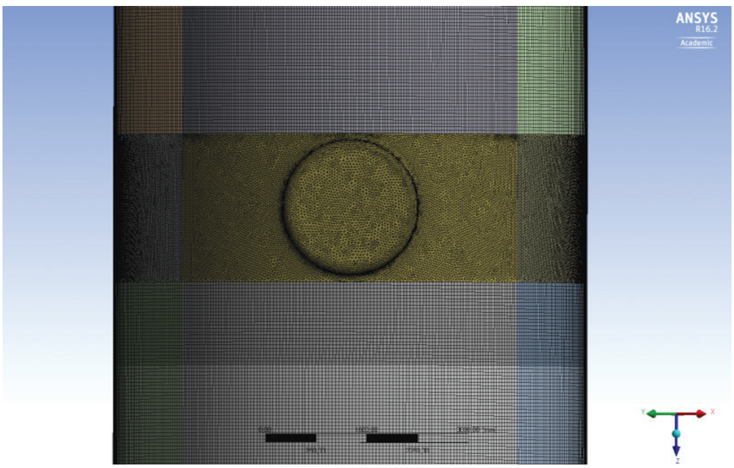

Fig. 3. Mesh detail (front view)

2.3. Flow parameters

Two different approaches were used for the regenerator flow simulation. First is the simulation of free flow of air, which can correspond to a flow where there is no fixed bed, and the second approach, where the fixed bed is modeled as a porous volume. By comparison of these two approaches, spots where the lining layer is more exposed to abrasion can be determined. Boundary conditions are presented in Table 1.

Table 1. Boundary conditions

Boundary condition	Type	Values
Inlet	Mass flow	$\dot{m}$ = 40 kg/s; gauge pressure 224 kPa
Outlet	Pressure outlet	gauge pressure 220 kPa;
Walls	Adiabatic walls	–

To describe the flow viscosity, k-ε turbulence model is applied. Brinkman correction described in equation (5) is used to calculate relative viscosity in the porous zone. For the porous media flow, the porous zone is defined at inflow zone under the hatch.

3. Results

The most important parameters which determine lining layer erosion could be velocity/dynamic pressure or turbulent kinetic energy which may occur near the eroded region. In Figs. 4 and 5 the velocity vectors are presented.

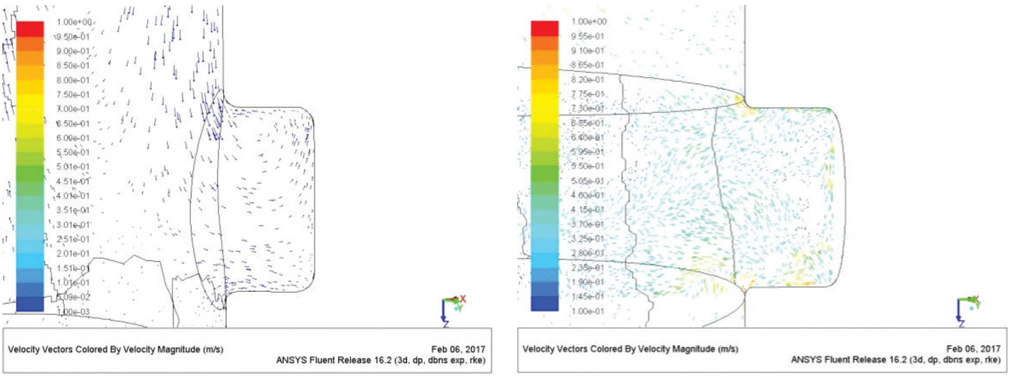

Fig. 4. Velocity vectors – with porous volume, coarse mesh, vmax~0.1 m/s (left), refined mesh, vmax~0.75 m/s (right)

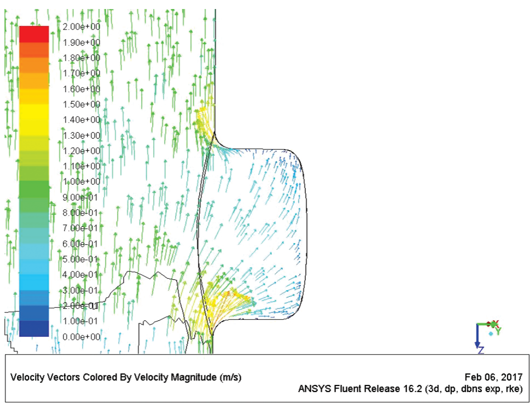

Fig. 5. Velocity vectors – pure gas, vmax~1.4 m/s

As it can be seen in Figs. 4 and 5, in the presented case the porous volume, which could be treated as a fluidized fixed bed, gives a more stable flow through the regenerator geometry. For the ideal gas flow model, some areas with higher velocity vectors magnitudes can be observed near the hatch region. This contributes to the lining layer abrasion, which in a real vessel lining occurred exactly in this region.

4. Conclusions

In the paper, the possibility to simulate a fluidized, fixed bed flow as a porous media flow is presented. In each application where the process comprises the flow through a fluidized bed, the problem with internal lining layer erosion and abrasion can be expected.

Hazardous regions are identified by means of simulation. Numerical simulation of a fluidized bed is very demanding for modeling, needs high computational effort and takes a large amount of time. This is even more demanding for real industrial cases with high capacity installation and a hardly defined process. Simulation of a fluidized fixed bed as a porous flow considerably reduces the time of computation. In the presented case, the comparison between the porous media flow and ideal gas flow confirmed the real process issue where the abrasion occurred in the hatch region exactly in part where velocity vectors resulting from simulation are of highest value near the lining inner surface. The simulation of the porous flow showed high dependency of the mesh density and quality. In case of the coarse mesh, the results were extremely different from reality, though the simulation convergence has been reached.

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