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LIQUID CRYSTAL THERMOGRAPHY IN A NEW MICROFLUIDIC DEVICE

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ABSTRACT

Since the early 1980s, attention has turned to the investigation of more complex microfluidic devices such as micro-reactors and micro-heat exchangers, due to the significantly increased transport capacity and efficiency when compared to their conventional macro counterparts [1]. Microfluidic geometries with small hydraulic diameters and high surface-to-volume ratio have been considered as most promising alternatives for various process engineering applications, especially in the field of Measuring, Sensing and Control, Aerospace and Energy. Moreover, further research has witnessed a prompt growth and uncovered exciting opportunity for new applications, especially in bio-medical and chemical engineering [2, 3]. However, due to its complexity, there are still some flow regimes, like churn or annular flows which appear in gas-liquid mixtures, that are not entirely understood. In particular, with the increasing interest in successful implementation of micro-flows, separation techniques and chemical reactions, it is necessary to obtain deeper knowledge of the underlying transport phenomena of heat and multi-phase fluid flows in micro-scale systems.

To investigate these phenomena, obtaining local process parameters such as pressure, temperature, and flow velocity at such small scales with high accuracy is of high importance for further improvements. It is particularly important to enhance techniques for measuring local surface and fluid temperatures developed without affecting the flow phenomena, so that the analytical models can be validated at a local level.

One possibility to achieve that is to use a non-intrusive optical technique called Liquid Crystal Thermography (LCT). It combines optical detection of reflected light of Thermochromic Liquid Crystals (TLC) with the temperature of the fluid in which they are applied [4, 5]. This technique has been widely used by many researchers to obtain the wall temperature and the wall heat transfer coefficient in liquid fluid flows [6, 7], but to the best of our knowledge, no one has used it to extract detailed quantitative information about local temperatures in gaseous fluid flows.

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Therefore, in this study, we introduce Liquid Crystal Thermography for the investigation of temperature gradients along the gaseous fluid flows at a low Reynolds number. The purpose of this work is to establish a good understanding of the capability and limitation of this technique in order to quantify the information of gaseous fluid flows and to encourage further improvements. Due to the challenges related to complex fluid behaviour, fluid-structure interaction, micro-device's material, heating system, optical access, etc. [6, 8], specific and optimized setup for gaseous system is required, as well as a customized design of an innovative microfluidic device.

Liquid Crystal Thermography for measurements in fluid flows

Liquid Crystal Thermography (LCT), unlike conventional methods based on thermocouples and resistance thermometers, is capable of measuring temperature fields on solid surfaces as well as in fluid flows. The principle of measuring the temperature in fluid flows is based on an observation of the colour change of seeded temperature-sensitive tracer particles along the flow (TLC). By using a syringe pump, TLCs can be seeded either in form of water-based droplets or as an aerosol. As the fluid temperature increases, every TLC particle starts to display a certain colour at a particular position in the fluid. The colour (dominant wavelengths) intensity can be then identified with intensity-based image processing, which corresponds to a certain temperature value. Consequently, that gives an insight in the developed temperature gradient along the fluid flow dependent on temperature change [4, 5]. Essentially, in order to improve measurement accuracy, TLC particles image quality and to provide uniformly distributed particles along the flow, a new geometry of microfluidic device for liquid-gas mixing and an optimized setup have been proposed.

New microfluidic device

The initial microfluidic device had to be cheap, simple and efficient. It is necessarily made of polymethyl methacrylate material (PMMA), which is suitable for in situ and biosystem requirements, with respect to temperature and pressure. Its transparency and low thermal conductivity (λ=0.167−0.25 W/mK) allowed observation of a temperature gradient of TLC particles along the channel. The device consisted of two PMMA plates, an upper and the bottom one, whose geometry and dimensions are reported in Fig. 1 and 2.

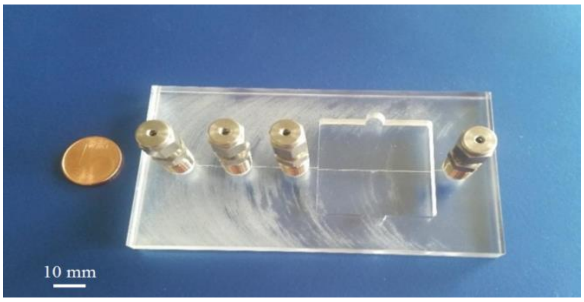
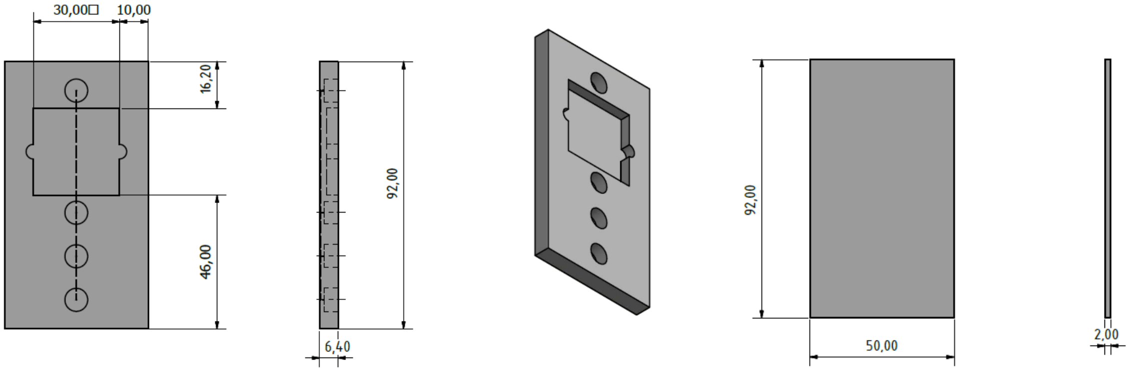


Figure 1: New microfluidic device prototype with multiple inlets



(a) (b)

Figure 2: AutoCAD files of an upper (a) and a bottom part (b) of the microfluidic prototype

A straight rectangular micro-channel (400 x 400 µm), milled into the upper plate of the micro-device, consists of one inlet for a gas phase, two inlets for a liquid phase and an outlet (from left to right respectively on Fig. 1). Between the third inlet and an outlet, one flat-surface pocket was milled for a flexible heater made in a polyimide substrate [9]. Firstly, both plates were microfabricated separately, after which were carefully glued together by using stitching tapes under the microscope.
The idea was to place the micro-device vertically, by reason of better TLCs distribution along the fluid flow and avoiding TLCs sedimentation and blockage of the channel. The sedimented particles would more likely give the information about the temperature of the channel's wall, rather than the local temperature of the fluid.
The direction of the fluid flow in a continuous recycle stream can be set to be either upside-down or downside-up. The schematic procedure of proposed experimental setup is depicted in Fig. 3.

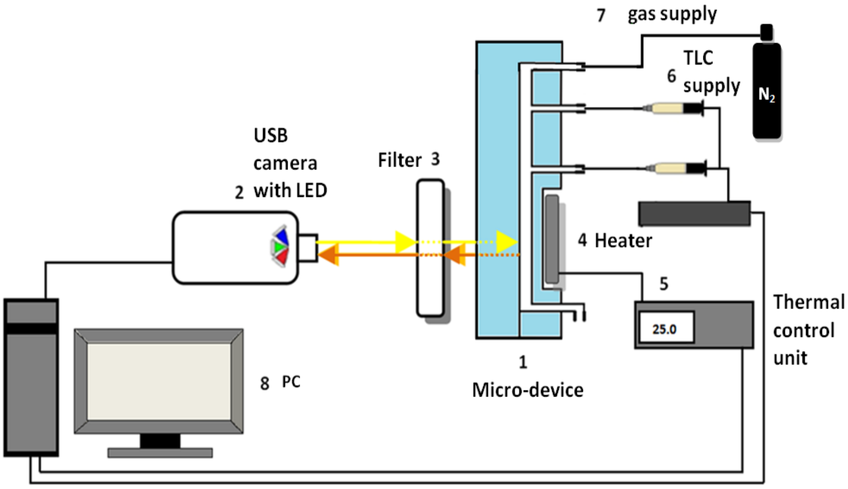


Figure 3: New experimental setup for gaseous fluid flow

The setup will consist of the microfluidic device, liquid and gas supplying system, USB camera, left-handed circular polarizing foil, flexible heater, thermal control unit and DC power supply. The desired fluid flow rate will be obtained by using a mass flow controller on the gas inlet and variable flow meter on the outlet. Both TLC water-based droplets [10] and aerosol (UN R25C10W, Hallcrest), with a relatively narrow temperature range (25–35˚C), will be tested in a new experimental setup, and the results will be compared. The influence of channel's geometry, gas fluid flow and pressure increase on introduced TLC particles will be further investigated.

In conclusion, this is a very promising cost-effective device with a new experimental approach. Not only that sedimentation can be avoided, but it also provides flexibility, particulary with regard to its placing position and great variety of applications. It should be of considerable use of improving the design of many types of microfluidic devices for gas flows.

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