Numerical Investigation of the Convective Heat Transfer Enhancement in Coiled Tubes

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Abstract

Introduction: The present work is focused on the numerical analysis of forced convection in curved tubes. The main purpose was to deeply investigate the correlation between the heat transfer and friction factor enhancement and the effects of the wall curvature. In the present study, a toroidal geometry characterized by a tube diameter of 14 mm and a curvature ratio of 0.06 was considered. The study was performed by considering the Reynolds number range 2-100 and the Prandtl number range 25-100. Use of COMSOL Multiphysics: The study was performed by integrating the continuity, momentum and energy equations within COMSOL Multiphysics 4.2a environment. The analysis was performed under the assumptions of incompressible Newtonian, constant properties fluid and of periodically fully developed laminar flow. For the thermal problem, a uniform wall heat flux boundary condition was assumed. Since the geometry shows a symmetric construction only one half of the tube has been simulated. Moreover, by considering a periodically fully developed flow is possible to analyze only a portion of the toroid. The domain of integration and the computation grid are reported in Figure 1. Results: In order to evaluate the overall performances of the geometry the friction factor and the Nusselt number were calculated. Moreover the flow pattern and the temperature distribution on the tube section were derived for different values of the Reynolds number. In addition, the numerical results were compared to the experimental values obtained on a coiled tube with the same tube diameter and the same curvature ratio. The values obtained within COMSOL Multiphysics 4.2a environment confirmed the experimental results: the local Nusselt number reaches values higher than the ones expected for straight pipes [1] (Figure 2). Moreover the numerical results are in agreement with the correlations proposed by Janssen and Hoogendoorn [2] for smooth wall curved tubes(Figure 2). Furthermore the friction factor is reported (Figure 3) versus Reynolds number and the results support the values obtained experimentally: they show that the increasing of the friction factor due to the wall curvature profile is negligible for this flow regime. Conclusion: The curvature of the wall tube, and in particular the geometry considered in the present analysis, constitutes an efficient solution for the heat transfer enhancement in case of laminar flow regime. This is of interest especially in processes in which highly viscous fluids are involved, such the ones used in food, chemical and pharmaceutics industries. Further analysis, by varying the geometry and the fluid properties, that could allow generalizing the results are in progress.

Reference

1. R.K. Shah, A.L. London, Laminar Flow Forced Convection in Ducts, Academic Press, (1978).
2. L.A.M. Janssen and C.J. Hoogendoorn, Laminar convective heat transfer in helical coiled tubes, Int. J. Heat Mass Transfer, vol. 21, pp 1197-1206 (1978).

Figures used in the abstract

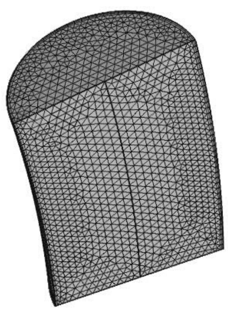

Figure 1: Domain of integration.

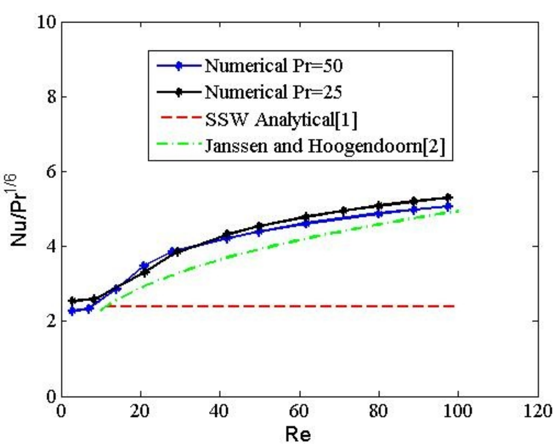

Figure 2: Average numerical Nusselt number versus Re for two different Prandtl numbers and comparison with the analytical solution for the straight smooth wall tube under uniform heat flux boundary condition (SSW: straigth smooth wall) and with the prediction of Janssen and Hogendoorn [2].

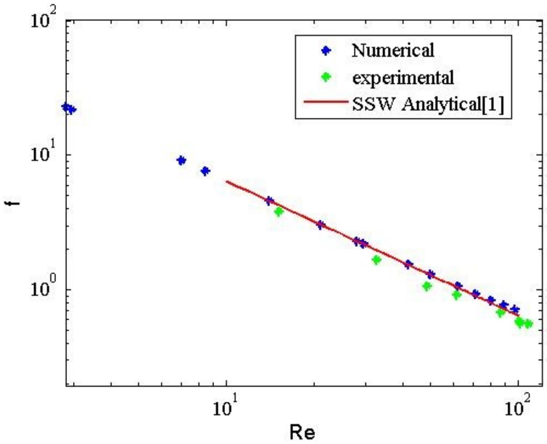

Figure 3: Friction factor versus Reynolds number for the numerical analysis compared to the one obtained experimentally and to the analytical solution for the straight smooth wall tube.