THE EFFECT OF SELECTED THERMAL BOUNDARY CONDITIONS ON A FULLY DEVELOPED TURBULENT PIPE FLOW

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Fully developed turbulent pipe flow with heat transfer is studied by means of well-resolved large-eddy simulations (LES) at $Re_b = u_b D/\nu = 5300$ ($Re_\tau = u_\tau R/\nu \approx 180$), where u_b, D and ν are the bulk velocity, diameter of the pipe and kinematic viscosity, respectively, and u_τ and R are the friction velocity and radius of the pipe. The simulations are carried out using the spectral-element code Nek5000 [1] with a relaxation-term (RT) filter. We are interested in the effect of different thermal boundary conditions on the temperature field for analysing and improving challenging heat transfer applications, such as the receiver of a concentrated solar power system (CSP).
Therefore, as a first step, three different Prandtl numbers Pr are considered (0.1, 0.71, 2) together with two kinds of thermal boundary conditions, namely the non fluctuating isoflux (IF) and (non fluctuating) isothermal (IT). Additionally, conjugate heat transfer (CHT) is investigated as a more realistic thermal boundary condition where the heat conduction in the solid part of the pipe is taken into account. Hence, temperature fluctuations at the fluid/solid interface are also simulated. Also in the CHT cases, the Prandtl number and the thermal boundary conditions on the outer wall are varied. Two additional parameters, the thickness of the solid wall d_w ($0.1D$, $0.04D$) and the thermal diffusivity ratio between fluid and solid $G = \alpha_f/\alpha_S$ ($0.033, 0.77, 3.33$) are introduced.

Figure 1 shows effects of the thermal boundary condition on the mean temperature and temperature fluctuations. The

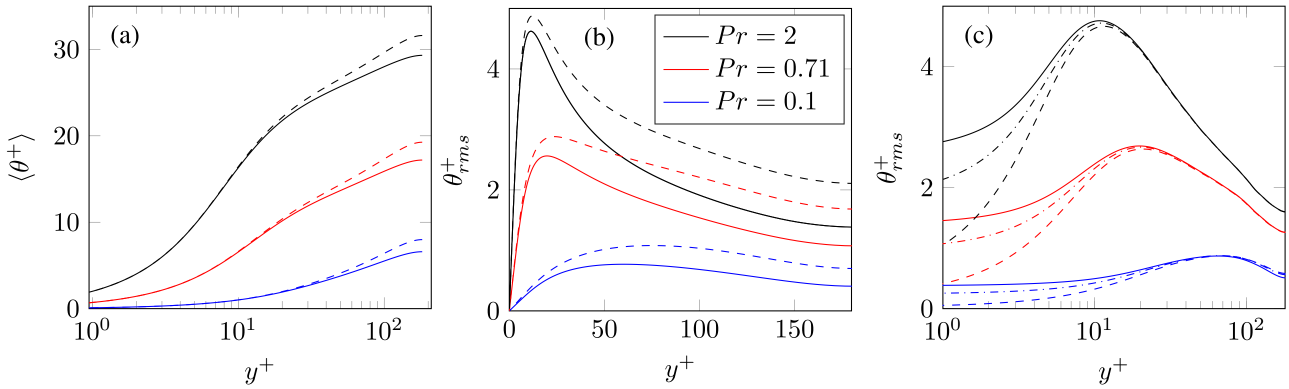

Figure 1: (a) Mean temperature and (b) RMS of temperature fluctuations for non CHT with IF (—) and IT (- -).
(c) RMS of temperature fluctuations for CHT with $d_w = 0.1D$; IT and $G = 3.33$ (—), $G = 0.77$ (-·-); $G = 0.033$ (- -).

mean temperature (a) in the centre of the pipe is slightly lower for the IF boundary condition in agreement with Ref. [2]. Furthermore, at the smallest Prandtl number investigated, the temperature profile does not show a clear log-law region for such low Reynolds number flows. The temperature fluctuations for the IT boundary condition in the non CHT setup (b) are larger than for the IF condition beyond the initial slope close the wall, and the near-wall peak is located farther away from the wall in the low Prandtl number cases. With CHT admitting temperature fluctuations at the fluid/solid interface, the temperature fluctuations are considerably affected by the thermal diffusivity ratio G. A smaller diffusivity ratio yields lower temperature fluctuations at the wall [3]. The mean temperature however is only marginally affected by different G values, whereas the influence of d_w is not negligible especially for the IT boundary condition (both not shown here).

Future studies will be conducted with non-homogeneous thermal boundary conditions in the circumferential and axial directions at lower Pr and higher Reynolds numbers as liquid metals are considered as heat transfer fluids in CSP systems.

References

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