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A nonlinear subgrid drift velocity model for filtered drag in turbulent fluidization

F. Dabbagh[1] and S. Schneiderbauer[1,2]

[1] Christian Doppler Laboratory for Multi-Scale Modeling of Multiphase Processes,
Johannes Kepler University, Altenbergerstraße 69, 4040 Linz, Austria.
firas.dabbagh@jku.at.
[2] Department of Particulate Flow Modelling,
Johannes Kepler University, Altenbergerstraße 69, 4040 Linz, Austria.
simon.schneiderbauer@jku.at.

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Small-scale turbulent topologies get highly complicated when merging into multiphase flows. For instance, when a turbulent flow pulls small inertia particles in a particle-laden turbulence, the particles at low mass loading drain kinetic energy from the carrier fluid and produce a kind of relaminarization. While, at significantly large mass loading, the particles get self-organized into dense clusters triggering a drag production and momentum feedback on the carrier-fluid, and enhance its turbulent kinetic energy as *cluster-induced turbulence (CIT)*. This drag production or CIT is relatively expressed by the subgrid-scale (SGS) drift velocity $\boldsymbol{v}_d$ on mesoscale description (*i.e.* spatially filtered coarse grid). Considering a gas-particles turbulent fluidization simulated in the framework of two-fluid model (TFM); the most classical closure for $\boldsymbol{v}_d$ assumes that $\boldsymbol{v}_d^{model}$ is linearly aligned against the resolved gradient of solid volume fraction $\bar{\epsilon}_s$, with a scalar turbulent dispersion D_{tg}, *i.e.* $\boldsymbol{v}_d^{Bur} \sim D_{tg}\nabla\bar{\epsilon}_s/(\bar{\epsilon}_s\bar{\epsilon}_g)$ [1], where $\bar{\epsilon}_g$ is the gas-phase volume fraction. Recently and on the base of our novel analysis of small-scale structures in dense turbulent fluidization [2], the linear model $\boldsymbol{v}_d^{Bur}$ has revealed a clear misalignment with the actual $\boldsymbol{v}_d^{A}$ due to the (strong tendency) boundary-layer-like turbulence on the gas-phase. This leads us in the current work to derive and explore the behaviour of a new proper nonlinear model basing on non-negative clipping (regularized) rate-of-strain gas-phase tensor and solids gradient, *i.e.* $\propto \bar{\mathsf{S}}_g^{\oplus}\nabla\bar{\epsilon}_s/(\bar{\epsilon}_s\bar{\epsilon}_g)$, where, $\bar{\mathsf{S}}_g = 1/2(\bar{\mathsf{G}}_g + \bar{\mathsf{G}}_g^t)$, and $\bar{\mathsf{G}}_g = \bar{\epsilon}_s[\nabla\bar{\boldsymbol{u}}_s - 1/3tr(\nabla\bar{\boldsymbol{u}}_s)\mathsf{I}]$ (similar to the framework of LES models).

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