PhD Open Position

Molecular Tagging Thermometry for near wall measurements of gas flow in rarefied regime

Main goal

Implementation of a molecular tagging technique for the measurement of temperature fields in gas microflows. An innovative experimental setup will be developed, coupling infrared thermography and molecular tagging thermometry. It will be validated on benchmark cases and used for analyzing more complex non-isothermal gas flows.

Duration: 3 years

Location: Institut Clément Ader, Toulouse, France

Starting date: 1-Oct-2019

Application deadline: 10-May-2019

Context and Objectives

Understanding the phenomena involved in gas microflows is of crucial interest for the development of new and innovative fluidic microsystems. Gas flows in such systems find nowadays more and more industrial applications in numerous fields such as environment, electronics, aerospace engineering…

In such microsystems, the shrinkage of the dimensions possibly coupled with a decrease of pressure leads to an increase of the rarefaction. Its effect is characterized by the apparition of thermodynamic disequilibria near the walls provoking non-linear phenomena leading to velocity and temperature discontinuities. The rarefaction level is characterized by the Knudsen number which varies in most of microsystems between 10^{-3} and 10^{-1}, range of the so-called "slip-flow" regime.

To describe gas flows in this moderate rarefied regime, the standard Navier-Stokes and Fourier equations are still valid if they are a coupled to velocity-slip and temperature-jump boundary conditions to take into account the presence of the Knudsen layer, a thin layer near the wall in which the gas is in a thermodynamic disequilibrium state.

In the past ten years, huge progress has been made on theoretical and numerical studies modeling rarefied gas flows and taking into account rarefaction effects, but there is still a crucial lack of experimental data in this field to be able to discuss the limits of validity of the developed models. Even if the theory of gas hydrodynamics in the slip-flow regime is now supported by smart experiments, most of these data are only related to flowrate measurements. Data on temperature distribution do not currently exist. It is thus necessary to develop techniques able to measure fluid temperatures at small scales to accurately design original fluidic microsystems involving gas flow and heat transfer.

Molecular tagging technique seems to be a good candidate for such measurements. Its principle is based on the luminescence phenomenon: a gas is seeded with tracer molecules which emit fluorescent or phosphorescent light when they are activated by photons. For temperature measurements, the phosphorescence lifetime and intensity dependence on the temperature will be exploited. As far as we know, Molecular Tagging Thermometry (MTT) has only been used once to measure temperature within a channel of millimetric dimensions, but it was in a liquid flow.

A first design of the experimental setup dedicated to MTT has been build and has permitted to obtain preliminary results on the dependency of the phosphorescence to gas temperature, showing that this technique could be used for temperature measurements in rarefied gas flows.

The objective of this work is to develop an experimental setup able to simultaneously measure the wall temperature by Infra-Red Thermography (IRT) and the near-wall fluid temperature by MTT, illuminating only a slice of molecules near the wall by evanescent waves. The final goal is to experimentally determine the temperature jump when rarefied conditions are reached for an in-depth analysis of the domain of validity of the various temperature-jump models.

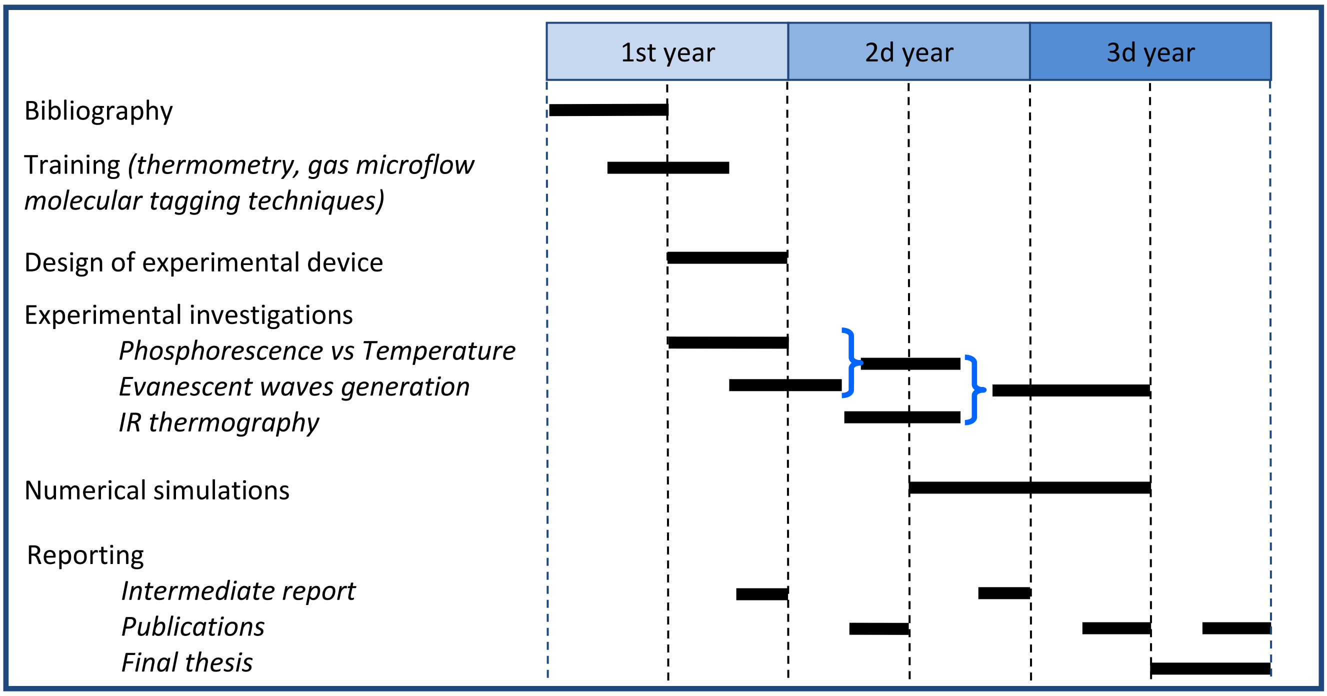
Methodology - Material

An experimental setup devoted to Molecular Tagging has been developed at Institut Clément Ader (ICA) for velocity measurement (MTV) and is being adapted for two years for thermometry. The UV light is generated by a laser and images are recorded with a camera coupled to an intensifier. This setup, associated with specific signal processing methods taking into account diffusion effects to reconstruct velocity profiles [1-3] allowed original works concerning the measurement of velocity in gaseous flows [4, 5]. The first slip-velocity measurements by MTV have been obtained a few months ago (PhD Thesis – Fratantonio). This setup has been adapted from MTV toward MTT purposes and has led to preliminary results.

The planed steps for this project will consist in:

1- Improving the implementation of MTT for gases at microscale. New developments with improved accuracy should be proposed in order to complete and reinforced the conclusions given by preliminary results;
2- Designing a test cell for the implementation of evanescent waves and make temperature measurements in the illuminated layer;
3- Studying the influence of the experimental parameters on the phosphorescent signal (acquisition parameters, gas conditions parameters such as pressure and temperature, tracer concentration, and thickness of the illuminated zone),
4- Designing the experimental setup (cellule and optical path) allowing simultaneous measurements of temperature by IRT and MTT,
5- Comparing the experimental data to results obtained with other techniques,
6- Developing numerical models of the experiments, based on the Direct Monte Carlo Simulation (DSMC) technique, in order to have a better understanding of the dependency of the luminescent signal on various flow parameters (temperature, pressure…),
7- Proposing an experimental methodology for the implementation of MTT technique in gas microflows and proposing an analysis of the obtained experimental data. Discussing on the validity of assumptions used in analytical models and numerical simulations of gas flows in the slip-flow regime.

Expected time schedule



Collaborations

This project will take place at ICA (Institut Clément Ader www.institut-clement-ader.org), in Toulouse, France. The microfluidics research group of ICA (http://microfluidique.com/) has an internationally recognized experience in experimental analysis of gas microflows [2, 3, 14]. It has already designed original experimental setups and provided accurate data on the hydrodynamics of gas microflows [3].

The PhD project will be co-supervised by Prof. Stéphane Colin (http://institut-clement-ader.org/author/scolin/) and Dr. Christine Barrot (http://institut-clement-ader.org/author/cbarrot/).

The candidate will benefit from the experience gained within the European Networks GASMEMS and MIGRATE (details can be found at http://microfluidique.com/european-projects/gasmems/ and http://www.migrate2015.eu). The proposed project will be conducted in the framework of already active international collaborations with the following Universities: the University of Limerick-Ireland for complementary experimental approaches (µ-interferometry), the University of Bologna-Italy for the development of heat transfer models at microscale, the Karlsruhe Institute of Technology-Germany for the fabrication of experimental micro-devices including pressure and temperature sensors and Politecnico Milano-Italy for molecular simulation by the Direct Monte Carlo Simulation method.

Requirements

- Master-level degree in Mechanical Engineering, Process Engineering, Physics or similar,
- Excellent communication skills and good written/verbal knowledge of the English language, good presentation skills,
- A good background in fluid mechanics and/or heat transfer,
- Experience in experimental techniques and/or knowledge on lasers would be a benefit.

Application procedure

Application procedure is detailed on Doctoral School web site: **http://www.ed-megep.fr/**

Applications for this position have to include a detailed Curriculum Vitae, a covering letter, attestation of the diploma / master degree and last transcript of records.

Financial information / Salary

Annual gross salary including employer's contribution to social security: 1758 €/month (~1400€ net charge)

Contacts

For futher information please contact either Prof. Stephane Colin – stephane.colin@insa-toulouse.fr or Dr. Christine Barrot - christine.barrot@iut-tlse3.fr

References

1. Frezzotti, A., et al., *Role of diffusion on molecular tagging velocimetry technique for rarefied gas flow analysis.* Microfluidics and Nanofluidics, 2015. **19**(6): p. 1335-1348.
2. Si Hadj Mohand, H., et al., *Molecular tagging velocimetry by direct phosphorescence in gas microflows: Correction of Taylor dispersion.* Experimental Thermal and Fluid Science, 2017. **83**: p. 177-190.
3. Fratantonio, D., et al., *Molecular tagging velocimetry for confined rarefied gas flows: Phosphorescence emission measurements at low pressure.* Experimental Thermal and Fluid Science, 2018. **99**: p. 510-524.
4. Samouda, F., *Développement de la technique de vélocimétrie par marquage moléculaire pour l'étude expérimentale des micro-écoulements gazeux*, 2012.
5. Si Hadj Mohand, H., *Micro-vélocimétrie par marquage moléculaire adaptée aux écoulements gazeux confinés*, 2015, INSA de Toulouse.