Numerical analysis of particle dispersion in indoor air using Lagrangian method

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Summary: *As particles in room air can result lung diseases, it is important to study how they are transported and dispersed in buildings. This study numerically investigated particle dispersion by using the Lagrangian approach. The turbulent air flow is solved by the RNG k-ε model; and a discontinuous random walk (DRW) model is applied to account for stochastic effect of particle movement in turbulent flow. The computed results agree reasonably well with the experimental data for particle dispersion in a wind tunnel, but are different from that by LES method for particle dispersion in a room.*

Keywords: *CFD, RANS, DRW, particles, RNG k-ε model*
Category: *modeling techniques*

1 Introduction

Small air borne particles of several microns or less may suspend in the air for a relatively long period of time. These particles may deposit in lung and lead to many lung diseases (http://www.lungusa.org). Since people spend most of their times indoors, it is necessary to study how particles are transported and dispersed in indoor environment.

2 Methodology

In order to numerically study the particle transportation and dispersion in a room, the airflow should be correctly predicted. Since particle amount and total volume fraction of particles in indoor air are small, their impact on the indoor air is usually negligible. It is reasonable to neglect the impact of particles on air movement when using computational fluid dynamics (CFD) technique.

2.1 Simulation of air flow field

This investigation used a Re-Normalization Group k-ε (RNG k-ε) turbulent model to simulate the airflow. Chen [1] suggested this model for indoor environmental analysis after comparing a number of alternatives.

2.2 Modeling of particle dispersion

This study further used the Lagrangian method to track the individual particles in room air by solving a set of momentum equations [2]:

$$m_p \frac{d\vec{u}_p}{dt} = D_p(\vec{u}_a - \vec{u}_p) + m_p g + F \qquad (1)$$

where, $\vec{u}_a$ and $\vec{u}_p$ is the air and particle velocity, respectively, and F represents forces caused by Basset history, the pressure gradient, and the Brownian movement, etc. For aerosol particles with a diameter of 0.01 to 20 microns, F is much smaller than the drag force so that it can be neglected.

To consider the turbulent effect on the particle dispersion, this investigation used a stochastic model to account for the random fluctuation velocity of the air from Gosman and Ioannides model [3]. The model assumes isotropic turbulent flow and the fluctuating velocities to follow a Gaussian probability distribution.

3 Validation of the Numerical Model

To validate the numerical model, this study first used the experimental data of particle dispersion in a wind tunnel from Snyder and Lumley (1971) [4]. Fig. 1 shows schematically the test section of the wind tunnel. Particles are released at 20 inches above the grid along the center line.

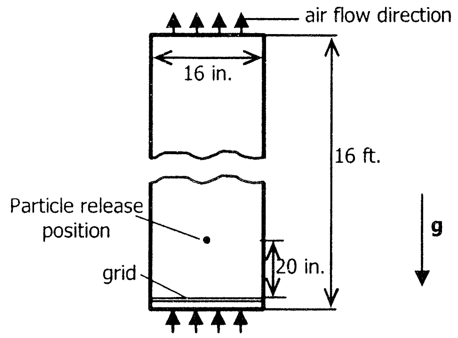


Fig. 1. Schematic of the test section of wind tunnel

The computed turbulent flow field and the particle lateral dispersion agree well with measured data as shown in Figs. 2 and 3. The turbulence predicted is crucial for the estimate of the standard deviation of the fluctuating velocity; and consequently the particle dispersion.

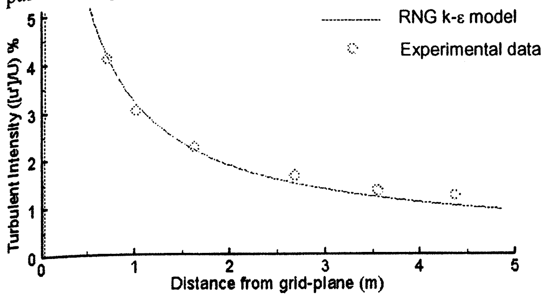


Fig. 2. Comparison of computed and measured turbulent intensity.

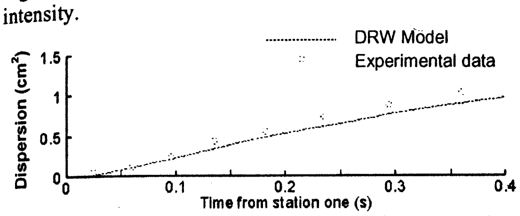


Fig. 3. Comparison of measured and predicted particle lateral dispersion (mean square dispersion $\overline{Y^2}$).

Although the particle dispersion in the wind tunnel is a good case for validation of the flow and particle model, the flow is not a representative in a room. Therefore, this study used another case to predict the particle dispersion in a ventilated room to examine its performance in indoor environment. However, no quality measurements of particle dispersion in rooms are available from literature. Our simulated results are hereby compared with those obtained by Large Eddy Simulation (LES) [4]. Unlike the RANS, LES calculates both the mean air velocity and the instantaneous fluctuating part. Thus, no statistical model is needed to account for instantaneous fluctuation.

Fig. 4 shows the room geometry. The particles are released from the center point of the air supply opening. The airflow by both methods are similar expect in the region near upper right corner where both the experiment and LES show a larger separation.

Fig. 5 shows the temporal evolution of the particles. In first few seconds after the release, the two results look similar. Afterwards, an obvious difference appears: the RANS model predicts a larger dispersion rate in x direction than the LES. It appears that the RANS simulation provides a larger fluctuating velocity. In addition, the RANS results show that the particles are more likely to attach to the ceiling during the transportation, whereas, the LES shows a greater tendency of dropping down in the vertical direction. This could be attributed to the bifurcation of the, flow field near the upper right corner.

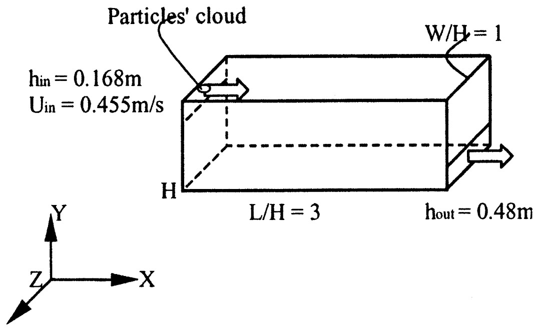
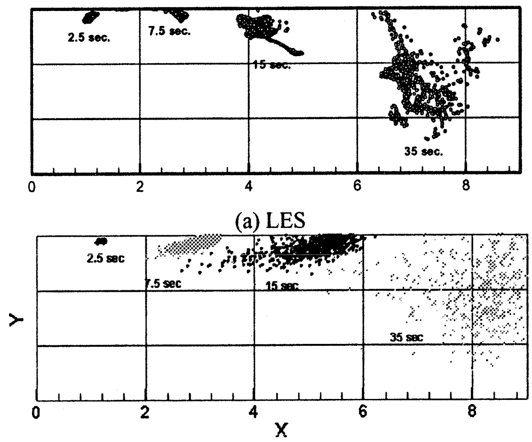


Fig. 4. Schematic of the ventilated cavity



(a) LES

(b) RANS

Fig. 5. Comparison of temporal evolution of particles

4 Conclusion

Correctly prediction of turbulent flow is crucial for the simulation of particle dispersion using the Lagrangian method. The RNG k-ε model can correctly predict the turbulent flow in a wind tunnel. However, the model could not predict the recirculation in the upper corner in a room. Thus, the model can predict correctly the particle dispersion in the wind tunnel, but less accurate in the room.

Reference

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