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Heat transfer implications and recovery of turbulent pipe flow past targeted wall shapes

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Abstract

In the present study, the thermal implications and recovery of turbulent pipe flow experiencing sudden variations in wall cross-sectional geometry are investigated using k – ω Shear Stress Transport (SST) turbulence model at Re = 158,600. The rapid wall modifications are deployed as pipe insertions, in which the cross-sectional shapes are designed to best replicate targeted azimuthal Fourier modes: m = 3 (Case I), m = 15 (Case II), and m = 3 + 15 (Case III). Preliminary results present up to 6% drop in convective heat transfer coefficient for Case II and Case III, downstream of the pipe-insert segment, compared to smooth pipe flow at similar operating conditions. Further, a considerable decrease in wall shear stresses and skin friction coefficients is detected and quantified to be 8.6% and 7.5% for Case II and Case III, respectively. The wall shape of Case I exhibits a relatively minor impact (1.0%) on the distributions of Nusselt number and skin friction coefficient, downstream of the pipe perturbation. A self-similar recovery trend is observed for Case II and Case III, such that fully-developed condition is retrieved at an axial location of 14D from the insert, where D is the pipe diameter. Case I reveals a relatively rapid recovery rate, at which the flow appears to return to its recovered state at 8D. The outcome of the present study hints at the feasibility of mitigating the loss in thermal energy with a reduction in skin friction and drag through deployment of wall modifications corresponding to Case II and Case III. These wall modifications present economic and environmental benefits in several thermal applications such as energy recovery processes and enhanced geothermal systems. This study will be expanded to examine the effects of Reynolds number on the modified heat transfer characteristics and recovery for Case II.