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The challenge to measure single-phase convective heat transfer coefficients in microchannels

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During the last twenty years a very strong interest on the analysis of forced convection in microdevices has been demonstrated by the large number of papers dealing with this topic appeared in scientific journals as well as by the impressive number of patents presented by researchers and industrial companies involving convective aspects in microdevices [1]. In this period the comprehension of the physical mechanisms of momentum and heat transfer phenomena activated in microfluidic devices has been dramatically increased by the improved capability to make accurate measurements at micrometric scales [2]. In fact, the scientific and industrial interest on microfluidics has stimulated the development of new experimental techniques for the measurement of local velocity, temperature, pressure, flow rates and other measurable quantities in microchannels [3].

In this lecture a critical review of the experimental techniques developed specifically for the investigation of forced convection in microchannels will be presented. The problem of the experimental determination of convective heat transfer coefficients in channels having dimensions lower than 1 mm is discussed by stressing the pro's and con's of each experimental approach [4].

A conclusion of this critical review is that, due to the small dimensions of the observed objects, the development of non-intrusive experimental techniques with a negligible impact on the observed system is very hard. There are two solution to this problem:

- reduce the presence of invasive sensors within the system; in this case the number of observed quantities decreases and from few experimental data one must infer the behavior of the whole system;
- accept the use of invasive experimental techniques in order to obtain more information about the microsystem; in this case the presence of sensors can determine a significant change of the behavior of the system and one must remove the effects due to the experimental techniques in order to know the real behavior of the system.

In the first case it becomes crucial to be able to model numerically the whole system in order to fill the information gap due to the limited number of available measured data.

As an example, in the analysis of forced convection in microchannels a series of practical issues linked to the real geometry of the microchannel, the real thermal boundary conditions imposed experimentally and the presence of micro-fittings and sensors within the test section can have a strong influence on the convective behavior of the system. In this case, only if the few experimental data are coupled to a complete computational thermal fluid-dynamics analysis of the whole tested micro-system it becomes possible to check the physical meaning of the experimental data and improve their interpretation. Conventional CFD codes can help for this [4].

In the second case, it become crucial to be able to model, by using a numerical approach, the disturbances induced by the experimental techniques on the system in order to extract the right values of the observed quantities. Bottom-up numerical approaches (like Molecular Dynamics, Lattice-Boltzmann, Montecarlo or kinetic approaches) can make this job. This means that in Microfluidics invasive experimental techniques must be generally integrated by numerical models in order to obtain an accurate data post processing avoiding wrong interpretations of the measured quantities. In this sense, the numerical models become an integrated part of the experimental technique. This concept will be fully exploited in the paper by considering two techniques for the measurement of local velocity in microdevices: μPIV (micro Particle Image Velocimetry) [5] and MTV (Molecular Tagging Velocimetry) [6].

In addition, this review highlights the presence of specific gaps in the experimental techniques proposed up to now for the analysis of convective phenomena in microchannels with the aim to stimulate and address the research on this topic in the next future.

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