Table 1
Summary of boundary condition requirements for each of the transport processes.

	Convection	Diffusion	Settling
Order of spatial derivatives	First	Second	First
Solid wall conditions	No-slip velocity None for c	$\frac{\partial c}{\partial n} = 0$	$U_{sett} = 0$ (except on the bottom wall $U_{sett} = \text{const.}$) None for c
Inlet condition	$c = \text{const.}$	$c = \text{const.}$	Not applicable
Outlet condition	None	$\frac{\partial c}{\partial n} = 0$	Not applicable

Fig. 5 is the computational results for this case. The time duration to reach the steady state is about the same as the convection–diffusion case, because, as mentioned previously, the diffusion process provides the mixing mechanism for reaching the steady state faster. The steady-state value of C is higher than the convection–settling case, but lower than all the cases without settling. This is also evident in the particle-number density contours in Fig. 5b, where the minimum value of c is lower than those in the convection only and convection–diffusion cases, but higher than that in the convection–settling case. The numerical leaking is still shown in the rate of change plot in Fig. 5a, about 4% of the inlet particle rate in this case.

3. Conclusion

Consistency of boundary conditions for each of convection, diffusion and settling processes as well as for several combination cases is investigated theoretically. By looking into the integral characteristics of the conservative form of the transport equation for particle-number density, the boundary-condition requirements are analyzed. Boundary conditions for each process are summarized in Table 1. For combined processes, the boundary conditions are consistently the corresponding combination of the processes without contradictions. That means for a combination of different processes, the boundary conditions required for each of the involved processes are either the same or complement to each other. Under no circumstances are different boundary conditions for particle-number density required on the same boundary, a situation that can cause physical and mathematical inconsistency. For convection, the no-slip velocity condition on the solid walls deems that the boundary condition for the particle-number density is not needed, and the only boundary for convection is the inlet Dirichlet-type boundary condition. For diffusion, the necessary boundary condition is the zero normal-gradient of the particle-number density on all the boundaries except the inlet. For settling, no boundary conditions are needed for the particulate phase when the settling speed is specified zero on the top boundary. Since the boundary conditions for each process do not contradict to each other, when different processes co-exist, there are no anomalous effects of the boundary conditions on the solutions. Numerical simulations using the finite-volume method show good agreement in comparison with the analytical integral results.

References

Fluent, 2006. Fluent 6. 3 User's Guide. Fluent Inc, 2006-09-20.

Friedlander, S.K., 1977. Smoke, Dust, and Haze. John Wiley & Sons, New York.

Hinds, W.C., 1982. Aerosol Technology. John Wiley & Sons, New York.

Reade, W.C., Collins, L.R., 2000. A numerical study of the particle size distribution of an aerosol undergoing turbulent coagulation. J. Fluid Mech. 415, 45–64.

Smoluchowski, M., 1917. Versuch einer mathematischen theorie der koagulationskinetic kolloider losungehn. Z. Phys. Chem. 92, 129.

Zhang, N., Zheng, Z.C., 2007. A collision model for a large number of particles with significantly different sizes. J. Phys. D: Appl. Phys. 40, 2603–2612.

Zhang, N., Zheng, Z.C., Maghirang, R.G., 2008. Numerical simulation of smoke clearing with nanoparticle aggregates. Int. J. Num. Methods Eng. 74, 610–618.

Zhang, N., Zheng, Z.C., Glasgow, L., Braley, B., 2010. Simulation of particle deposition at the bottom surface in a room-scale chamber with particle injection. Adv. Powder Technol. 21, 256–267.

Zheng, Z.C., Zhang, N., Eckels, S., 2004. Validation of particle/fluid interaction models. In: 2004 International Mechanical Engineering Congress & Exposition, Paper Number IMECE2004-61324, Nov. 13–19, 2004, Anaheim, CA.