EFFECTS OF GAS INLET VELOCITY CONDITIONS ON SYSTEM HYDRODYNAMICS OF CIRCULATING FLUIDIZED BED RISER BY USING 3D CFD SIMULATIONS

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Abstract: In this current study, 3D simulation of gas-solid in the riser of circulating fluidized bed (CFB) reactor has been conducted using computational fluid dynamics (CFD) to investigate the effects of different gas inlet velocity conditions (for case 1-4: varied the percent opening of gas inlet velocity channels, (1) 25%, (2) 50%, (3) 75% and (4) 100%, comparing to system geometry; for case 5-7: varied the shape of fully developed velocity profiles, (5) flat, (6) convex and (7) sharp). Comparisons were made with experimental results which were time-averaged pressure drop through the system height and time-averaged solid mass flux across the system radius. The results of time-averaged solid mass flux for case 3-7 showed a reasonable agreement near the wall but slightly under-predicted at the center of the riser. The prediction for pressure drop were in good agreement with experimental data except for case 1 and case 2, however, case 6 showed their superiority in predicting than the others. It can be concluded that the model for case 6 is suitable to predict the system hydrodynamics in the riser of circulating fluidized bed, however, further improvements are required to achieve quantitative agreement with the experimental data. For the effect of percent opening of gas inlet velocity channels, the solid volume fraction decreased with increasing opening percentage (case 1-4) while, for the shape of fully developed velocity profiles, the solid volume fraction increased in the center and decreased near the wall of system when convex profile was used (case 5-7). This study also explored the effects of restitution and specularity coefficients which are the two important parameters in simulating the multiphase flow system.

1. Introduction

Circulating fluidized beds are applied in many industrial processes due to the advantages over other methods of gas-solid reactors [1]. Computational fluid dynamics (CFD) is a technique that uses numerical methods and algorithms to solve problems and analyze phenomena that involve fluid and chemically reacting flows [2]. This technique is currently used in various circulating fluidized bed system and allows us to study the effects of important reactor components such as the inlet configuration.

In circulating fluidized bed riser, the inlet configuration has strongly effects on flow behaviors which are consistent with the previous studies of Cheng et al. [3] and De Wilde et al. [4]. Cheng et al. [3] reported that this parameter can be affected on the hydrodynamics in the bottom zone of the riser and found that the inlet configuration can be classified into two main types: the restriction on the gas-solid circulating flow and the arrangement of open area. In this study, the effect of open area percentage was studied. Moreover, the effect of shape of fully developed velocity profiles was investigated.

Then, the two important modeling parameters were explored which were the restitution and specularity coefficients. Many researchers [5-6] reported that these parameters have an influence on the hydrodynamics of circulating fluidized bed riser. On the other hand, some researchers [7-9] found that these parameters do not significantly affect in numerical prediction. These parameters are only adjusting values that can provide better accuracy in numerical simulation.

As stated above, 3D simulation of gas-solid in the riser of circulating fluidized bed reactor has been conducted using computational fluid dynamics to investigate the effects of different gas inlet velocity conditions (for case 1-4: varied the percent opening of gas inlet velocity channels, (1) 25%, (2) 50%, (3) 75% and (4) 100%, comparing to system geometry; for case 5-7: varied the shape of fully developed velocity profiles, (5) flat, (6) convex and (7) sharp). Furthermore, the results were extended to investigate the effects of different values of the restitution and specularity coefficients. The time-averaged pressure drop through the system height and time-averaged solid mass flux across the system radius from experimental data from Knowlton et al. [10] were used as reference conditions for comparison with the results from 3D numerical simulations.

2. Materials and Methods

2.1. System description

To compare the simulation model with the experimental data, the system conditions of Knowlton et al. [10] were used as the system conditions for simulation. Their circulating fluidized bed had cylindrical geometry with 0.2 m diameter and 14.2 m height. The gas entered the system at the bottom of the riser while the solid entered from a side inlet at 0.3 m above the bottom of the riser with a width of 0.1 m. The gas and solid exited through a side outlet at 0.3 m below the top of the riser with similar width as the side inlet. The system solid was FCC particles with averaged diameter of 76 μm and density of 1,712 kg/m^3 while the system gas was air with gas inlet velocity of 5.2 m/s. The solid velocity of 0.476 m/s was used with a mass flux of 489 kg/m^2. The time-averaged during 20-30s were used in this simulation.

Figure 1 shows the computational domain of the circulating fluidized bed riser used in this study. The computational domain mesh consisted of 51,789 cells. The used time step was 1×10^{-3} s. The simulation was conducted for 30 s of simulation time, which was estimate as 2 weeks of computational time on the core i3 3.20 GHz with 8 GB RAM workstation.

2.2. Model description

The Eulerian-Eulerian multiphase model with kinetic theory of granular flow was used to solve numerical simulation. The model equations were solved with FLUENT 6.2.16 program. The used numerical schemes for convection terms were second-order upwind scheme. The conventional SIMPLE algorithm for each phase [11] was used to relate the velocity and pressure corrections to recast the continuity equation in terms of a pressure correction calculation. More detail about the model equations can be found in Chalermsinsuwan et al. [12] and Chalermsinsuwan and Piumsomboon [13].

3. Results and Discussion

3.1 Effect of inlet conditions

Figures 2 and 3 show the predicted radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m for case 1-7. The case 3-7 results showed a reasonable agreement near the wall but slightly under-predicted at the center of the riser. Figures 4 and 5 illustrate the predicted axial distributions of time-averaged pressure drop for case 1-7. The predicted pressure drops were in good agreement with experimental data except for case 1 and case 2, however, case 6 showed their superiority in predicting than the others.

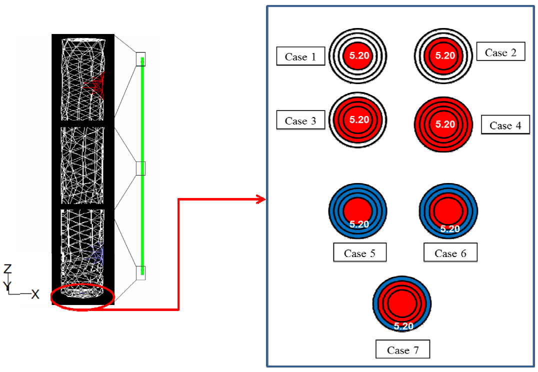

Figure 1. Computational domain of circulating fluidized bed riser (left) and schematic drawing of a simplified inlet of the riser used in this study (right).

It can be concluded that the model for case 6 is suitable to predict the system hydrodynamics in the riser of circulating fluidized bed, however, further improvements are required to achieve quantitative agreement. Figure 6 displays the contour plots of solid volume fraction in the riser for case 1, 3, 5 and 6 (at 30 s of simulation time). For the effect of percent opening of gas inlet velocity channels, the solid volume fraction decreased with increasing opening percentage (case 1-4) while, for the shape of fully developed velocity profiles, the solid volume fraction increased in the center and decreased near the wall of system when convex profile was used (case 5-7).

3.2 Effect of wall boundary conditions

To investigate the effect of different wall boundary conditions, different values of the restitution and specularity coefficients were tested.

The particle-wall restitution coefficient is the elastic of collisions between the particle and the wall where the value of zero represents fully inelastic collisions and the value of unity represents fully elastic collisions.

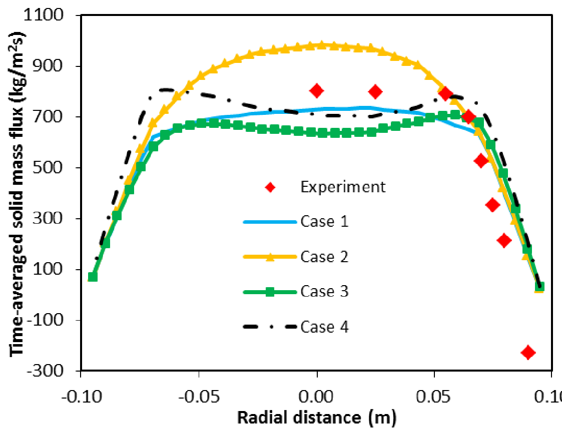

Figure 2. Radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m for case 1-4.

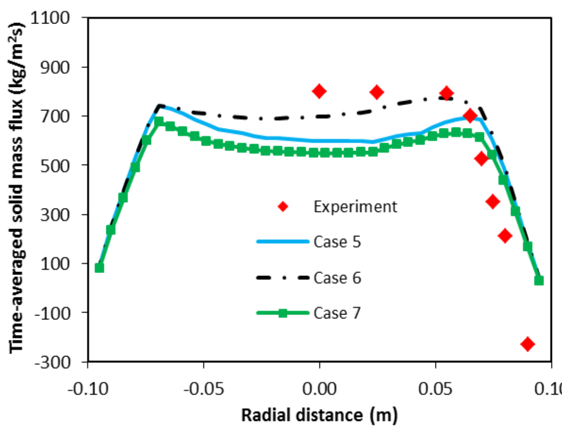

Figure 3. Radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m for case 5-7.

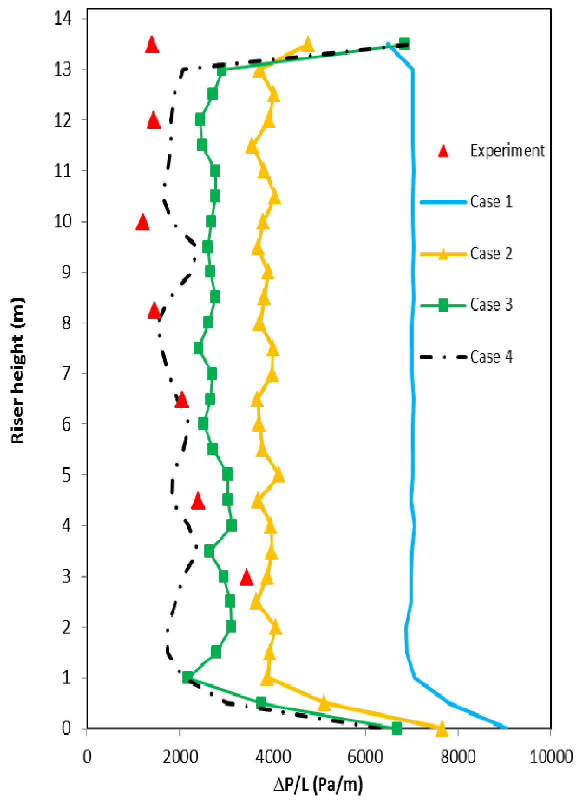

Figure 4. Axial distributions of time-averaged pressure drop for case 1-4.

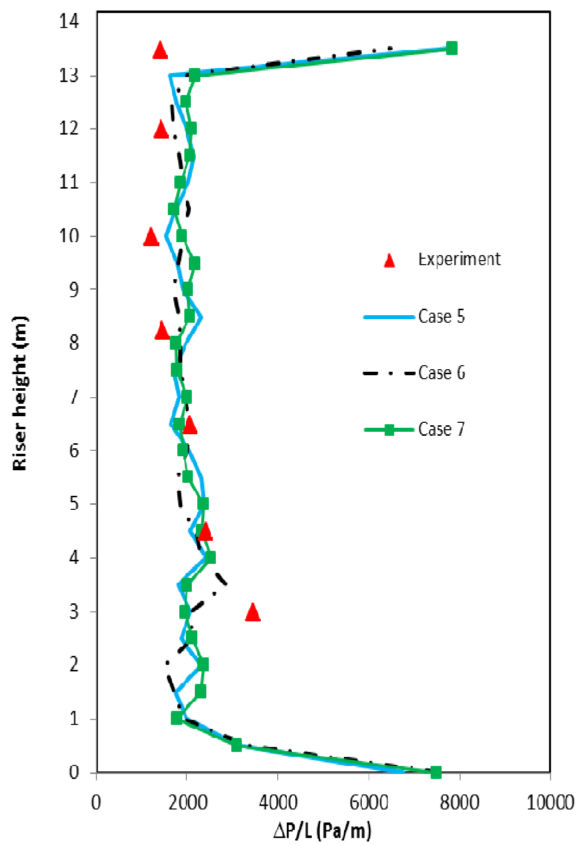

Figure 5. Axial distributions of time-averaged pressure drop for case 5-7.

In this study, four particle-wall restitution coefficients were investigated which were 0.50, 0.80, 0.90 and 0.95.

Figure 7 displays the predicted radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m with different particle-wall restitution coefficients. The result showed that the influence of restitution coefficient was slightly affected on this system position which was consistent with previous studies of Almuttahar and Taghipour [9]. However, according to Natarajan and Hunt [14] and Benyahia et al. [15], at the bottom zone, lowering the restitution coefficient resulted in the increasing of solid volume fraction near the wall. Therefore, the particle-wall restitution coefficient has major effect at the bottom of the riser while it has minor effect at the top of the riser.

The specularity coefficient indicates the degree of slippage between the particle and the wall. The value of zero and unity indicate that the wall is smooth and rough, respectively.

In this study, four specularity coefficients were studied which were 0.50, 0.10, 0.001 and 0.0001.

Figure 8 shows the predicted radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m for different specularity coefficients. For the reason of the observed solid mass flux profiles, the smaller values of specularity coefficient leads to higher solid concentration near the wall and dilute at the center of the riser.

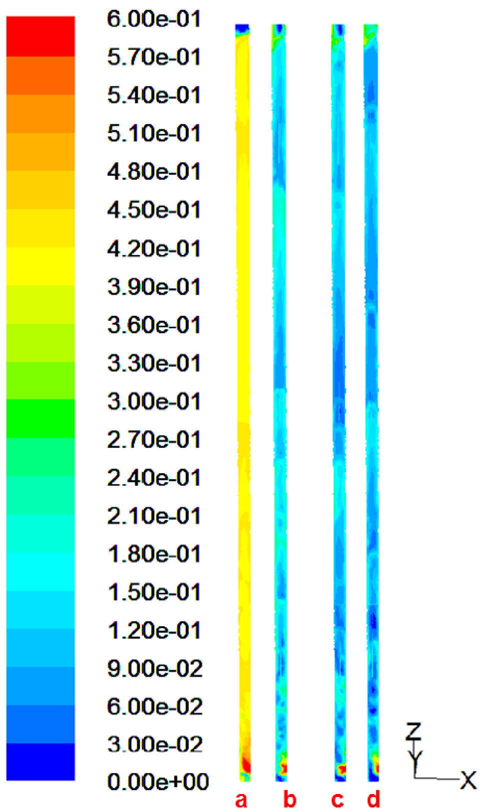

Figure 6. Contour plots of solid volume fraction for (a) case 1, (b) case 3, (c) case 5 and (d) case 6.

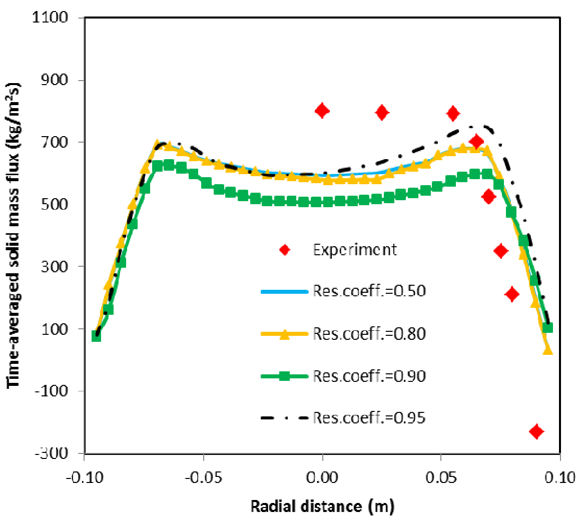

Figure 7. Radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m with different particle-wall restitution coefficients.

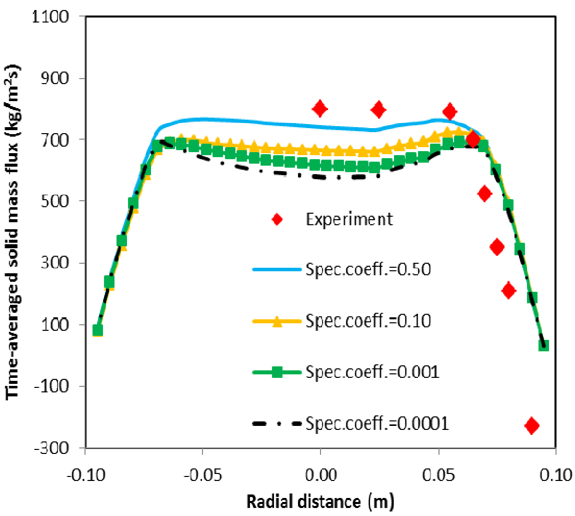

Figure 8. Radial distributions of time-averaged solid mass flux at the riser height equals to 3.9 m with different specularity coefficients.

The obtained result was consistent with the previous work of Benyahia et al. [16]. The specularity coefficient of 0.50 is in good agreement with the experimental data. Thus, it can be concluded that the strong effect of specularity coefficient is observed especially at the bottom of the riser. In contrast to restitution coefficient, the specularity coefficient at the top of the riser still has an effect on the system.

4. Conclusion

Simulations were conducted in a three-dimensional domain with Euleian-Eulerian approach and kinetic theory of granular flow model to investigate the effects of different gas inlet velocity conditions and the effect of different values of the restitution and specularity coefficients. The model was evaluated by comparing with the experimental data in the literature. It was found that the model for case 6 is suitable for predicting the system hydrodynamics in the riser of circulating fluidized bed, however, additional improvements are required to achieve quantitative agreement with the experimental data. For the effect of percent opening of gas inlet velocity channels, the solid volume fraction decreased with increasing opening percentage (case 1-4) while, for the effect of shape of fully developed velocity profiles, the solid volume fraction increased in the center and decreased near the wall of system when convex profile was used (case 5-7). Moreover, the strong effect of the system modeling parameters which were restitution and specularity coefficients were observed at the bottom of the riser. At the top of the riser, specularity coefficient still had a role while restitution coefficient only had slightly effect in the system.

Acknowledgements

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