DNS of forced turbulent convection in circular pipes

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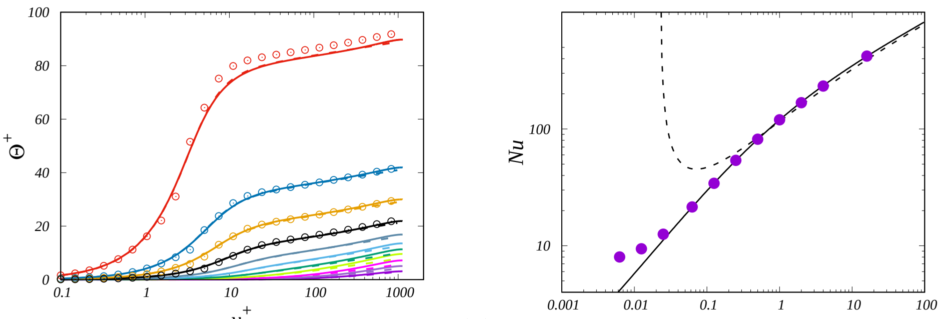
We study passive scalars (either temperature or concentration of a diffusing substance) at friction Reynolds number up to $Re_\tau = 6000$, for turbulent flow within a smooth straight pipe of circular cross–section, in the range of Prandtl numbers from $Pr = 0.00625$, to $Pr = 16$, using DNS. Whereas the organization of passive scalars is similar to the axial velocity field at $Pr = O(1)$, similarity is impaired at low Prandtl number, at which the buffer-layer dynamics is filtered out, and at high Prandtl number, at which the passive scalar fluctuations become confined to the near-wall layer. The mean scalar profiles at $Pr \gtrsim 0.0125$ are found to exhibit logarithmic overlap layers, and universal parabolic distributions in the core part of the flow. Near-universality of the eddy diffusivity is exploited to derive accurate predictive formulas for the mean scalar profiles, and for the corresponding logarithmic offset function. Asymptotic scaling formulas are derived for the thickness of the conductive layer, for the peak scalar variance, and its production rate. The DNS data are leveraged to synthesize an improved version of the classical predictive formulas for the mean temperature profiles [1], and heat transfer coefficient [2], which are capable of accounting accurately for the dependence on both the Reynolds and the Prandtl number, for $Pr > 0.01$.



(a) (b)

Figure 1: (a) Comparison of mean temperature profiles obtained from DNS (solid lines), with our analytical prediction (dashed lines), and with Kader's empirical profiles (open symbols). (b) Comparison of Nusselt number given by DNS (symbols) with our analytical prediction (solid line), and with Kader and Yagloms's formula (dashed line).

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[1]Kader, *Int. J. Heat Mass Transfer* **24**

[2]Kader and Yaglom, *Int. J. Heat Mass Trans.* **15**