MIGRATE Summer School - June 27 - 28, 2016
University of Strasbourg

DAY 1 - June 27th, 2016		
9:00	**Introduction to the 1st MIGRATE Summer School**	
	Industrial and Application aspects: I&A Session	
9:30	Lessons learned from failures in research **Dr. N. Jeffers and Dr. J. Stafford (BELL)**	
10:30	**Coffee break**	
10:45	Vacuum applications in macro- and micro-world: Focus on vacuum pumps **Dr. S. Varoutis (Karlsruhe Institute of Technology)**	
	Theory & Design Session T&D Basic Courses	**Experiments & Microfabrication Session** E&M Basic Courses
11:45	Particularities of the gas flow simulations in MEMS devices: review of main approaches **Prof. I. Graur (Aix Marseille University)**	Manufacturing of Microstructure Devices from Metal, Ceramics and Polymers **Dr. J.J. Brandner (Karlsruhe Institute of Tech.)**
13:15	**Lunch**	
	T&D – Basic Courses	E&M Basic Courses
14:30	Heat and mass transfer within gas flows in the slip flow regime **Prof. S. Colin (INSA Toulouse)**	Introduction to Microfluidics - Scaling and micro effects for convective flows **Prof. G.L. Morini (University of Bologna)**
15:30	**Plenary Session – Theory & Design** The Good, the Bad, and the Ugly: the challenges of simulating micro gas flows for technological design **Prof. Jason Reese (University of Edinburgh)**	
17:00	**Coffee break**	
	T&D Basic Courses	**E&M Basic Courses**
17:15 18:45	Introduction to the Direct Simulation Monte Carlo (DSMC) method **Prof. S. Stefanov (Institute of Mechanics, Bulgarian Academy of Sciences)**	Overview of rarified gas experiments (Pressure gradient, Temperature gradient) **Dr. P. Perrier (Aix Marseille University)** Measurement of accommodation coefficients **Dr. M. Rojas (INSA Toulouse)**

DAY 2 - June 28th, 2016		
	T&D Advanced Courses	**E&M Advanced Courses**
8:45	Kinetic theory and modelling in gaseous transport phenomena **Prof. D. Valougeorgis (University of Thessaly)** Introduction in Molecular Dynamics (MD) **Dr. A. Frijns (Technische Universiteit Eindhoven)**	Techniques for temperature measurements **Dr. D. Newport (University of Limerick)** **Dr. C. Barrot (University of Toulouse)**
10:15	**Coffee break**	
10:30	**Plenary Session – Experiments & Microfabrication** Micro structure technology **Dr. Uwe Köhler (Karlsruhe Institute of Technology)**	
12:00	**Lunch**	
	Complementary skills session	
14:00	Working in a multicultural environment: build on diversity **N. Clery (Clery Consulting)**	
16:00	**Coffee break**	
16:15 17:45	Conflict management: how to get unstuck **N. Clery (Clery Consulting)**	

Course Contents

Lessons learned from failures in research

Dr. N. Jeffers and Dr. J. Stafford (BELL)

In this workshop I will explore how research projects fail and what we can learn from that. I'll explain one case study in detail and the problems that we had. Ultimately the lessons learned from this project can be extracted and applied to most of our projects, thus avoiding the same failures and hopefully increasing the chances of success.

Vacuum applications in macro- and micro-world: Focus on vacuum pumps

Dr. S. Varoutis (Karlsruhe Institute of Technology)

The calculation of flows over a wide range of the Knudsen number has seen significant progress in the last decade, much triggered by R&D performed in support of microsystem design and by the increase of computational power. It is known that the deviation from the continuum hypothesis and thermodynamic equilibrium and the dominance of surface and wall effects, which appear in microflows, result in fluid mechanics, which is largely different from the conventional understanding of flows. However, there are macroscopic systems, which work in similar conditions, namely the vacuum systems.

The function of a vacuum system is to withdraw amount of gas from a designated volume so that the pressure is lowered to a value suitable for the purpose in hand. Additionally, the flow in such systems may cover all flow regimes from viscous to free molecular. Typical example of a vacuum system is a vacuum pump. Modern methods of non-equilibrium flow simulation have been used for the design and predictive modeling of a number of vacuum pump types (turbomolecular, drag, scroll, Knudsen, Holweck). The wide range of modern pumps in the macro and micro world may be broadly divided by their working principle. In general, the following three types of pumps can be presented, namely those which involve displacing gas by repetitive mechanical actions, those which induce directed molecular motion in the gas by its interaction with fluid stream or solid surface, and those that capture molecules at surfaces by cryogenic condensation and other surface processes.

The aim of this talk is twofold. The first part will be devoted to the presentation of the types of pumps that are available in the micro and macro world as well as the corresponding operation principles and limitations. Illustrative examples of vacuum systems met in a wide range of scientific applications, as for instance the vacuum system of the nuclear fusion reactor ITER, will be presented. The second part of this talk is mainly focused on the common theoretical basis and the corresponding stochastic and deterministic numerical tools, which may be applied in both micro and macro vacuum applications.

Particularities of the gas flow simulations in MEMS devices: review of main approaches

Prof. I. Graur (Aix Marseille University)

The lecture presents the main properties of the gas flows in MEMS devices showing their difference from the conventional devices. The review of the main approaches for modeling and simulations of gas flows at microscale is presented. Three methods are reviewed: the continuum approach usually based on the Navier-Stokes (NS) equation with the special type of the boundary conditions; the kinetic approach based on the kinetic theory of gases, involving deterministic (Boltzmann equation and its kinetic models) and statistical (the DSMC) methods and the molecular dynamic (MD) approach. For all approaches the main advantages and disadvantages are presented along with the range of most appropriate physical parameters for each method.

Manufacturing of Microstructure Devices from Metal, Ceramics and Polymers

Dr. J.J. Brandner (Karlsruhe Institute of Technology)

The lecture provides fundamental information on the background and the reasons for miniaturization. An overview on manufacturing techniques for miniaturized structures in metal, ceramics and polymers is given, including some remarks to assembly of devices made from those material classes. Some problems will also be highlighted. The lecture is, by no means, comprehensive, but will provide an introduction to the topic to stipulate further interest.

Heat and mass transfer within gas flows in the slip flow regime

Prof. S. Colin (INSA Toulouse)

Gas microflows must be accurately controlled for a lot of microsystem applications (micro-heat exchangers, pressure gauges, fluidic micro-actuators for active control of aerodynamic flows, mass flow and temperature micro-sensors, micropumps and microsystems for mixing or separation for local gas analysis, mass spectrometers, vacuum and dosing valves…). The main particularity of gas microflows is a local thermodynamic disequilibrium which appears first at the walls, in the so-called Knudsen layer. It is a consequence of rarefaction resulting from an increase of the Knudsen number, which represents the ratio of the mean free path over a characteristics length of the fluidic microsystem. Most of the above listed microsystems are partly or totally operating in the so-called slip-flow regime. In this slightly rarefied regime, the Navier-Stokes-Fourier equations are still valid, provided they are supplemented with appropriate boundary conditions that correctly describe the velocity slip and temperature jump observed in the Knudsen layer close to the walls.

These boundary conditions are physically explained and discussed, with a focus on the viscous slip, thermal slip and temperature jump coefficients. The consequence of the associated effects are illustrated by various applications. The main steps for a correct implementation of these boundary conditions to extend the classic no-slip analytical solutions for mass flow rate and convective heat transfer in microchannels are detailed.

Introduction to Microfluidics - Scaling and micro effects for convective flows

Prof. G.L. Morini (University of Bologna)

In this lecture an introduction to the scaling analysis of microsystems is presented. A definition of scaling and micro-effects is given by means of a series of practical examples. The main scaling effects which play a role in micro-convection are discussed by comparing experimental and theoretical data.

The Good, the Bad, and the Ugly: the challenges of simulating micro gas flows for technological design

Prof. Jason Reese (University of Edinburgh)

Micro- and nano-scale gas flows are technologically important, but computational fluid dynamics struggles to capture the local thermodynamic non-equilibrium that makes the behaviour of these rarefied flows uniquely complex. In this talk I will outline our recent work on developing and exploring new fluid dynamic models that balance improved accuracy with computational efficiency. I will focus on two quintessentially non-equilibrium phenomena that are critical to the overall flow system performance: gas velocity slip at solid surfaces, and the associated Knudsen layer extending from the surface into the flow. I will describe the successes and failures of various hydrodynamic and computational molecular models in capturing the non-equilibrium flow physics, and show results from applications that include the aerodynamic drag on micro spheres and the performance of a micro gas pump with no moving parts.

Introduction to the Direct Simulation Monte Carlo (DSMC) method

Prof. S. Stefanov (Institute of Mechanics, Bulgarian Academy of Sciences)

The lecture includes: a short description of the physical principles of the DSMC method and some historical remarks; description of the basic elements of the particle method such as time and space discretization, scheme of splitting of the simulation process into two steps –collisions and free motion of the simulated particles, different collision schemes; choice of boundary conditions, sampling of macroscopic quantities etc. Finally, several application to typical gas microflows will be presented.

Overview of rarified gas experiments (Pressure gradient, Temperature gradient)

Dr. P. Perrier (Aix Marseille University)

We present different types of experiments designed to extract gas interaction coefficient wall. We quickly present the issue and after we will describe the different experiences that have been developed for measuring the interaction gas/wall. Each of these experiments have key point which will be discussed. Often these key points are the sensitivity of the types of measures or the nature of the measure.

Measurement of accommodation coefficients

Dr. M. Rojas (INSA Toulouse)

An interesting characteristic of gas flows in micro-systems is related to the fact that gas can be often considered to be in a state of slight or even strong rarefaction, which means a gas having its molecular mean free path (λ) of the same order of dimensions of the characteristic length (L_c) of the system itself. The mean free path is the average distance traveled by a molecule before colliding against another molecule and it is inversely proportional to the gas pressure and directly proportional to temperature, for example the gas mean free path of air at ambient pressure and temperature is around 70nm. Thus, if the gas is rarefied, local thermodynamic disequilibrium may appear in the fluid flow and this may generate phenomena such as slip at the wall, temperature jump at the wall or thermal transpiration. Gas/surface interaction at the solid boundaries of the system plays a fundamental role in respect to these non-equilibrium phenomena and more specifically in respect to the quantitative values obtained of viscous and thermal velocity slip at the wall and temperature jump at the wall. Due to the practical impossibility of considering each molecule/surface interaction, it is of great interest to study statistical coefficients that can give us information about the global momentum and energy exchange between gas molecules and surface. These so-named accommodation coefficients can vary as a function of the gas molecule and the solid surface material and roughness. In this talk we will treat the experimental measurement of these coefficients which is often achieved by indirect measurement methodologies.

Kinetic theory and modelling in gaseous transport phenomena

Prof. D. Valougeorgis (University of Thessaly)

The seminar covers the basic concepts of kinetic theory, a description of the main approaches for modeling and simulations and the solution of benchmark problems in micro gas flows and heat transfer. Following the definition of the average macroscopic properties in terms of the mesoscale distribution function the classical derivation of the Boltzmann and kinetic model equations is presented. Then, the main deterministic numerical methods for solving kinetic equations are discussed focusing on the discrete velocity method. Finally, the applicability of the kinetic methodology is demonstrated by solving some benchmark problems in gas micro flows and heat transfer.

Techniques for temperature measurements

Dr. D. Newport (University of Limerick) & Dr. C. Barrot (INSA Toulouse)

Various thermometry techniques for measurements of bulk fluid or temperature fields will be presented focusing on microflows applications. The general principle of measure of each technique and the instrumentation requested for their use at microscale will be described including issues of measurements such as accuracy, thermal disturbance or calibration. The remaining challenges for their applicability to gas microflows will be discussed.

<u>Outline</u>

1. Introduction
    1. What is temperature?
    2. Why/ Importance of measuring temperature in micro-flows.
    3. The classification : invasive/semi-invasive/non-invasive
2. Invasive methods : common ways to measure temperature / limitations
    1. Thermal expansion
        1. Gas thermometry
        2. Liquid in glass
        3. Solid expansion
    2. Thermoelectric devices : thermocouple
    3. Electrical resistance (RTD)
3. Semi-invasive methods
    1. Liquid crystal thermometry
    2. Heat sensitive paints
4. Non-invasive methods
    1. Laser interferometry
    2. Raman thermometry
    3. Optical fiber thermometry
    4. Infrared Red
    5. Laser Induced Fluorescence thermometry (LIF)
    6. MTT
5. References

Introduction in Molecular Dynamics (MD)

Dr. A. Frijns (Technische Universiteit Eindhoven)

In Molecular Dynamics (MD) the trajectories of each individual molecule are computed. These are based on the attracting and repulsing intermolecular forces and external force fields. Because the movements of each individual molecule is computed, MD can also be applied for rarefied and non-equilibrium gas flows.

Content:

- Introduction in molecular dynamics
- Interaction potentials, intermolecular forces & internal energy
- From molecular properties to macroscopic properties
- Heat and mass transfer under rarefied conditions

Micro structure technology

Dr. Uwe Köhler (Karlsruhe Institute of Technology)

This course will provide an overview of the basic technologies to fabricate silicon microstructures and MEMS. It will give an introduction into the principles of photolithography and the main applications using different set ups and wavelength, the deposition of metallic and nonmetallic thin films by physical and chemical processes and an overview of structuring thin films with wet and dry etching.

Working in a multicultural environment: build on diversity

N. Clery (Clery Consulting)

Each of us, born and raised in a cultural environment, have assimilated our own culture without consciously understanding it. Either living abroad or interacting with people from different cultures, we are faced with significant misunderstanding and potential conflicts.

Going through a structured characterization of our own culture and the culture of others will help us establish a good communication and build on the wealth of diverse cultures.

Conflict management: how to get unstuck

N. Clery (Clery Consulting)

Even if we have overcome the cultural differences, we still experience conflicts at time with people from our own culture.

After a short characterization of the key elements of a conflict, we will explore the various building blocks of the dialogue model which will enable you and the other party to develop a constructive and creative solution. As part of the session, you will also discover your style under stress.