Modeling of aerosol deposition using the Diffusion-Inertia Model (DIM) in OpenFOAM

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The existing strategies of modeling turbulent two-phase flows can be subdivided into two groups depending on the Lagrangian tracking and Eulerian continuum approaches for handling the particulate phase. In the framework of the Lagrangian method, the particles are assumed to encounter randomly a series of turbulent eddies, and the macroscopic particle properties are determined solving stochastic equations along separate trajectories. As a consequence, such a method requires tracking a very large number of particle trajectories to achieve statistically invariant solution. As the size of particles decreases, the representative number of realizations should increase because of the increasing contribution of particle interactions with turbulent eddies of smaller and smaller scale. Thus, this technique provides a very useful research tool of investigating particle-laden flows, but it can be too expensive for engineering calculations. The Eulerian method deals with the particulate phase in much the same manner as with the carrier fluid phase. Therefore, the two-fluid modeling technique is computationally very efficient, as it allows us to use the governing equations of the same type for both phases. In addition, the description of fine particles does not cause great difficulties because the problem of the transport of particles with vanishing response times reduces to the turbulent diffusion of a passive impurity. Overall, the Lagrangian tracking and Eulerian continuum modeling methods complement each other. Each method has its advantages and, consequently, its own field of application. The Lagrangiam method is more applicable for non-equilibrium flows (e.g., high-inertia particles, dilute dispersed media), while the Eulerian method is preferable for flows that are close to equilibrium (e.g., low-inertia particles, dense dispersed media). Since the particulate phase combines simultaneously the properties of continuum medium and discrete particles, the situation with these two approaches resembles the well-known “wave-particle” duality in the micro-word.

To simulate the dispersion of low-inertia particles in turbulent flows, the Eulerian models of diffusion type appear to be very efficient. In [1–3], a simplified Eulerian model called the diffusion-inertia model (DIM) was developed. This model was based on a kinetic equation for the probability density function (PDF) of particle velocity distribution [4–6] and was coupled with fluid RANS in the frame of one-way coupling. The Eulerian models of diffusion type were also proposed in coupling with DNS and LES approaches for calculating the turbulent carrier fluid [7−12]. The advantage of the Eulerian diffusion-type models is that the particle velocity can be explicitly expressed in terms of the properties of the carrier fluid flow. By this means, one avoids the need to solve the momentum balance equations for the particulate phase, and the problem of modelling the dispersion of the particulate phase amounts to solving a sole equation for the particle concentration. Thus, computational times are seriously shortened as compared to full two-fluid Eulerian models. The disadvantage is that these are applicable only to the two-phase flows laden with low-inertia particles. For example, the DIM is valid when the particle response time is less than the integral timescale of fluid turbulence. Nevertheless, these models are capable of predicting the main trends of particle distribution, in particular, the effect of preferential accumulation due to turbophoresis.

We extend the DIM to include the back-effect of particles on the fluid turbulence in the frame of two-coupling. Moreover, the boundary condition for the particle concentration equation is augmented to include the gravity, the centrifugal force, and some other mechanisms of deposition. This extended model is applied to the three-dimensional simulation of aerosol deposition in circular bends when the transport of particles is caused by the simultaneous action of the turbophoretic, gravitational and centrifugal forces.

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