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# MICRO MOLECULAR TAGGING THERMOMETRY

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## KEY WORDS

Rarefied gas flow, molecular tagging, thermometry, internal flows, DSMC

## EXTENDED ABSTRACT

Miniaturization of macro devices and processes has seen an exponential growth in the past decades. This has led to flourishing of the new and exciting field of microfluidics [1]. The advances in the fabrication techniques of microdevices, especially aided by the silicon revolution of electronics, has been the prime mover towards this shift. Today, worldwide, extensive research is being carried out to study the behavior of gases at microscale [2]. In such dimensions, the Knudsen number, ratio of the mean free path over the characteristic length, is between $10^{-3}$ and $10^{-1}$, typical range of the well-known slip-flow regime. The flow behavior of gases, in this moderate rarefied regime, remains a challenging and interesting field of study [3] because of the onset of a local thermodynamic disequilibrium [2-5].

The primary challenge stems from the fact that there is a need to rethink the validity of continuum assumption of fluids in this regime due to a velocity slip and temperature jump at the wall which strongly influence heat transfer.

Due to the practical difficulties encountered in experimental study of gas flows, the initial emphasis of researchers was on theoretical and numerical understanding of the gas flow behavior in microchannels. Therefore, there is a significant amount of theoretical data on gas microflows. However, the validity of the theoretical expressions of slip boundary conditions can only be justified if they are in close agreement with the experimental data. Today, there is a clear shift of research emphasis towards experimental understanding of the gas flow behavior at microscale.

Recent experiments have focused on measuring the velocity and pressure fields of gases in microchannels [6, 7]. However, the distribution of temperature in the microchannels, even for simple geometrical configurations, still remains a challenging task, the primary roadblock being the very small dimensions involved. Our research group has gained significant expertise in the field of micro molecular tagging velocimetry (µMTV). The next goal is to come up with a novel experimental setup utilizing the non-intrusive optical method, i.e. molecular tagging, to measure temperature distribution of internal gas flows in the slip flow regime. The focus is not only to get an idea about the global temperature distribution, but also to measure the local distribution. Therefore, the goal of this study would be to have a fair understanding of the applicability, benefits, and limitations of the technique.

The micro molecular tagging velocimetry (µMTV) experimental set up developed at the Institut Clément Ader (ICA) will be employed in this study. A detailed description about the µMTV experimental set-

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up is presented in the work of Samouda et al. [6]. This experimental set-up essentially consists of two main parts: (1) a gas circuit and (2) µMTV elements. The first part, i.e. the gas circuit, is for flow seeding and control of operating conditions. The important components in this circuit are the vacuum pump to control the downstream pressure in the channel, the pressurized cylinder for argon gas, the bubbling chamber for seeding with acetone tracer molecules, the capacitive pressure gauges for pressure measurement. Extensive experimental investigation on this set-up has been carried out by adopting argon as the carrier gas and acetone as the tracer molecules. The second part, i.e. the µMTV elements, is for molecules tagging, signal detecting, data acquisition and processing. The molecules are tagged by a Quantel Twins Brilliant laser. The laser beam is guided at the intended location on the channel by a laser guiding arm. The diameter of the laser beam is modified by employing an optical focusing system. A progressive La Vision imager intense CCD camera coupled to an IRO (Intensified Relay Optics) is employed to capture the phosphorescence of the tagged molecules. The IRO delay, gain and gate are controlled by a IRO controller. A computer equipped with the data acquisition and processing software treats the recorded images. A PTU (programmable timing unit) synchronizes the entire system.

The initial challenge of the micro molecular tagging thermometry (µMTT) study would be to explore options in order to try and modify the experimental set-up of µMTV to measure temperature. It would also be necessary to consider the challenges associated with the design of the existing experimental chamber, i.e. maintaining it an intended controlled temperature (constant or varying, uniform or with a gradient). At the onset, few experiments would be done on simple isothermal configurations. Numerical analysis, especially using Direct Simulation Monte-Carlo (DSMC) methods, would be carried out on the experimental configurations to understand the role and effect of diffusion of gas molecules for improving the accuracy of the measurements, as well as a correct data processing. Thereafter, a detailed experimentation campaign would be carried out to understand the luminescent properties of tracers gases. The experimental set up would also be tested for more complex configurations. The relevance of this work in an industrial context is also to be studied by having close collaboration with Alcatel Lucent Bell labs. Once a fair understanding of the technique is achieved, further experiments would be carried out to have a deep insight into the limits of µMTT, especially in terms of spatial resolution, pressure and temperature ranges of applicability, types of tracer gas molecules to be employed, etc.

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