Investigation of near-wall particle statistics of dense gas-solid fluidized bed using CFD-DEM and development of Eulerian particle velocity wall boundary conditions

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Abstract

Gas-particle fluidized beds have exceptional characteristics in terms of transport and mixing, contact between a dispersed phase and a reactive gaseous medium, thermal inertia and wall transfer. This makes them highly relevant to the energy industry, particularly for the development of innovative processes that meet the challenges of the energy transition, such as biomass gasification or chemical looping combustion plants, fluidized bed solar receivers, hydrogen combustion or heat storage on particles. Unsteady three-dimensional numerical simulation of these flows, on a pilot or industrial scale, is increasingly emerging as a key tool for supporting the development of new processes. However, its development continues to pose numerous modeling problems due to the wide range of scales encountered and the many multi-physical couplings involved and to the difficulty to carry out detailed experiments.

Over the last twenty years or so, high-performance computing has made it possible to develop a multi-scale approach for the modeling and simulation of gas-solid fluidized beds based on:

- fully resolved" microscopic simulations of ensembles of particles up to several thousand, modelling local interactions and transfers with the fluid for very simple flow configurations;
- mesoscopic CFD-DEM simulations of ensembles of particles up to several million, capturing the collective effects of particles interactions with the fluid and the walls, for flow configuration close to laboratory experiments;
- macroscopic N-Euler simulations of the statistical properties of the set of particles, such as number density, average velocity and kinetic energy of the random motion, for pilot or industrial flow configurations.

Detailed analysis of the results of the microscopic and mesoscopic simulations makes it possible, on the one hand, to improve understanding and modelling of local phenomena and, on the other hand, to inform and validate the closure models developed as part of the statistical approaches associated with the Eulerian equations governing the macroscopic quantities.

The presentation will focus on recent results concerning one key closure problem for the simulation of fluidized beds using n-Euler approach and consisting in the accurate prediction of the particle-wall-friction effect with the velocity boundary conditions. Detailed analysis of CFD-DEM simulations of dense fluidized bed allows to characterize the very specific behavior of solid particles in the near-wall region. In particular, these simulations show the formation of quasi-bidimensional arrangements of the particles which are dominating the particle-wall interaction mechanism. These effects are found to be effective mostly in the very near wall region, at a distance of the order of the particle diameter. These effects cannot be represented by n-Euler simulation based on granular kinetic theory modeling approach. However, under the local boundary layer assumption, the particle stress on the wall can be given in terms of particle statistics at a few particle diameters from the wall, accessible to the n-Euler simulation. The corresponding modelling approach for the wall boundary condition of the particle velocity is tested using n-Euler simulations of the dense fluidized beds, leading to very good agreement with the CFD-DEM results.

References

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