PhD Research project

Molecular Tagging Velocimetry (MTV), for exploring gas microflows

Abstract

Micro-Electro-Mechanical-Systems are of great importance in many day-to-day useful applications, such as portable electronic devices, gyroscopes, accelerometers, micro-valves, propulsion systems for satellites and so on... The better understanding of mass and heat transfer at these scales is of the greatest interest in order to improve the efficiency of such products. In a world-wide contest where the energy demand is rising exponentially, energy efficiency or energy consumption optimization has become a great societal challenge. At the Institut Clément Ader laboratory we propose an innovative methodology to study non-equilibrium gas flows at the micro scale by performing local measurements by means of the molecular tagging technique. This technique has been developed in-situ in order to be able to visualize for the first time complex phenomena such as velocity slip and temperature jump at the wall. The PhD candidate will have to develop further this technique in order to adapt it for general case configurations of velocity mapping in gas flows.

Short subject description

In fluidic microsystems, shrinking down the dimensions leads to an increase of the Knudsen number Kn defined as the ratio of the mean free path of the molecules over a characteristic length of the microsystem. In classic microsystems, Kn is frequently between 0.001 and 0.1, which is the range of the instauration of well-known thermodynamic non-equilibrium phenomena, such as viscous and thermal slip flows. In this moderate rarefied regime, velocity slip and temperature jump at the wall strongly influence mass transport and heat transfer.

Although the theory of gas hydrodynamics in the slip flow regime is now supported by smart experiments, most of these data are only related to indirect measurements. The experimental analysis of the velocity and the temperature distributions even in simple geometric configurations remains an issue.

The objective of the project is to implement a non-intrusive technique, the Micro Molecular Tagging Technique (μ MT technique) where velocity profiles can be observed by tracking phosphorescent molecules in gas microflows. The recruited researcher will have to use the experimental setup which is already in situ, to analyze the potentials of the μ MT technique applied to reference gas microflows in thermodynamic disequilibrium, such as viscous slip and thermally induced flows. The final objective would be to visually characterize the origin of the thermodynamic disequilibrium which is greatly influenced by the gas/surface interactions.

Keywords

Microsystems, Microfluidics, Rarefied Gas, Experimental Analysis, Molecular Tagging

Technical information

This project will take place at INSA Toulouse (<u>www.insa-toulouse.fr</u>), a French engineering school, at the Clément Ader Institute (ICA, <u>www.institut-clement-ader.org</u>) and will be co-supervised by Dr. Marcos ROJAS-CARDENAS, Prof. Stéphane COLIN (Microfluidics research team of ICA www.microfluidique.com).

Contacts

stephane.colin@insa-toulouse.fr marcos.rojas@insa-toulouse.fr

Requirements

- a Master-level degree in engineering, mechanical engineering or physics
- written and verbal knowledge of the English language
- a good background in fluid mechanics and/or heat transfer
- some experience in experimental techniques or knowledge on lasers would be a benefit.

Subject detailed description

Gas flows in microsystems find nowadays more and more industrials applications in numerous fields such as aerospace engineering, vacuum systems or MEMS. In such fluidic microsystems, shrinking down the dimensions leads to an increase of the Knudsen number, $Kn = \lambda/Lc$, ratio of the mean free path of the molecules λ over a characteristic length Lc of the microsystem. The Knudsen number encountered in classic microsystems is frequently between 10⁻³ and 10⁻¹, which is the typical range of the well-known slip flow regime [1]. In this moderate rarefied regime, the classical continuum physics is no longer valid but it is well established that the standard Navier-Stokes and energy equations can be used if accompanied by the appropriate velocity-slip and temperature-jump boundary conditions.

In the past ten years, a number of theoretical and numerical studies, taking into account rarefaction effects, have been aimed at modeling gas flow and heat transfer, but there is still a crucial lack of experimental data in this field. Even if the theory of gas hydrodynamics in the slip flow regime is now supported by smart experiments [2-4], most of these data are only related to indirect measurements. The experimental analysis of the velocity distributions even in simple geometrical configurations remains an issue since conventional visualization techniques struggle to achieve the task due to the small size scale involved.

At small scale, measurements of mass transport both induced by pressure gradients or temperature gradients have been performed most commonly by means of the constant volume technique [3-5]. Low-intrusive velocimetry techniques have already been applied at microscale for liquid flows, but almost none have been used for confined gas flows. Providing accurate experimental data on velocity and temperature distributions in gas microflows is a challenge for the coming years [6], which would allow a real discussion on the validity of various velocity slip and temperature jump boundary conditions, as well as on the limits of applicability of slip flow theory, in terms of degree of rarefaction. It is then necessary to develop techniques to be able to measure both kinematic and thermodynamic parameters at small scales and to design original fluidic microsystems involving gas flow and heat transfer.

The objective of the project is to improve the current experimental setup to be found in ICA laboratories which is based on the molecular tagging technique (MT technique) for velocity measurements in mini- and microsystems. In our research group, this technique has been successfully applied to millimetric confined gas flows in hydrodynamic regimes [7-10]. The principle is based on a luminescence phenomenon [11]: the flow is seeded with fluorescent and phosphorescent molecules which re-emit light once they have been previously excited by a laser beam. A comparison between the initial tagged line and the distorted line allows determining the displacement of the molecules in space and thus reconstruct a velocity profile. The setup is shown in Figure 1 and an example of velocity profile extraction is illustrated in Figure 2.

Further on, the microfluidics research group of the Institut Clément Ader (ICA) at INSA Toulouse has an internationally recognized experience in experimental analysis of gas microflows [2, 3, 12] and its well known for original experimental setups designs and for providing accurate data on the hydrodynamics of gas microflows (Figure 3).

Inlet chamber



Figure 1. µ-MTV experimental setup for velocity measurements [19]



Figure 2. Velocity measurement by molecular tagging and signal processing [22]



Figure 3. Example of experimental setup for the measurement of gas flows in microchannels developed at ICA-INSA Toulouse. Comparison of the experimental data with different models

The PhD project will be co-supervised by Prof. Stéphane Colin, Dr. Marcos Rojas-Cardenas and Stéphane Colin is the editor and author of several textbooks in microfluidics [13, 14]. Marcos Rojas-Cardenas is best known for his work in non-equilibrium gas flows specifically on the thermal transpiration flow. The candidate will benefit from the experience gained within the GASMEMS European Network, coordinated by Stéphane Colin (see details at http://www.gasmems.eu), and the ongoing MIGRATE European Network (http://www.migrate2015.eu), coordinated in collaboration with the Microfluidics team of ICA. This Initial Training Network offered training to young researchers in the field of rarefied Gas Flows in Micro Electro Mechanical Systems and Miniatuized Gas Flow for Applications with enhanced Thermal Effects. In the framework of the proposed project, an international collaboration is foreseen with the following universities from the MIGRATE Network: the University of Limerick-Ireland (Dr. Newport) for complementary experimental approaches (μ - interferometry), the University of Bologna-Italy (Pr. Morini) for the expertise in the development of heat transfer models at microscale, the University of Karlsruhe-Germany (Pr. Brandner) for the fabrication of the experimental micro-devices including pressure and temperature sensors and the Polytechnic University of Milano-Italy (Pr. Frezzotti) for molecular simulation by the Direct Monte Carlo Simulation method. Our research team has already active collaborations with joint publications with these research groups.

Previsional work plan



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