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Momentum transport between two granular phases of spherical particles with large size ratio: Two-fluid model versus discrete element method

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ABSTRACT

Two-fluid Eulerian method is widely used in computer simulations of gas–solid systems such as fluidized beds. The models for describing drag forces play key roles in the reliability of simulation results. The solid–solid drag model is calculated by the formulas such as Syamlal-O'Brian's model [Syamlal, M. The particle–particle drag term in a multiparticle model of fluidization. Topical report, DOE/MC/21353-2373, NTIS/DE87006500, National Technical Information Service, Springfield, VA. 1987]. However, the performance of the model has not been examined in the mixtures of solid phases with a large size ratio between the particles of the phases, which is found in fluidized beds containing biomass particles (big particles) and the neutral phase particles (small particles) such as sand. The present study compares the results of Eulerian simulations using the Syamlal-O'Brian's formula with the results of Lagrangian simulations performed by the discrete element method (DEM) in the bidisperse mixtures of the size ratio of 10. Results suggest a significant difference between the Eulerian model and the DEM, which is basically due to the inhomogeneities triggered by the existence of large particles. The current methodology can be used to present correction factors for the solid–solid drag forces in Eulerian simulations for the bidisperse mixtures of large size ratios.

1. Introduction

Fluidized bed technology provides an efficient way to the combustion of solid fuels grinded to diameters that could vary from several millimeters to several centimeters. The technologies corresponding to bubbling fluidized bed (BFB) and circulating fluidized bed (CFB) are in use for combusting coal and biomass with a high efficiency. In a CFB boiler, there is a granular phase of finer inert particles [1] that is usually sand and it facilitates the fluidization of biomass particles. Biomass fuel particles are an order of magnitude larger than the sand particles and they are injected into the fluidized bed in a given rate from certain location near the bottom of the bed. Therefore, the coexistence of the two phases will result in the exchange of momentum between the two phases. It is also known as the momentum transfer rate or the solid–solid drag force which is in addition to the gas–solid drag forces.

The evaluation of the momentum transfer rate was given by the formula derived by Syamlal [2] in particulate mixtures comprised of uniformly-distributed particles. In an attempt to assess the accuracy of the Syamlal's formula [3] in monodisperse particle mixtures, the discrete element method (DEM) was employed to verify the solid–solid drag force resulted from Syamlal's formula. It was shown that the two-fluid Eulerian model with Syamlal's formula for solid interaction is in good agreement with the results obtained from DEM simulations. However, it was not clear how the bidispersity of particles especially with large size ratio such as the one existing in biomass and sand mixtures could influence the validity of Syamlal's formula. The performance of Eulerian simulations was examined by constructing the biomass fuel particles as discrete objects surrounded by a continuous medium representing the inert bed material (sand) [4]. The results showed good agreement between the Eulerian simulations based on Syamlal's formulas for particle interactions to the DEM simulations in particle arrays where the location of fuel particles was identically selected as in the Eulerian simulations. However, the performance of Syamlal's formula is not addressed when the biomass fuel particles are treated as a continuum. Due to large size ratio between biomass fuel particles and the inert particles of bed phase (e.g., sand), the homogeneity of the bed phase around fuel particles is substantially affected [4]. Therefore, the applicability of Syamlal's formula to calculate the momentum exchange rate between the two homogeneous solid phases is under critical suspicion. The coexistence of two solid phases is not considered in some studies related to biomass in fluidized beds [5], or if it is considered it is assumed that the inert phase is not affected by the fuel phase due to low percentage of fuel particles in the studies [6]. However, in real systems, the percentage of fuel particles may not be very low locally to ignore the momentum transfer rate between the solid phases. Therefore, any two-fluid Eulerian method must be capable of calculating the solid–solid momentum transfer rate accurately in order to obtain a reasonable prediction of the hydrodynamics of CFB.

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In the present study, the Eulerian model is independently employed that treats the biomass fuel particles and the inert sand particles as continuous phases. The instantaneous values of volume fraction and velocity are obtained from calculations at each time step in the absence of gas phase for excluding any effect of continuous phase on the results. These values are substituted in Syamlal's formula [3] to calculate the volumetric solid–solid drag force. Independently, the DEM simulations have been conducted for the fuel and sand particles as discrete media. Then the results from Eulerian and DEM simulations are compared. These results show how carefully the Syamlal's formula must be used in Eulerian simulations when the size ratio of solid phases is about 10. In section 2, the methods of simulations are explained. The results of simulations are presented and discussed in Section 3. Finally, some concluding remarks are mentioned in Section 4.

2. Methods and formulations

In the present study, DEM is used for Lagrangian simulations with no effect of the interstitial fluid. On the other hand, the Eulerian simulations are carried out in which both solid phases with small and large particles are considered as continuous media.

2.1. Discrete element method (DEM)

The Lagrangian approach in particulate systems can reproduce results similar to experimental observations because particles are tracked instantaneously. In this context, the interaction of contacting particles plays an important role in the accuracy of the approach. The interaction of particles is introduced via spring and dashpot models of contact between solid bodies. The coefficients used in the contact model are the stiffness and damping factors which depend on some mechanical properties such as Young's modulus, Poisson's ratio and the coefficient of restitution. The method was first used by Cundall and Strack [7] and later on various versions were employed including the one by Tsuji et al. [8] that is adopted in the present study. The details of the method are given in Ref. [4]. It should be mentioned that due to large size ratio the number of neighbors for large particles is considerably higher than that in monodisperse system. Thus a separate list of neighbors is built for large particles that contain larger number of neighbors than small particles. Obviously, this requires a bigger portion of random memory, which can limit the maximum number of large particles in simulations. In present study, we have used 20 big particles in a box filled with about 80,000 small particles in three different densities, as shown in Fig. 1. The choice of 20 big particles is not only due to the computational limits but also because of the lower fraction of fuel particles usually found in fluidized beds of biomass fuels [6]. Moreover, higher number of big particles essentially requires a larger number of small particles in the simulations. Note that the volume fractions of phases corresponding to big and small particles are different through Fig. 1a to c, as given in Table 1. At the initial time, the velocity of small particles is assigned as zero, while the velocity of big particles is assigned equally in *z*-direction and zero in *x* and *y*-directions. Therefore, there is also no initial granular temperature for the phases. This is mainly for simplifying the study conditions, while a separate study can focus on the effects of granular temperature on the results. Moreover, there is no gravitational acceleration in the current simulations. As the duration of simulations is short (as comes in the results), the presence of gravity is not important.

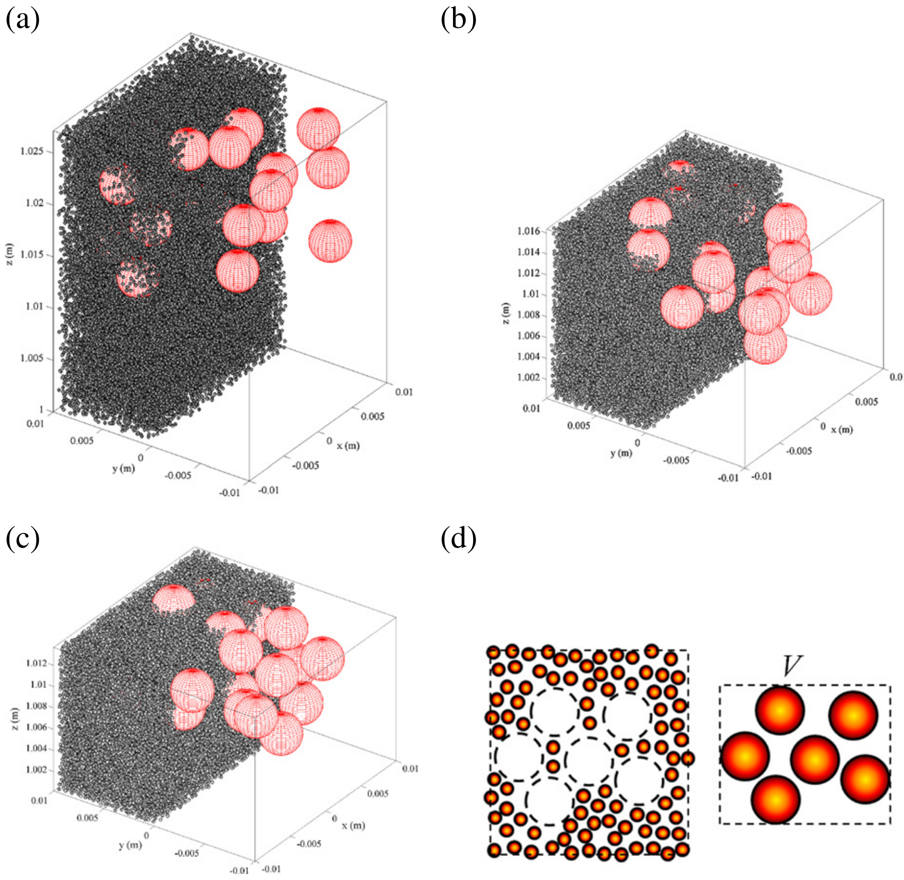

Fig. 1. Initial configuration of particulate mixtures simulated by DEM. Red and black particles represent the big and small spherical particles with the diameters of 3.6 and 0.3 mm, respectively. (a) Case 1 with $\varepsilon_s = 0.12$, $\varepsilon_b = 0.08$, (b) Case 2 with $\varepsilon_s = 0.20$, $\varepsilon_b = 0.14$, (c) Case 3 with $\varepsilon_s = 0.25$, $\varepsilon_b = 0.14$. All cases contain 20 big particles and 80,000 small particles. Note that only the small particles located in the half part of the box with positive *y* are shown. (d) Schematic representation of the volumes used for calculation of ε_s (left) and ε_b (right). The volume *V* is used in Eq (1).