Chapter 7

Conclusions and Recommendations

During the course of this research, turbulent gas-particle flows in several engineering geometries were numerically investigated. There have been three major outcomes from this study: (i) the physical behavior of the turbulent gas-particle flow over the backward facing step and the turbulent gas-particle flow in a 90-degree bend were numerically investigated via an Eulerian-Lagrangian model and an Eulerian-Eulerian model; (ii) the performance of different turbulence models in simulation of indoor airflow and contaminant particle transportation were evaluated and the influences from the turbulence models and particle-wall collision model to the particle phase prediction was investigated via the Eulerian-Lagrangian model; iii) two particle-wall collisions and a stochastic wall roughness model were developed to accurately account for the particle-wall collision phenomenon in turbulent gas-particle flow, and the models were used to simulate the gas-particle flow in an in-line tube bank and to investigate the effects of wall roughness on the particle flow in a two-dimensional 90-degree bend.

For a backward facing geometry, the RNG k-ε model and realizable k-ε model gave the better prediction than the standard k-ε model. Therefore, RNG k-ε model was used for studying gas-particle flows over the backward facing step geometry, the 90-degree bend geometry and the in-line tube bank.

By validating the simulation results of both Eulerian-Lagrangian model and Eulerian-Eulerian model with the experimental data, it was found that both approaches provided reasonable good predictions of the velocities and turbulent fluctuations for the gas and particle phases. The Eulerian-Eulerian model provided useful insights into the particle concentration and turbulence behavior when compared to the Eulerian-Lagrangian approach, while Eulerian-Lagrangian model can give detailed particle trajectories and particle-wall interactions. It also has been demonstrated that more computational time is required for Eulerian-Lagrangian approach than Eulerian-Eulerian approach. In engineering applications, the Eulerian-Lagrangian approach is recommended when the detailed physics for the particle phase is needed. For complex flows that require large computational resources for the Lagrangian model, the Eulerian-Eulerian model is an attractive alternative.

The indoor airflow and contaminant particle concentration in two geometrically different rooms have been investigated using the Eulerian-Lagrangian model. In the first room geometry, the simulated air phase velocity profiles obtained by the standard k-ε, RNG k-ε and RNG-based LES models are validated against the measurements of Posner et al. (2003). All the three turbulence models provide good prediction of the air phase velocity, while the RNG-based LES model prediction provides the best agreement with the measurements; the RNG k-ε model gives better performance than Standard k-ε model in velocity prediction. The RNG-based LES model is able to provide the instantaneous information such as the instantaneous air velocity and turbulence that is required for the evaluation and design of the ventilation system. The RNG-based LES model provides time-dependant LRN turbulence information to the particle phase, which results in more realistic particle dispersion and distribution than the conventional two-equation k-ε models. Therefore, it is recommended that instead of the expensive experimental measurement, the LES prediction can be effectively employed to assess the performance of k-ε models that are commonly applied in many building simulation investigations.

In the second room model, the LES model combined with a Lagrangian particle tracking model provided acceptable prediction of the contaminant particle concentration, compared to the particle concentration decay measured by Lu et al. (1996). The numerical results also revealed that the particle-wall impact model has a considerable effect on the Lagrangian concentration prediction.

It is necessary to apply realistic particle-wall model in numerical simulations of confined, wall-bounded gas-particle flows, since the particle wall collision is one of the governing phenomenon in such flows (Sommerfeld and Huber, 1999). As a part of this thesis, the algebraic particle-wall collision model (Brach and Dunn, 1992 and 1998) and the stochastic wall roughness model (Sommerfeld, 1992) were implemented into the Eulerian-Lagrangian model in the FLUENT code via the User-defined subroutines. This allows the flexibility for extending the collision model to handle complex engineering flows. This

Eulerian-Lagrangian model was utilized to simulate the gas-particle flow over an in-line tube bank. The predictions of mean flow fields (velocities and fluctuations) for both gas and particle phase were validated against experimental data of Tu et al. (1998) and close agreements were achieved.

It was also found that the wall roughness considerably altered the rebounding behaviors of large particles, and consequently affected their motions downstream and particle impact frequency on tubes. Therefore, the particle-wall collision model should be included to account for the effect of wall roughness in order to provide a more realistic description of the particle-wall collision phenomenon. Also, the numerical results confirmed that the particle fluctuations were mainly determined through the particle-wall collisions for large particles, but not by the gas phase fluctuations. For small particles, the influence of particle-wall collision on the particle phase fluctuations was found to be negligible.

Then, the physical behaviors of a turbulent gas-particle flow in a two-dimensional 90-degree bend were numerically investigated using the particle-wall collision model of (Sommerfeld and Hubber, 1999) and the stochastic wall roughness model (Sommerfeld, 1992). It was found that the wall roughness considerably altered the rebounding behaviours of particles by significantly reducing the 'particle free zone' and smoothing the particle number density profiles. The effects of wall roughness on the particle mean and fluctuating velocities were also investigated. The numerical results confirmed that the particle mean velocities for 2.5° and 5° roughness angles were reduced due to the wall roughness which, on average increases the momentum loss for the particle phase. Also, the particle fluctuating velocities were increased when taking into consideration the wall roughness, since the wall roughness produced greater randomness in the particle rebound velocities and trajectories. This work will also be beneficial to the understanding and the accurate prediction of gas-particle flows as well as furthering the understanding of the erosion distribution in 90-degree bends.

Further work is required to investigate the performance of both the Eulerian-Lagrangian model and Eulerian-Eulerian model in simulation of gas-particle flows in more complex engineering geometries, such as the tube banks, coal-fired boilers, and human nasal cavity.

For the numerical modelling of indoor airflow and particle transportation, it is proposed that further experimental investigation of particle-surface interaction is required to develop realistic particle-wall impact model, which is essential to correctly predict the contaminant particle concentration through the Lagrangian model.

Moreover, the erosion model that accounts for the erosion rate on the wall surface will be implemented in the existing particle-wall collision model. This will be helpful to predict the erosion distribution on the heat exchange tubes.