ESTIMATION OF LOCAL HEAT TRANSFER COEFFICIENT IN COILED TUBES

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In the thermal processing of highly viscous fluids, wall curvature represents a widely used technique to passively enhance convective heat transfer. Since in these applications the momentum transfer mechanism usually falls in the laminar flow regime, the effectiveness of the heat transfer apparatuses is inevitably penalized and the use of coiled tubes could provide an interesting solution. A comprehensive literature review of flow in curved pipes has been presented by Berger et al. [1] and Naphon and Wongwises [2].
In coiled tubes the enhancement effect is due to the fact that the fluid experiences the centrifugal force, depending on the local axial velocity and on the radius of curvature of the coil. This causes the fluid to be pushed from the core region towards the outer wall by producing a thinning of the boundary layers. This phenomenon also generates counter-rotating vortices, generally called secondary flows, that increase both heat transfer and pressure drop when compared to the straight tube [3].
As a consequence of the highly not symmetrical fluid velocity field, both the wall temperature and the wall heat flux strongly vary along the circumferential coordinate: convective heat flux shows values at the extrados wall surface much higher than the ones at the intrados wall surface. This unevenness could impact on the performance of the fluid thermal treatment.
Although many authors have investigated the forced convective heat transfer in coiled tubes, most of them have presented the results only in terms of the Nusselt number averaged along the wall circumference: only few authors have studied the phenomenon locally, most of them by numerical approach [4-7] and only a few experimentally [8].
A promising way to estimate the local convective heat transfer coefficient on the interior surface of a tube is found by solving the inverse heat conduction problem (IHCP) in the solid domain from the temperature distribution acquired on the exterior wall surface [9]. The majority of the solution strategies for this kind of problems consists in reformulating it as a well-posed problem by minimizing an objective function, which generally expresses the squared difference between measured and estimated temperature discrete data. When the signal to noise ratio is particularly critical, the objective function obtained in that way is not adequate to overcome the problem’s instability while the regularization scheme suggested by Tikhonov and Arsenin [10] proved to be very successful, although the selection of the regularization parameter requires some care.
In this paper a procedure to estimate the local convective heat flux in coiled tubes is presented and tested. A smooth wall helically coiled stainless steel type AISI 304 tube was tested. The working fluid entered the coiled test section equipped with stainless steel fin electrodes which were connected to a power supply. This setup allowed investigating the heat transfer performance of the tube under the prescribed condition of uniform heat generated by Joule effect in the wall. The temperature distribution of a small portion of the external tube wall, near the downstream region of the heated section, was acquired by means of an infrared camera, as sketched in Fig.1 At the observed tube position the fully developed condition was reached, in agreement with the observations of Rainieri et al. [3]. Ethylene Glycol was used as working fluid in the Reynolds number range 70−1200.
The temperature maps acquired on the external coil wall were employed as input data of the inverse heat conduction problem in the tube wall under the solution approach based on Tikhonov regularization method which aims to compute the smoothest approximated solution consistent with available data.
In order to limit the number of unknowns in the inverse problem approach, the convective heat transfer distribution was here simplified by considering a continuous piecewise linear function composed of 4 sections.

The direct problem was solved by finite element method implemented in Comsol Multiphysics® environment while the minimization of Tichonov target function was run within the Matlab Optimization Toolbox®.
The distribution of the convective heat transfer coefficient restored by the minimization procedure is reported in Fig. 2 for three different Reynolds numbers. The variation of the convective heat transfer coefficient along the boundary of the duct section points out that, in the fully developed heat transfer region, h_{int} is almost negligible close to the intrados surface of the coil, while reaching its maximum at the extrados surface. This pattern is analogous to the ones obtained numerically by Jayakumar et al. [5] for turbulent heat transfer in helical pipes.

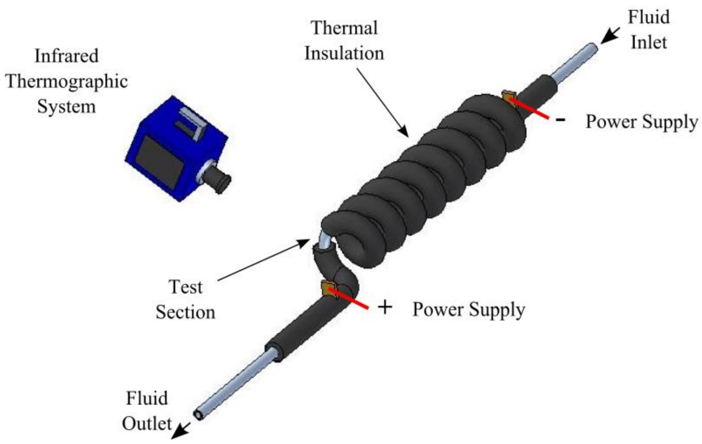

Figure 1: Sketch of the experimental set-up.

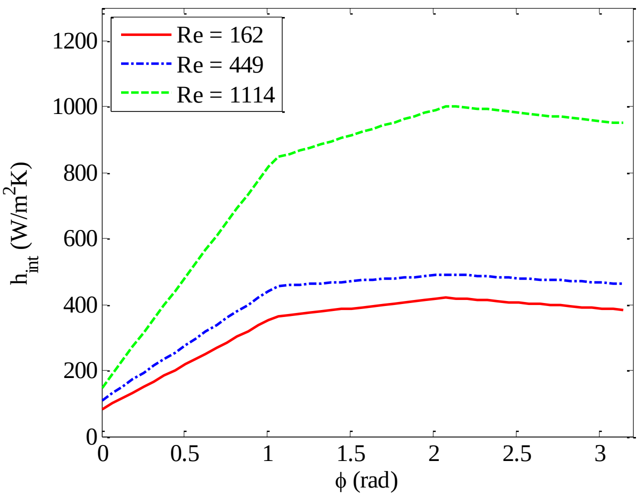

Figure 2: restored convective heat transfer distribution for different Re.

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