EHD-ODT: a stochastic turbulence model for the study of heat and mass transfer in wire-tube electrostatic precipitators

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We present an extension of the One-Dimensional Turbulence (ODT) model aimed at the evaluation of coupled heat and mass transfer in wire-tube electrostatic precipitators. The reduced dimensionality of the model allows the direct study of the complete and two-way coupling effects of the molecular diffusion and turbulent advection from the Navier-Stokes equations, as well as the electroquasistatic distributions of the electric field and free charge density derived from the Maxwell equations. Numerical results for the skin friction coefficient, the Nusselt number and the Sherwood number as a function of the electrohydrodynamic (EHD) body force will be presented with a comparison to available literature and experimental results, as well as experimental results obtained by the group of authors in a joint research project. An outlook on the effects of aerosol transport will also be presented.

A brief overview of the ODT model

Although there is a general consensus in the idea that the best possible approach for numerical evaluation of EHD flows remains in the direct solution of the Navier-Stokes and Maxwell equations, the fact is that, as of today, there are still not enough computational resources in order to carry out Direct Numerical Simulations (DNSs) of industrially relevant flows. Therefore, a large body of models have been developed [1]. As an alternative to traditional filter-based turbulence models, ODT is a stochastic turbulence model which relies on the modeling of the three-dimensional turbulence by an ensemble of stochastic one-dimensional linear transformations. These must be solved together with a system of deterministic one-dimensional Partial Differential Equations (PDEs). The latter fully incorporate the molecular diffusion and source terms from the Navier-Stokes equations. The ODT model has been proven reliable for a variety of incompressible and variable density reactive flows [2, 3]. This work incorporates an extension of the ODT model which considers the EHD body force source term in a cylindrical wire-tube ESP as a source of turbulent advection. The implementation of the linear mappings, or eddy events in ODT, is governed by an energy balance of the change in kinetic energy, a modeled energy dissipation effect due to viscosity and the change in electrostatic potential energy derived from the

EHD body force. An additional Joule heating effect can be incorporated for heat transfer studies. The latter is considered as a source term in the deterministic PDEs.

Results for Skin friction and Nusselt number enhancement

Preliminary results for skin friction and Nusselt number enhancement are shown next. The results for skin friction are shown in Figure 1 a), in terms of the friction Reynolds number enhancement as a function of the bulk Reynolds number and the electrohydrodynamic number. ODT results of an incompressible pipe flow with one-way coupled electric fields are compared in this case to experimental results obtained by the group of authors. As expected, both experiments and simulations reproduce the increase in the skin friction (or pressure drop) as a function of the increased electrostatic body force. The results for Nusselt number enhancement are shown in Figure 1 b). Here, ODT results are compared to the experimental results from Nelson et al [4]. The reproducibility of the experimental results for Nusselt number enhancement with ODT is achieved well within the experimental uncertainty. The results indicate a relaminarization effect on the flow at the exit of the numerical pipe for the low Reynolds number flows with increased EHD body force.

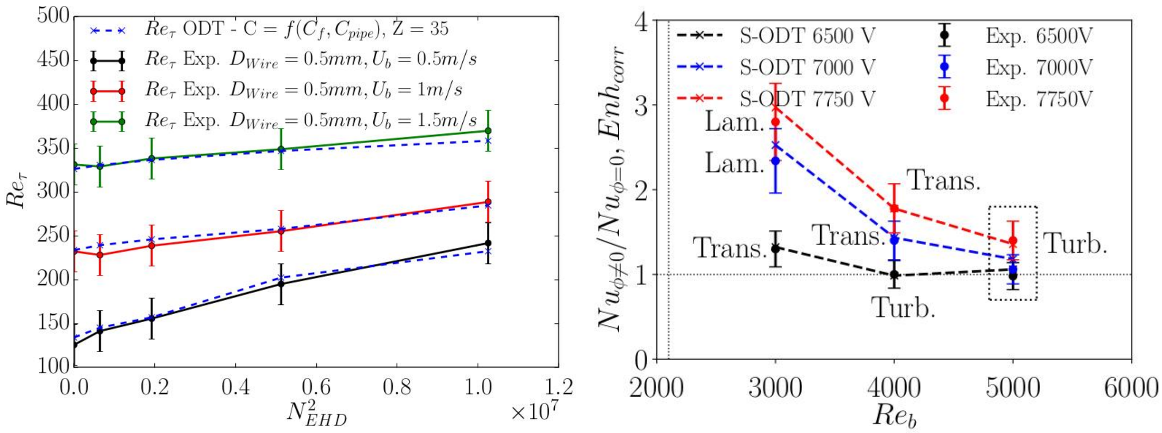

Figure 1: Friction Reynolds number (left) and Nusselt number enhancement (right) results as a function of the bulk Reynolds number and the electrostatic body force (EHD number or electrostatic potential) in a pipe flow with a concentric electrode.

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