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Development and Experimental Validation of Coupled Flow-Aerosol Microphysics Model for Hot Wire Generator

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Abstract : We have developed a CFD coupled aerosol microphysics model in the context of aerosol generation from a glowing wire. The governing equations can be solved implicitly for mass, momentum, energy transfer along with aerosol dynamics. The computationally efficient framework can simulate temporal behavior of total number concentration and number size distribution. This formulation uniquely couples standard K-Epsilon scheme with boundary layer model with detailed aerosol dynamics through residence time. This model uses measured temperatures (wire surface and axial/radial surroundings) and wire compositional data apart from other usual inputs for simulations. The model predictions show that bulk fluid motion and local heat distribution can significantly affect the aerosol behavior when the buoyancy effect in momentum transfer is considered. Buoyancy generated turbulence was found to be affecting parameters related to aerosol dynamics and transport as well. The model was validated by comparing simulated predictions with results obtained from six controlled experiments performed with a laboratory-made hot wire nanoparticle generator. Condensation particle counter (CPC) and scanning mobility particle sizer (SMPS) were used for measurement of total number concentration and number size distribution at the outlet of reactor cell during these experiments. Our model-predicted results were found to be in reasonable agreement with observed values. The developed model is fast (fully implicit) and numerically stable. It can be used specifically for applications in the context of the behavior of aerosol particles generated from glowing wire technique and in general for other similar large scale domains. Incorporation of CFD in aerosol microphysics framework provides a realistic platform to study natural convection driven systems/ applications. Aerosol dynamics sub-modules (nucleation, coagulation, wall deposition) have been coupled with Navier Stokes equations modified to include buoyancy coupled K-Epsilon turbulence model. Coupled flow-aerosol dynamics equation was solved numerically and in the implicit scheme. Wire composition and temperature (wire surface and cell domain) were obtained/measured, to be used as input for the model simulations. Model simulations showed a significant effect of fluid properties on the dynamics of aerosol particles. The role of buoyancy was highlighted by observation and interpretation of nucleation zones in the planes above the wire axis. The model was validated against measured temporal evolution, total number concentration and size distribution at the outlet of hot wire generator cell. Experimentally averaged and simulated total number concentrations were found to match closely, barring values at initial times. Steady-state number size distribution matched very well for sub 10 nm particle diameters while reasonable differences were noticed for higher size ranges. Although tuned specifically for the present context (i.e., aerosol generation from hotwire generator), the model can also be used for diverse applications, e.g., emission of particles from hot zones (chimneys, exhaust), fires and atmospheric cloud dynamics.

Keywords : nanoparticles, k-epsilon model, buoyancy, CFD, hot wire generator, aerosol dynamics
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