Workshop
Multiphysical Modelling in OpenFOAM
Riga, October 20-21, 2011

Diffusion-inertia Model for Two-phase Turbulent Flows and its Implementation into OpenFOAM

R. Mukin[1]

The existing strategies of modelling 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 a series of turbulent eddies randomly, and the macroscopic particle properties are determined by solving stochastic equations along separate trajectories. As a consequence, such a method requires tracking of a very large number of particle trajectories to achieve a statistically invariant solution. Thus, this technique, especially when coupling with DNS or LES for the computation of fluid turbulence, 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 modelling 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 modelling methods complement each other. Each method has its advantages and, consequently, its own field of application. The Lagrangian method is more applicable for the nonequilibrium flows (e.g., high-inertia particles, dilute dispersed media), while the Eulerian method is preferable for the flows which are close to equilibrium (e.g., low-inertia particles, dense dispersed media). Thereby the particulate phase simultaneously combines the properties of continuum medium and discrete particles.

To simulate the dispersion of low-inertia particles in turbulent flows, the Eulerian models of diffusion type appear to be very efficient. In Zaichik et al. (1997) and Zaichik et al. (2004) , 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 Zaichik (1997), Zaichik (1999), Zaichik et al. (2004a). 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. It follows that 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 single equation for the particle concentration. Thereby the computational times are significantly shortened in comparison with the full two-fluid Eulerian models. The disadvantage is that these are applicable only to the two-phase flows laden with the 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, including the effect of preferential accumulation due to turbophoresis, in a fairly wide range of particle inertia.

In this talk I will present a DIM implemented in OpenFOAM for simulating three-dimensional, incompressible two-phase turbulent flows. The first part is devoted to modelling of the particle-laden turbulent flows, taking into account the following aspects: 1. anisotropy modulation of turbulence by particles in the framework of two-way coupling; 2. the so-called inertia and crossing-trajectory effects; 3. action of diffusion, turbophoresis, gravity, and inertia force. The performance of the model for particulate flows was examined on aerosol deposition in straight tubes and circular bends and backward-facing step. Moreover, anisotropy modulation of turbulence by particles was modelled by fully explicit self-consistent algebraic Reynolds stress model (ARSM) for the two-phase turbulent flows (Alipchenkov & Zaichik, 2010) combined with DIM. ARSM for two-phase flows is constructed similar to ARSM model for single-phase proposed by Girimaji, 1996.

The second part is devoted to modelling of the polydispersed bubbly flow. Validation process of DIM for bubbly flows can be divided into several sections. In the first section, acting of various forces on bubbles was studied by means of comparing with experiments for monodisperse bubbly flow. However, in the experiments, due to bubbles coalescence and breakup the flow always becomes polydispersed. Thus, in the second section models for break-up and coalescence in polydispersed flows were validated based on extensive experiments performed by Krepper et. al, 2005; Lucas et. al, 2005; Lucas et. al, 2010. Where measuring the radial gas volume fraction distribution, the bubble size distribution and the radial residence of bubbles dependent on their size were determined for different distances from the gas injection were performed for vertical pipe flow. Basing on these experiments the applicability and the limits for the simulation of bubbly flow by DIM are demonstrated.

References

Alipchenkov, V., Zaichik, L., 2010. Nonlinear algebraic model of the reynolds stresses for a disperse turbulent flow with low-inertia particles. Fluid Dynamics 45, 909–923.

Girimaji, S. S., 1996. Fully explicit and self-consistent algebraic reynolds stress model. Theoret. Comput. Fluid Dynamics 8, 387–402.

Krepper E., Lucas D., Prasser H.-M. On the Modelling of Bubbly Flow in Vertical Pipes, Nuclear Engineering and Design. 2005. V. 235. P. 597.

Lucas D., Beyer M., Kussin J., Schütz P. Benchmark Database on the Evolution of Two-Phase Flows in a Vertical Pipe, Nuclear Engineering and Design. 2010. V. 240. P. 2338.

Lucas D., Krepper E., Prasser H.-M. Development of Co-Current Air–Water Flow in a Vertical Pipe, Int. J. Multiphase Flow. 2005. V. 31. P. 1304.

Zaichik L.I., Modelling of the motion of particles in non-uniform turbulent flow using the equation for the probability density function, J. Appl. Mathematics and Mechanics, Vol. 61, 127-133 (1997).

Zaichik L.I., Pershukov V.A., Kozelev M.V., Vinberg A.A., Modelling of dynamics, heat transfer, and combustion in two-phase turbulent flows, Exper. Thermal and Fluid Science, Vol. 15, 291-322 (1997).

Zaichik L.I., Soloviev S.L., Skibin A.P., Alipchenkov V.M., A diffusion-inertia model for predicting dispersion of low-inertia particles in turbulent flows, in: Proceedings of the 5th International Conference on Multiphase Flow, Yokohama, Japan, (2004).

Zaichik L.I., Oesterle B., Alipchenkov V.M., On the probability density function model for the transport of particles in anisotropic turbulent flow, Physics Fluids, Vol. 16, 1956-1964 (2004a).

Zaichik L.I., Simonin O., Alipchenkov V.M., An Eulerian approach for large eddy simulation of particle transport in turbulent flows, Journal of Turbulence, Vol. 10, 4 (2009).

[1]Nuclear Safety Institute of the Russian Academy of Science, 52 Bolshaya Tulskaya Ulitsa, Moscow, 113191, Russia