Graduation project(s)

FAST HEAT TRANSFER BY SMART FLOW CONTROL

Description Efficient mixing is commonly regarded as the best way to enhance heat transfer in fluid flows. This suggests that flow-forcing/control strategies designed to accomplish efficient mixing automatically enhance heat transfer yet implicit in this "engineering wisdom" is the presumption that heat transfer by *convection* (i.e. via fluid motion) dominates the thermal transport. However, particularly in increasingly important technological fields as compact devices for process intensification and microfluidic systems, heat transfer by *diffusion* (i.e. via molecular motion) may contribute significantly to the thermal transport. This results in a highly non-trivial connection between flow and heat transfer and may thus render current flow-forcing/control strategies ineffective for heat-transfer enhancement. Topic of the project is development of dedicated flow-control strategies for heat-transfer enhancement.

Goal and approach A prototype flow-control strategy for heat-transfer enhancement is to be developed for a representative case study: unsteady flow inside a circular container driven by moving wall segments (Fig. 1(a) gives the streamline patterns associated with activation of a single wall segment). Objective is accomplishment of the fastest possible heating of the cold fluid by the hot circular boundary by "smart" flow control (Fig. 1(b) gives a typical temperature evolution during heating). To this end a controller is to be developed that regulates the activation protocol (i.e. sequence/duration) of the wall segments ("input") on the basis of the temperature distribution estimated by an observer from discrete temperature measurements ("output") (Fig. 1(c)).

The research goals are to be realized via <u>two</u> complementary MSc projects:

MSc project I (computational):

1a Numerical simulation of velocity and temperature field for a number of activation protocols (including steady forcing by a single wall segment) by a commercial flow solver (e.g. `COMSOL`) following [1].

MSc project II (experimental):

1b Measurement of the temperature field for a number of activation protocols (including steady forcing by a single wall segment) using Infrared (IR) thermography in the dedicated laboratory set-up following [1] (Fig. 2).

2 Decomposition of the single-segment temperature evolution into its thermal eigenmodes by "Dynamic Mode Decomposition" according to [1] (algorithm available in `MATLAB`).

3 Development of a compact model (using e.g. `MATLAB`) for synthesis of the (approximate) temperature evolution for arbitrary activation protocols. This compact model is to be constructed from linear combination of the dominant thermal eigenmodes of the single-segment case.

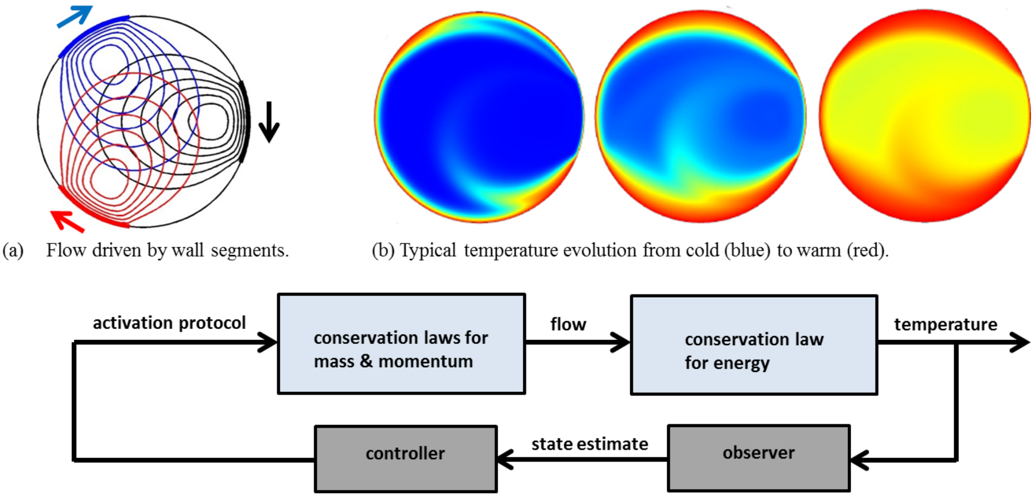
4 Development of an observer (by `MATLAB`) that enables estimation of the temperature evolution from <u>discrete</u> temperature sensors. This observer is to be based on the above compact model.

5 Development of a controller that accelerates the heating process by "optimal" activation of wall segments as a function of the estimated temperature field. To this end efficient control strategies based on regulation of the dominant thermal eigenmodes similar to [2] must be designed.

6a Implementation of observer and controller in a closed-loop computational model for the thermal system (by e.g. linking `COMSOL` with `MATLAB` via the `LiveLink` functionality).

6b Implementation of observer and controller in a closed-loop laboratory set-up for the thermal system (by e.g. linking `LABVIEW` with `MATLAB` via the `LiveLink` functionality).

Goals 2–5 are to be realized both for the computational and experimental temperature fields. The projects can be performed both <u>in tandem</u> by 2 MSc students (i.e. one project per student) and <u>individually</u> by <u>one</u> MSc student (i.e. either the computational or experimental project). Projects performed in tandem may involve close collaboration on items 2–5.



(a) Flow driven by wall segments. (b) Typical temperature evolution from cold (blue) to warm (red).

(c) Control loop

Figure 1: *Heat-transfer enhancement in a flow driven by moving wall segments by "smart" flow control.*

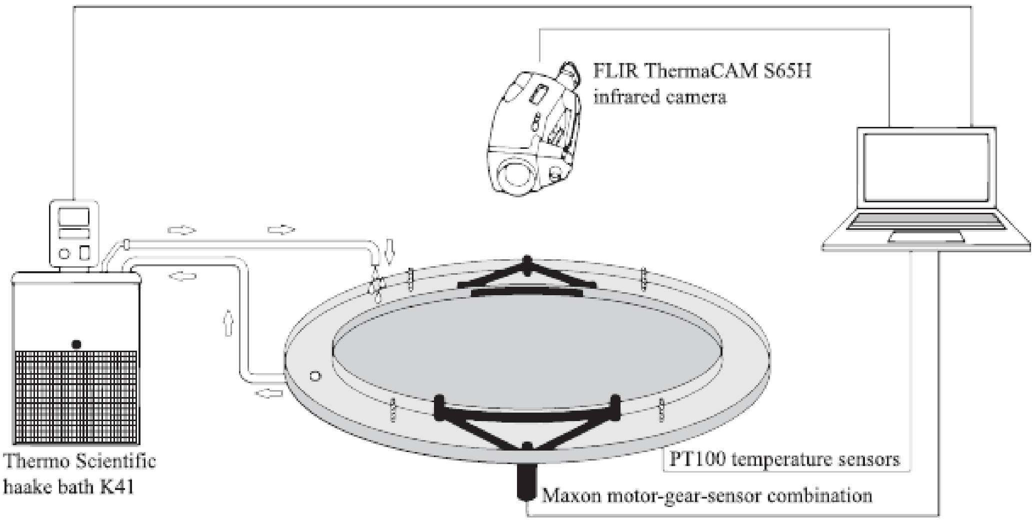


Figure 2: *Laboratory set-up for IR thermography.*

The projects are a collaboration between Mechanical Engineering (research groups Energy Technology and Dynamics & Control) and Applied Physics (research group Turbulence & Vortex Dynamics).

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[1] O. Baskan, M. F. M. Speetjens, G. Metcalfe, H. J. H. Clercx, Experimental and computational study of scalar modes in a periodic laminar flow. *Int. J. Therm. Sci.* **96**, 120 (2015).

[2] R.W. van Gils, M.F.M. Speetjens, H.J. Zwart, H. Nijmeijer, Feedback stabilisation of a two-dimensional pool-boiling system by modal control. *Int. J. Therm. Sci.* **61**, 38 (2012).