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Numerical Investigation of Particle Deposition in a Room Using Large Eddy Simulation Based on Lattice Boltzmann Method

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1. Introduction

People spend more than 85% of their time indoor; therefore, indoor air quality (IAQ) has been receiving increasing attention. The lattice Boltzmann method (LBM) is a powerful numerical technique for simulating flows in indoor environment. In comparison with traditional CFD methods, the advantages of LBM are: i) simple calculation procedure, ii) simple implementation procedure for parallel computation, iii) simplicity for application to complex geometries and etc. Investigating particle dispersion and deposition in indoor environment and in turbulent flows is very important and the Large Eddy Simulation (LES) model is one of the proper models for simulating particle transport and deposition in turbulent flows.

The main aim of this paper is investigating the deposition of particles with diameters of 10nm to 10µm on the walls of a modeled room using the LES-LBM. Also, the effects of various forces such as drag force, Brownian force, and buoyancy force are investigated.

2. MRT Lattice Boltzmann method with LES model

In this study the Multi Relaxation Time (MRT) LBM with D3Q19 model as shown schematically in Figure 1 is used for the 3D flow simulation of the airflow in the room. To improve the modeling of the sub-grid scales, the SISM (Shear Improved Smagorensky Model) was proposed to resolve the fluctuating velocities. Various forces such as drag force, the buoyancy force, and the Brownian force are considered in the simulation of particle motions. Lift forces that are comparatively small are neglected.

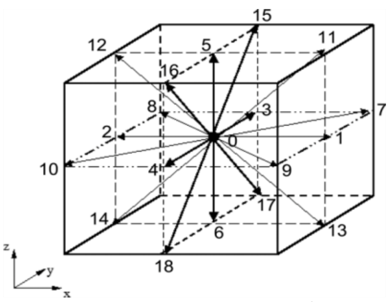

Fig. 1. The discrete velocity vectors for D3Q19.

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3. Results and Discussion

To simulate the particle dispersion and deposition in the room, four sizes of particles (10 nm, 100 nm, 1 µm, and 10 µm) were investigated and a total of 86400 particles were injected into the flow. Two different boundary conditions (BC) for the interaction of the particles with the walls were considered. One was the reflect BC that assumes that when a particle collides with a wall, it bounces back with a coefficient of restitution of 1. The second was the trap BC that implied when the distance of particle center from the wall is less than its radius the particle is deposited on the wall.

Figure 2 compares the number of suspended 1 µm particles in the room for the trap and reflect boundary conditions. It is obvious that the number of suspended particle rises with time until t=100s when the injection stops, and then the number of particles declines gradually.

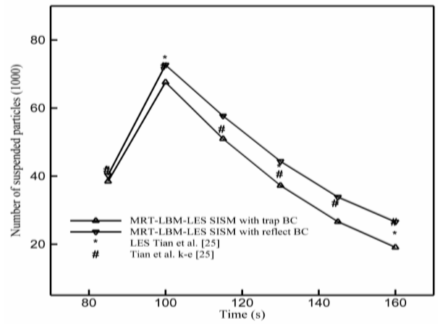

Fig. 2. Comparison of the number of suspended 1 µm particles in the room.

Figure 3 shows the comparison of the number of suspended particles of various sizes for trap BC. It is seen that the number of suspended 10 µm particles is less than other sizes because gravitational sedimentation effects.

Concentration contours of 1µm particles at time 130s at the midsection of the room is shown in Figure 4. It is seen that at this time, most of the particles follow the airflow field and move to the left side of the room. Also the particles in this low velocity region do not reach the outlet at this time and remain suspended in the air or are deposited on the wall. Therefore, the concentration on the left side of the room enhances.

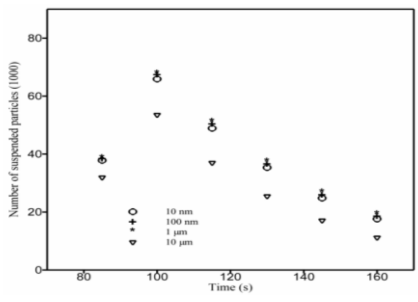

Fig. 3. Comparison of the number of suspended particles of different sizes in the room.

Fig. 4. 1µm particle concentration contours at the mid-plane of the room at t=130 s.

Figure 5 illustrates the total number of deposited particles of various sizes on the modeled room walls. The number of deposited 10µm particle is more than other sizes due to their high inertia and gravity. Moreover, the deposition of 10nm particles is more than 100nm and 1µm because of the more intense Brownian excitation.

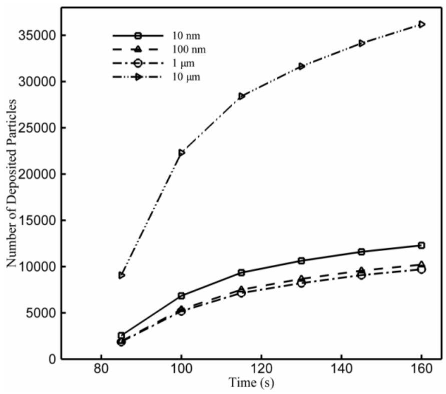

Fig. 5. The number of total deposited particles on the walls of modeled room.

4. Conclusion

The LES model in conjunction with the Lattice Boltzmann method was used to simulate particle deposition in a room. For the LES model the sub-grid scale turbulence effects were included through the Smagorinsky model. Deposition of particles with various sizes in a room was studied and the following conclusions are drawn:

- The present method captured the particle deposition in the room reasonably well.
- The number of deposited 10µm particles was more than the other sizes due to the gravitational sedimentation and inertial impaction.
- By augmentation of particle diameter from 10nm to 1µm, particles deposition in the room declines by about 15%, because of the decreasing intensity of Brownian excitation.