Modeling simultaneous momentum and passive scalar transfer in turbulent annular Poiseuille flow

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Numerical simulation of coupled scalar and momentum transport in turbulent flows remains a challenge for various engineering applications (e.g. [1]), for example, heat exchangers [2] and chemical reactors [3]. A relevant flow configuration in this context is annular Poiseuille flow in which a prescribed mean pressure gradient drives an axial flow that is confined between two coaxial concentric cylinders. In this set-up, complications arise due to wall-curvature effects that yield nonuniversal boundary layers [4]. We demonstrate that such effects notably limit the predictive capabilities of Reynolds-averaged Navier–Stokes (RANS) and large-eddy simulations (LES) manifesting itself by a strong grid dependence of the predicted flow. This lack in modeling is addressed in the present study with the aid of a stochastic one-dimensional turbulence (ODT) model formulated for cylindrical geometry [5]. ODT is a dimensionally reduced flow model that can be economically utilized as stand-alone tool. Here, the model aims to resolve transient radial transport processes on all relevant scales of the flow by modeling turbulent stirring motions by a stochastically sampled sequence of mapping events that punctuate the continuous (molecular-diffusive) flow evolution. In the contribution, we will show model results for the momentum and passive scalar transfer to the cylindrical domain wall. We demonstrate that the model captures radius ratio, Reynolds, and Prandtl number effects for fixed model parameters. A comparison of low-order flow statistics with available reference data suggests that the nonuniversal boundary layer over the inner cylinder is reasonably captured for radius ratios down to $\approx 1/10$. For even smaller radius ratios, the ODT modeling error increases presumably due to unresolved flow features that enclose the inner cylinder. Nevertheless, preliminary ODT results suggests that curvature effects remain notable up to very high Reynolds numbers even for moderate radius ratios suggesting that wall modeling must be done carefully.

References

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