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Inverse problem of fluid temperature estimation inside a flat mini-channel starting from temperature measurements over its external walls

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Abstract

Modelling fluid flow and heat transfer inside a mini- or micro-channel constitutes a challenge because it requires taking into account many effects that do not occur in traditional macrostructured systems [1]. In a mini-channel, presence of solid walls, whose volume fraction is not negligible, modifies heat diffusion (conjugated heat transfer) [2]: this means that traditional Nusselt correlations for forced convection have to be revisited, because the heat flux distribution at the wall is not always normal to it and the location of the heat source modifies the distribution of the heat transfer coefficient in the flow direction [3]. This study concerns the numerical and experimental modelling of both single phase water flow and heat transfer (conduction and advection) in a flat mini-channel [4] (see figure 1 and figure 2). The flowing fluid layer (1 mm thickness) is located in between two parallel polycarbonate solid walls (1 and 2 mm thicknesses).

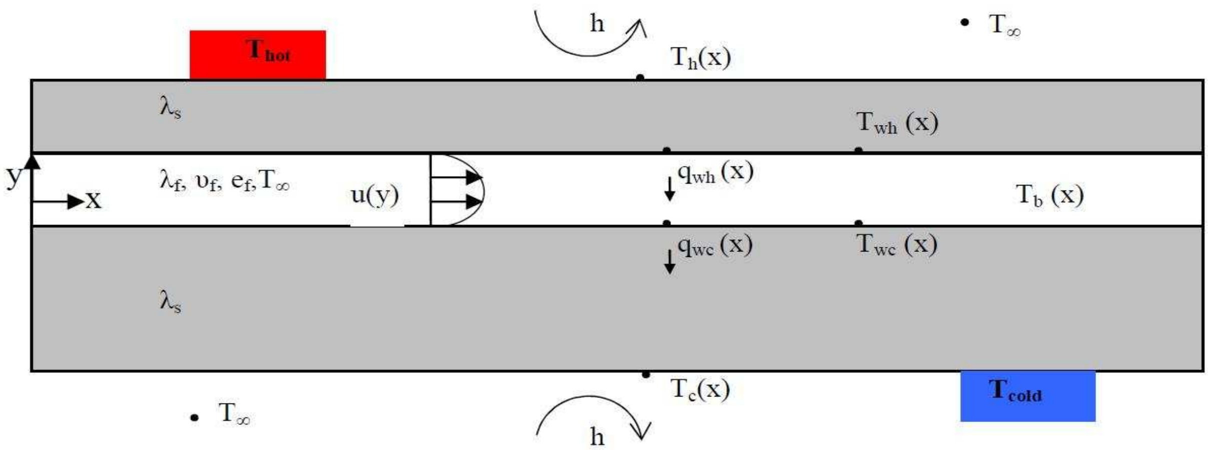

***Fig. 1.** Geometry of mini-channel*

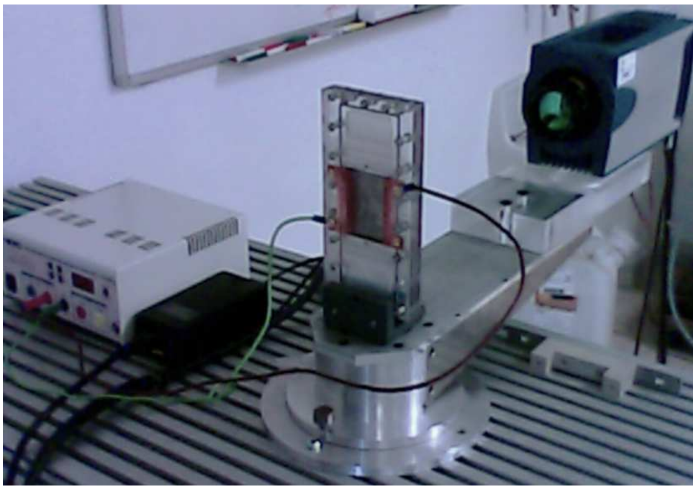

***Fig. 2.** Experimental device*

The laminar flow is supposed to be fully developed with a velocity distribution $u(y)$:

$$u(y) = \frac{3}{2}U\left(1 - 4\left(\frac{y}{e}\right)^2\right) \tag{1}$$

Two uniform temperatures T_{hot} and T_{cold} are imposed on part of the two outer surfaces. The remaining parts of these faces are subject to convective and linearized radiative losses to the ambient environment at T_∞ with a uniform h coefficient. Our objective is to retrieve the bulk temperature distribution of the flow in the channel $T_b(x)$ using inversion of a model whose inputs are the hot and cold temperature sources (T_{hot} - T_∞) and (T_{cold} - T_∞), using infrared temperature measurements over both external faces, $T_h(x)$ and $T_c(x)$. The interest of such an indirect "measurement" is to prevent the use of any intrusive temperature sensor inside the channel. Solution of the direct problem is found through Comsol Multiphysics® without the use of any heat transfer correlation. The external hot face temperature and the bulk fluid temperature are shown in figure 3, for the particular case of an insulated internal wall ($q_{wc}(x) = 0$).

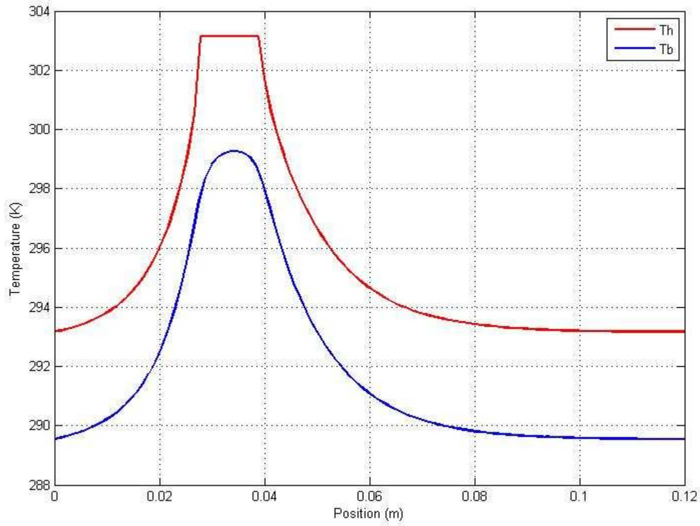

Fig. 3. *Temperature over the external hot face $T_h(x)$ and water bulk temperature distribution $T_b(x)$*

Prior to any estimation of the inner fluid temperature, another inverse problem has to be solved, using the same measurements, that is estimation of the mean velocity U and of the external heat exchange coefficient h. The internal wall temperature (T_{wh} and T_{wc}) and heat flux (q_{wh} and q_{wc}) distributions are calculated next, using inverse heat conduction in both walls. This allows to recover the bulk temperature distribution through solution of the an integral (Voltera) equation corresponding to a heat balance of the flow (for large enough Péclet numbers where advection is the dominant mode of heat transfer in the fluid).

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