Modeling electrohydrodynamically-enhanced drag in channel and pipe flows using one-dimensional turbulence

Marten Klein   Juan Alí Medina Méndez   Heiko Schmidt

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Electrohydrodynamically (EHD) enhanced flows are encountered in various technical applications ranging from air-cleaning devices (like precipitators) to liquid metal or electrolyte (like redox flow) batteries. For numerical analysis and optimization of such technical devices, it is crucial to accurately and economically model the interactions of hydrodynamics and electrokinetics as these determine the system characteristics (like pressure drop, precipitation efficiency, or mixing properties). The main challenge for flow modeling is nonlocal and nonlinear interactions between the fluid flow, charge-carrier distributions, and electric fields. Previous and recent research in the field hints at nonuniversal turbulent boundary-layer processes that need to be captured by any model with predictive capabilities. Traditional sub-filter-scale parameterizations used in Reynolds-averaged Navier-Stokes simulations (RANS) and large-eddy simulations (LES) are, therefore, of limited applicability. Here, we address this lack in available models by a lower-order approach that utilizes stochastic one-dimensional turbulence (ODT). ODT aims to resolve all relevant scales of the flow but only for a notional line-of-sight. A stochastic process is used to mimic the effects of turbulent stirring motions whereas deterministic molecular diffusion is directly resolved.

In the talk, we address three canonical internal flow configurations in order to validate the approach and demonstrate its applicability for numerical simulation of multiphysical EHD-enhanced flows. We first discuss the model representation of momentum and passive scalar transfer in turbulent channel flow. After that, we investigate EHD effects in zero-pressure-gradient turbulent boundary layers for plane Couette flow using a dilute electrolyte as working fluid. Last, we apply the model to low-Mach-number vertical EHD pipe flow with an inner concentric electrode treating particulate charge carriers as continuum. By making use of the model's predictive capabilities, we analyze flow regimes and investigate turbulent processes responsible for previously observed EHD-enhanced friction drag.