EULERIAN-LAGRANGIAN SIMULATION OF A BUBBLING FLUIDIZED BED REACTOR: ASSESSMENT OF DRAG FORCE CORRELATIONS

by

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An Eulerian-Lagrangian approach is developed within the OpenFOAM framework to investigate the effects of three well-known inter-phase drag force correlations on the fluidization behavior in a bubbling fluidized bed reactor. The results show a strong dependency on the restitution coefficient and the friction coefficient and no occurrence of bubbling and slugging for the ideal-collision case. The mean pressure drops predicted by the three models agree quite well with each other.

Key words: *Eulerian-Lagrangian/DEM, fluidization, drag correlations, pressure drop*

Introduction

Gas-solid fluidized bed reactors are widely used in many industrial operations. A good understanding of the hydrodynamic behavior of this system is important for the design and scale up of the new efficient reactors. Thus, in the last two decades research efforts have been devoted to the development of numerical models to study the hydrodynamics in fluidized bed reactors [1, 2]. All the modeling methods are broadly categorized into Eulerian-Eulerian and Eulerian-Lagrangian approaches. The latter, called discrete element method (DEM), has come more and more into the focus of engineers and researchers [3-9]. The coupling between the phases comprises the effect of (a) volume displacement by the particles, and (b) fluid-solid interaction forces exerted on the particles [10-12]. There are various drag correlations available in the literature [13]. The Gidaspow correlation [14] is a combination of the Ergun equation [15] for dense granular regime and the Wen *et al.* equation [16] for dilute granular regime. Although some works have investigated the effects of different drag models within the Eulerian-Eulerian framework, few are reported for Eulerian-Lagrangian approach. Here we present an Eulerian-Lagrangian approach with a soft-sphere collision model for the simulation of a bubbling fluidized bed. The three drag correlations [13, 14, 17] are implemented in our model.

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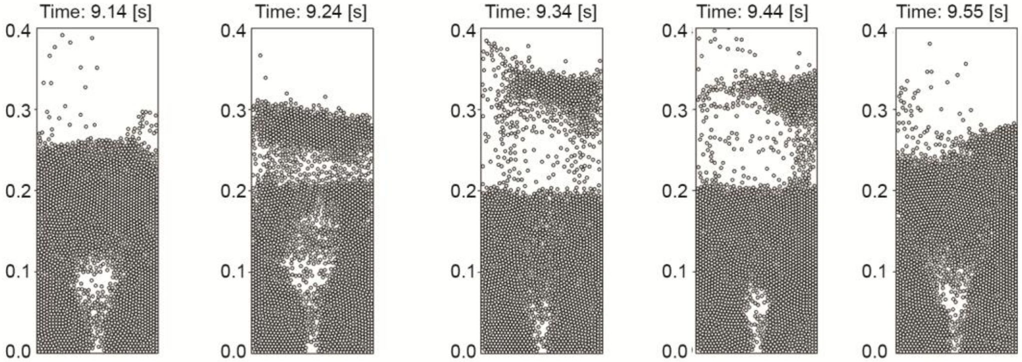
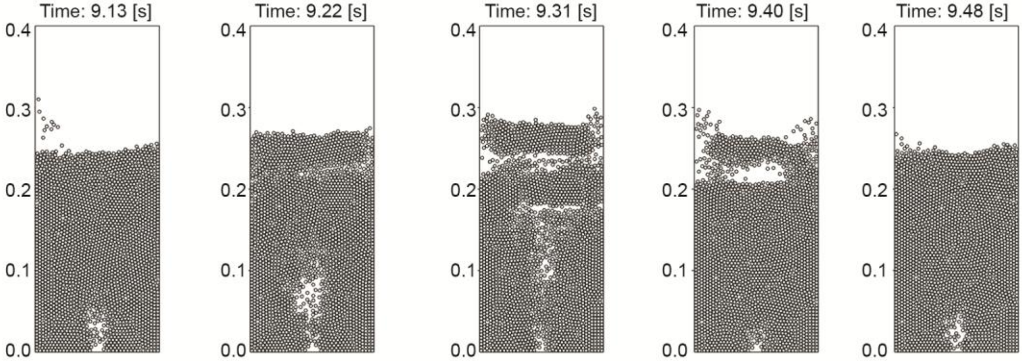
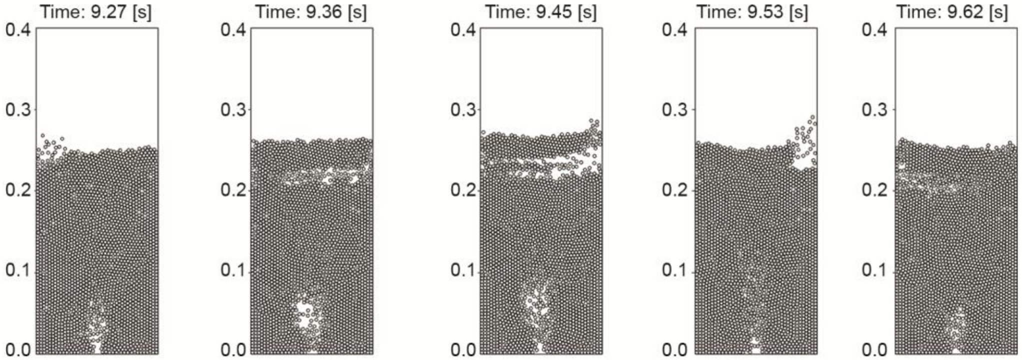


(a) Gidaspow model



(b) Di Felice model



(c) EHKL model

Figure 1. Typical particle flow patterns at the fluidization stage

Mathematical modeling

A particle in a gas-solid system undergoes motions as described by Newton's second law of motion. A soft-sphere model using a spring, slider and dashpot is adopted to formulate the contact forces between two spherical particles. In this model, the particles are allowed to overlap slightly. The normal force tending to repulse the particles can be deduced from this spatial overlap and the normal relative velocity at the contact point. The spring stiffness can be calculated by Hertzian contact theory. Concerning the wall properties the same values as the particle could apply. The continuum gas phase are calculated from the continuity and volume-averaged Navier-Stokes equations which are coupled with particle phase through the porosity and the inter-phase momentum exchange, and the momentum equation is given by:

$$\frac{\partial}{\partial t}(\varepsilon_{\mathrm{g}}\rho_{\mathrm{g}}\boldsymbol{u}_{\mathrm{g}}) + \nabla\cdot(\varepsilon_{\mathrm{g}}\rho_{\mathrm{g}}\boldsymbol{u}_{\mathrm{g}}\boldsymbol{u}_{\mathrm{g}}) = -\nabla p + \nabla\cdot(\varepsilon_{\mathrm{g}}\boldsymbol{\tau}_{\mathrm{g}}) + \varepsilon_{\mathrm{g}}\rho_{\mathrm{g}}\boldsymbol{g} - \boldsymbol{S}_{\mathrm{p}} \tag{1}$$

where ε_{g} is the porosity $\varepsilon_{\mathrm{g}} = 1-(\sum_{i=1}^{k_c} V_i \big/ \Delta V_{cell})$ (V_i is the volume of particle i and k_c is the number of particles in the computational cell with volume ΔV_{cell}), and ρ_{g}, $\boldsymbol{u}_{\mathrm{g}}$, τ_{g} and p are the density, velocity, viscous stress tensor and pressure of the gas phase, respectively. $\boldsymbol{S}_p$ is a source term that describes the momentum exchange of gas with solid particles $\boldsymbol{S}_{\mathrm{p}} = \Sigma_{\forall i \in \mathrm{cell}} \boldsymbol{f}_{\mathrm{g},i} / \Delta V_{\mathrm{cell}}$ ($\boldsymbol{f}_{\mathrm{g},i} = V_i \beta(\boldsymbol{u}_{\mathrm{g}} - \boldsymbol{v}_i) \big/ \varepsilon_{\mathrm{p}}$, $\boldsymbol{u}_{\mathrm{g}}$ – the instantaneous gas velocity at the particle position, $\varepsilon_{\mathrm{p}} = 1 - \varepsilon_{\mathrm{g}}$, and β – the inter-phase momentum transfer coefficient.

Results and discussions

After the start-up stage, a dynamically stable fluidization stage is reached in which a periodic generation of bubbles and slugs is observed as shown in fig. 1. The bubbling period is longest for Gidaspow model and almost same for Di Felice and EHKL models. The particle flow patterns predicted by the three models featured by a gas cavity at the jet region above which a bubble is formed and continuously grows and rises until converts to a slug. However, the bubble and slug patterns can differ significantly among the drag models and their intensity is strongest for Gidaspow model and weakest for EHKL model. It can be seen that the performance characteristics obtainable from the different drag models differ, perhaps significantly, depending on the particular application.

As shown in fig. 2, although all the three models predict no bubble and slug formation for the ideal case, the height of the expanded bed is different and the Gidaspow model has the largest bed expansion. It is worth to mention that Hoomans *et al.* [8] who adopted a hard-sphere collision model in contrast to our soft-sphere model also reported the same phenomenon for the ideal-collision case, which qualitatively verifies the capacity of our approach.

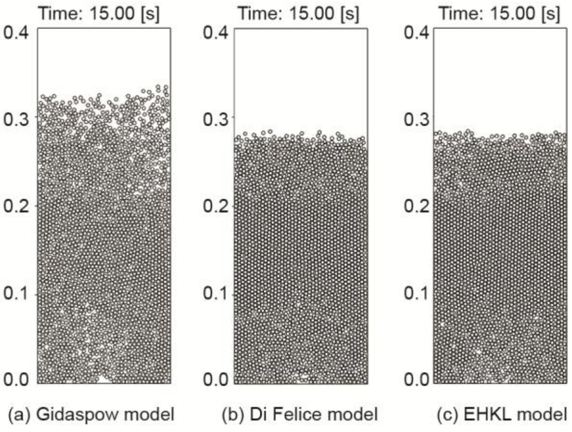


Figure 2. Snapshots of particle flow patterns at *t* = 15 s for ideal-collision case (*e* = 1, *μ* = 0)

Conclusions

Qualitatively, formation of bubbles and slugs and the process of particle mixing are observed to occur for all the drag models, although the Gisadpow model is found to be most energetic and the Di Felice and EHKL models yield minor difference. The effects of restitution coefficient *e*, and friction coefficient μ on the fluidization behavior are also investigated. It is found that no bubbling and slugging occur at all for the ideal-collision case ($e = 1$, $\mu = 0$).

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References

[1] Esmaili, E., Mahinpey, N., Adjustment of Drag Coefficient Correlations in Three Dimensional CFD Simulation of Gas-Solid Bubbling Fluidized Bed, *Advances in Engineering Software*, *42* (2011), 6, pp. 375-386

[2] Loha, C., *et al.*, Assessment of Drag Models in Simulating Bubbling Fluidized Bed Hydrodynamics, *Chemical Engineering Science*, *75* (2012), pp. 400-407

[3] Song, X. Q., *et al.*, Research on Reducing Erosion by Adding Ribs on the Wall in Particulate Two-Phase Flows, *Wear*, *193* (1996), 1, pp. 1-7

[4] Lin, J. Z., *et al.*, The Motion of Fibers in an Evolving Mixing Layer, *International Journal of Multiphase Flow*, *29* (2003), 8, pp. 1355-1372

[5] Lin, J. Z., *et al.*, Effects of the Aspect Ratio on the Sedimentation of a Fiber in Newtonian Fluids, *Journal of Aerosol Science*, *34* (2003), 7, pp. 909-921

[6] Lin, J. Z., *et al.*, Numerical Research on the Orientation Distribution of Fibers Immersed in Laminar and Turbulent Pipe Flows, *Journal of Aerosol Science*, *35* (2004), 1, pp. 63-82

[7] Zhou, Z. Y., *et al.*, Discrete Particle Simulation of Gas-Solid Flow in a Blast Furnace, *Computers and Chemical Engineering*, *32* (2008), pp. 8, 1760-1772

[8] Hoomans, B. P. B., *et al.*, Discrete Particle Simulation of Bubble and Slug Formation in a Two-Dimensional Gas Fluidised Bed: A Hard-Sphere Approach. *Chemical Engineering Science*, *51* (1996), 1, pp. 99-118

[9] Su, J., *et al.*, Discrete Element Simulation of Particle Flow in Arbitrarily Complex Geometries, *Chemical Engineering Science*, *66* (2011), 23, pp. 6069-6088

[10] Nie, D. M., Lin, J. Z., A Fluctuating Lattice-Boltzmann Model for Direct Numerical Simulation of Particle Brownian Motion, *Particuology*, *7* (2009), 6, pp. 501-506

[11] Nie, D. M., Lin, J. Z., A LB-DF/FD Method for Particle Suspensions, *Communications in Computational in Physics*, *7* (2010), 3, pp. 544-563

[12] Nie, D. M., Lin, J. Z., Dynamics of Two Elliptical Particles Sedimentation in a Vertical Channel: Chaotic State, *International Journal of Computational Fluid Dynamics*, *25* (2011), 7, pp. 401-406

[13] Benyahia, S., *et al.*, Extension of Hill-Koch-Ladd Drag Correlation over all Ranges of Reynolds Number and Solids Volume Fraction, *Powder Technology*, *162* (2006), 2, pp. 166-174

[14] Gidaspow, D., Multiphase Flow and Fluidization, Academic Press, San Diego, Cal., USA, 1994

[15] Ergun, S., Fluid Flow through Packed Columns, *Chemical Engineering Progress*, *48* (1952), 2, pp. 89-94

[16] Wen, C. Y., Yu, Y. H., Mechanics of Fluidization, *Chemical Engineering Progress Symposium Series*, *62* (1966), pp. 100-111

[17] Di Felice, R., The Voidage Function for Fluid-Particle Interaction Systems, *Int. J. Multiphase Flow*, *20* (1994), 1, pp. 153-159

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