Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 51(2) (2019) 97-99
DOI: 10.22060/mej.2017.12532.5359

Simulation of Two Circular Particles Falling in Vertical Channel: Combination of Immersed Boundary Lattice Boltzmann Method and Discrete Element Method

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ABSTRACT: In this study, Immersed Boundary-Lattice Boltzmann Method (IB-LBM) as a fluid solver is combined with Discrete Element Method (DEM) as a collision model. The consequences of this arrangement go to a numerical great model (IB-LB-DEM) which is capable to simulate particulate flows with second-order accuracy. To apply non-slip boundary condition, Eulerian velocities are interpolated in Lagrangian nodes using diffuse delta function. In DEM, two particles can penetrate to each other which this approach generates more realistic model rather other collision rules. Generally, in this model, the most important parameter is overlap distance between two particles which is directly related to amount of particles rigidity. The mentioned hybrid method is validated by simulation of dry-contact of two particles and sedimentation of single particle in vertical channel, individually. Finally, sedimentation of two circular particles in vertical channel is studied and effects of physical parameters such as rigidity, restitution coefficient and friction coefficient in particles behavior has been investigated. Finally, it is shown that increasing friction coefficient leads to increasing in kissing time that causes a change in particles path. For this particular model, It is also dedicated that restitution coefficient does not have significant effect in particles behavior.

Review History:

Received: 12 February 2107
Revised: 27 April 2017
Accepted: 7 May 2017
Available Online: 17 May 2017

Keywords:

Immersed boundary–lattice Boltzmann
split-forcing technique
discrete element method
sedimentation of two particles

1- Introduction

Investigation of particle sedimentation has wide application in industrial field and natural sciences. For example application in water treatment, dust movement in atmosphere layers can be mentioned.

In the most hybrid models that is used in fluid/structure interaction problems, the fluid and solid motion are separately evaluated, whereas there are conventional approaches that solve two-phase flows, concurrently [1]. Combination of Lattice Boltzmann and Immersed Boundary Method (IB-LBM) has significant advantage for solving the Flow Structure Interaction (FSI) problems, which was first attempted by Feng and Michaelides [2]. Mohd-Yusof [3] introduced a new type of IB method that does not require choosing arbitrary parameters and forcing terms. In this approach (so-called direct-forcing method), a forcing term is added to the discretized equations that implicitly imposes the non-slip boundary condition in the immersed boundary method. There are several techniques for simulation of particle collision which have been proposed in the literature. In the case of fixed-mesh technique, Feng and Michaelides [2] included a repulsive force for accounting for inter-particle and particle–wall collisions. A Distributed Lagrange Multiplier (DLM) is combined with the Finite Element Method (FEM) was used by Niu et al. [4] and Wu and Shu [5]. In this study, we define a more realistic method rather than previous models in which collision forces are as a function of penetration values. In this way, we combine immersed boundary-lattice Boltzmann method as a flow solver with discrete element method as a collision models. Using this hybrid method is capable to demonstrate effect of physical parameters on particles behavior during contact. We use the hybrid model to simulate drafting, kissing and tumbling behavior of two particles during sedimentation.

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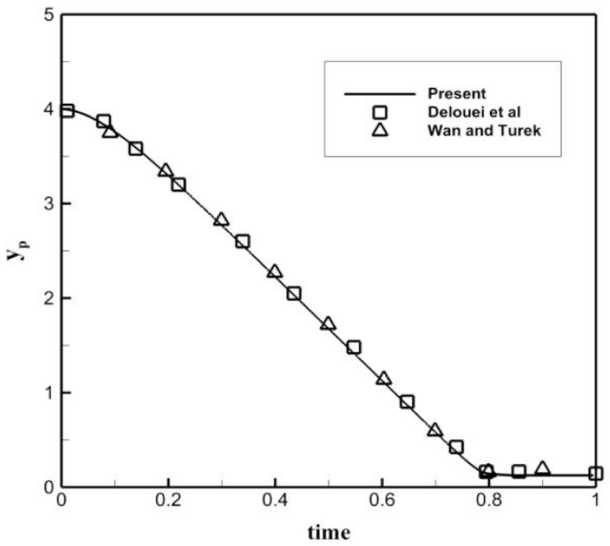
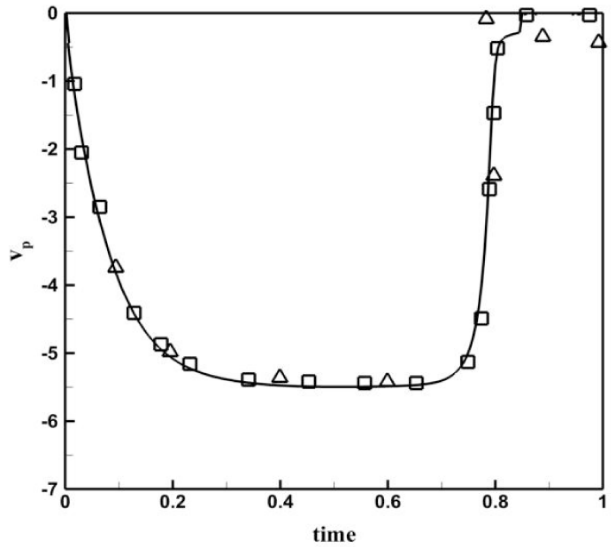
2- Methodology

In this study, the immersed boundary-lattice Boltzmann method (IB-LBM) based on the split forcing scheme with discrete element method is developed for simulation of particles settling in vertical channel. The present immersed boundary method relies on a direct momentum forcing. The force is distributed on the Eulerian nodes (in the fluid domain) by a simple interpolation based on the four point diffuse delta functions. Using this approach, the required boundary conditions on the Lagrangian nodes at the boundary of the particles are satisfied. In the presented DEM, the collision was implemented by including the restoring and dissipative forces that depend, respectively, on the overlap distance and relative velocity.

There are different ways for calculating the collision forces within context of DEM. We adopt the classical Hookean model for collision of circular particles, as shown schematically in Fig. 1. The total collision force includes normal forces and tangential forces. Both of these can be divided to two restoring and damping forces. In each direction, restoring force is as a



(a)



(b)

Fig. 1. Time evolution of (a) vertical position and (b) vertical velocity

function of overlap distance and damping force is calculated regarding to relative velocity between two particles. The tangential force between two particles can be evaluated for two regimes. a) Sticking and b) Sliding. Based on Coulomb's law, these two regimes cannot exist simultaneously. In other word, based on this theory, minimum value of sticking and sliding forces has to be considered as a tangential force. For evaluation of collision model parameters that were described in the previous section, the penetration and repelling behavior of two particles and the contact duration are evaluated using a vibration model. In the present study, for determining the contact model parameters, the following steps are taken:

- Select appropriate value for the overlap distance. .
- Select physical parameters $0<e_n<1$ and $0<c_F<1$.
- Compute contact parameters k_n and γ_n.

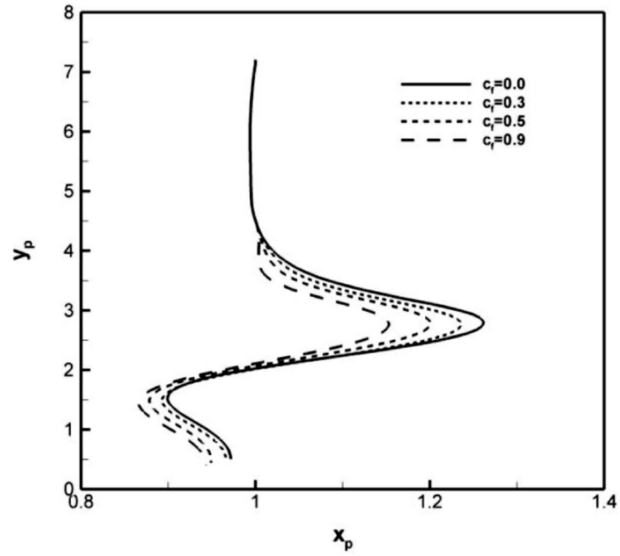


Fig. 2. Upper particle path in different friction coefficient.

3- Validation and Results

In this study, we use behavior of particle settling in vertical channel. This problem was studied by Delouei et al. [6] and Wan and Turek [7]. Time evolution of particle vertical position (y_p) and vertical velocity (v_p) are compared with the previous works in Fig. 1.

In the results session, we show effect of restitution coefficient and friction coefficient on behavior of two particles. It was found that restitution coefficient cannot change particle path. Because the value of relative velocity is very low and causes weaker damping force rather than elastic force. As it is shown in Fig. 2, It was also depicted that friction coefficient has sensible effects on particle path during sedimentation.

Finally, we showed that kissing time is under affected of friction coefficient. As it is shown in Fig. 3, increasing friction coefficient lead to increase in kissing time.

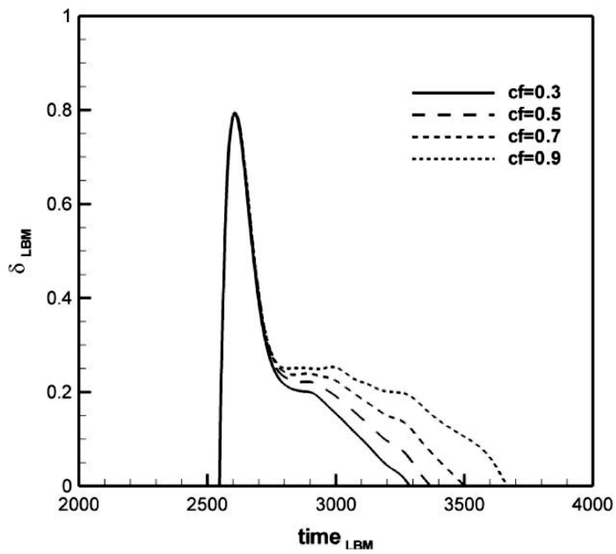


Fig. 3. Effect of friction coefficient on kissing time.

4- Conclusion

In this paper, a new method based on immersed boundary lattice Boltzmann method combined with discrete element method has been presented. In this way, we will be able to simulate particulate flow in realistic condition. We showed that physical parameter can effect on particles behavior during settling. One of the most effective parameter is friction coefficient.

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B. Afra, M. Nazari, M.H. Kayhani, Simulation of Two Circular Particles Falling in Vertical Channel: Combination of Immersed Boundary Lattice Boltzmann Method and Discrete Element Method, *Amirkabir J. Mech. Eng.*, 51(2) (2019) 97-99.
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