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PRELIMINARY INVESTIGATION ON TEMPERATURE DEPENDENCY OF ACETONE VAPOR LUMINESCENCE FOR MOLECULAR TAGGING THERMOMETRY

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KEY WORDS

Molecular tagging thermometry, gas microflows, phosphorescence, OPO laser

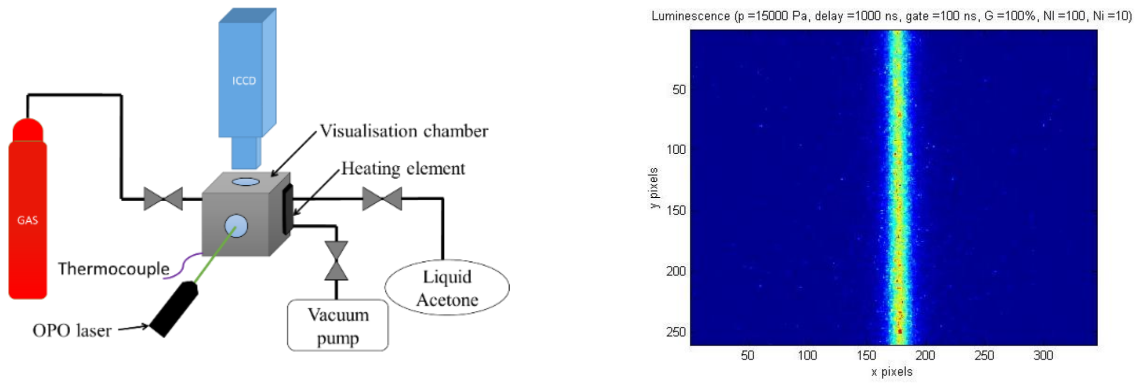
ABSTRACT

The past couple of decades has seen significant research progress in the field of microfluidics [1]. The behavior of gases at microscale has always received special attention from researchers. Microdevices with gas flows often have a Knudsen number, defined as the ratio of the mean free path over the characteristic length, between 10^{-3} and 10^{-1}. This corresponds to the typical range of the well-known slip-flow regime. Studying gas flows in this moderate rarefied regime remains a challenging and interesting field of study because of the onset of a local thermodynamic disequilibrium. The other challenges encountered in this domain have been well documented by various researchers [2-5]. One of the major challenge is the crucial lack of experimental data on velocity and temperature distribution to fully justify the results of theoretical studies on gas microflows [3-5].

In this regard, molecular tagging technique may provide a possible solution to the measurement of temperature in gas microflows. In the literature, there have been studies in which acetone and biacetyl have been adopted as tracers in gas flows to measure temperature [7,8]. However, most of these studies are carried out at atmospheric or above atmospheric pressures in macro gas flows. To study the behavior of gas microflows at moderate Knudsen numbers, either the characteristic dimensions have to be reduced or the system must operate at pressures considerably lower than the atmospheric pressure. Therefore, there is a necessity to study the temperature dependent behavior of the above tracer molecules at pressures which are significantly lower than atmospheric pressure. This study would enable to discuss the feasibility of using these tracers for micro molecular tagging thermometry (µMTT) in rarefied gas flows. Towards this goal, in this study, a preliminary experimental investigation has been carried out to study the temperature dependency of acetone vapor luminescence at low pressures.

The micro molecular tagging velocimetry (µMTV) set-up developed at Institut Clement Ader (ICA) was adapted to carry out the experimental study. A detailed description of the µMTV experimental set-up is presented in the work of Samouda et al. [6]. Some modifications of this experimental setup have been done in order to adapt it to temperature measurements. Figure 1a shows the schematic of the µMTT setup. This experimental set-up essentially consists of two main parts: (1) a gas circuit and (2) µMTT elements. The first part, i.e. the gas circuit, is for flow seeding and control of operating conditions. The second part, is for heating, monitoring temperature, molecular tagging, signal detection, data acquisition and processing. An Opolette 355 tunable laser system based on optical

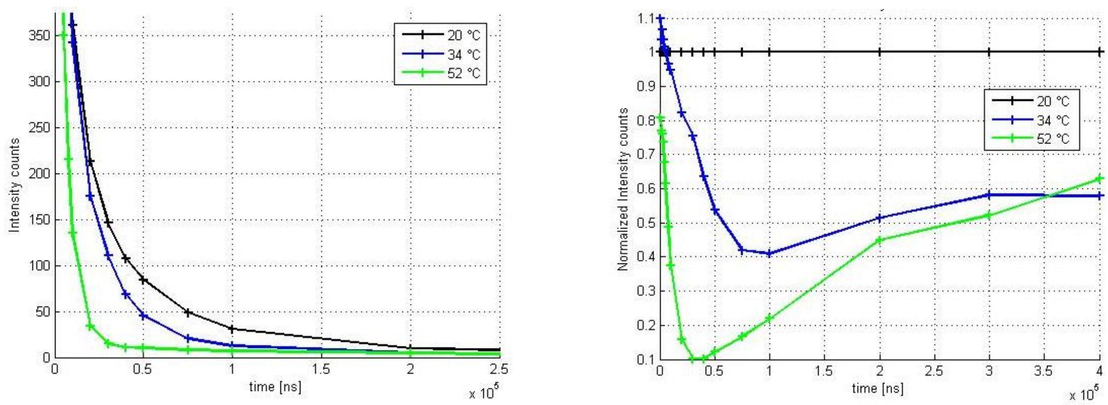
parametric oscillator (OPO) technology is employed. This laser is capable of generating wavelengths over a broad range in the ultraviolet, visible and near infrared.



(a) (b)

Figure 1: (a) Schematic of the experimental set-up, (b) Typical experimental image

The visualization chamber is made up of anodized aluminum. It has two optical accesses, one for the laser beam and the other for the camera to capture phosphorescence of the tracer. Two heating elements were used to heat the experimental chamber. Four thermocouples were located at different locations on the chamber to monitor the temperature. At steady state, the temperature distribution of the chamber was almost uniform (with a maximum difference of 1.5 K among the thermocouples). Regular monitoring of the temperature distribution and pressure variation was carried out during the course of experimentation. Experiments were carried out with acetone as the tracer excited with a wavelength of 310 nm. Figure 1b shows a typical image obtained in our experiments. For a fixed pressure and temperature, the intensity (and width, due to diffusion) of the luminescence varies as a function of delay time. These experimental images are post-processed with a MATLAB code. The Figure 2a shows the intensity dependency of acetone at $P = 15{,}000$ Pa for various temperatures. Figure 2b shows the data normalized with respect to the signal at 20 °C. These two images clearly indicate that there exists a significant difference in intensity at different temperatures. Similar experiments were carried out for different conditions of pressure (from 15,000 Pa to 1,000 Pa) and different temperatures of the chamber (20 °C, 34 °C, 50 °C). A few experiments were also carried out to study the temperature behavior of acetone-helium mixture and pure biacetyl.



(a) (b)

Figure 2: (a) Intensity dependency of acetone at $P = 15{,}000$ Pa for varying temperature at a 310 nm wavelength excitation, (b) data normalized with the intensity values at 20 °C

This preliminary study demonstrates the strong temperature dependence of acetone phosphorescence in a wide pressure range, and paves the way for further research to investigate the relationship between intensity, lifetime of acetone, biacetyl, and acetone–helium mixtures with temperature. At a later stage, this study would enable us to map the temperature profiles in gas microflows and measure temperature jump at the walls in the slip flow regime.

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