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ACETONE LUMINESCENCE AT LOW PRESSURE FOR MOLECULAR TAGGING VELOCIMETRY IN CONFINED RAREFIED GAS FLOWS

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ABSTRACT

In the last decades the rapidly growing technological advances in micro-fabrication processes has allowed the scientific community to considerably develop the state of the art on miniaturized electromechanical systems. In particular, some research fields are specifically oriented towards the investigation of gas flows in micro-electro mechanical systems.

In confined gas flows, shrinking down the size of a device can produce evident changes in the macroscopic physical behavior of the fluidic system itself. By reducing the scale of the device a local thermodynamic non-equilibrium is engendered by the decrease of the number of gas inter-molecular collisions with respect to wall-molecule collisions. The thermodynamic disequilibrium can be quantified by means of the achieved level of rarefaction. The rarefaction inside a micro-device can be measured by the Knudsen number Kn, which is defined as the ratio of the mean free path λ of the gas molecules and the characteristic length L of the system. If the Knudsen number is high enough, the rarefaction effect produces phenomena such as viscous and thermal slip velocity at the wall [1,2]. Both are well-known phenomena and the latter is of great practical interest since thermal slip at the wall -also called thermal transpiration or thermal creep [2]- is at the basis of thermally driven gas flows such as those encountered in Knudsen pumps.

Up to now, all experimental studies on confined rarefied gas flows described in the literature have been achieved only by measuring global quantities such as pressure and temperature in order to investigate the macroscopic effects of viscous and thermal slip on the macroscopic mass flow rate through a channel [3, 4]. In this context, our interest is focused on the analysis of the slip flow phenomenon at the wall, in both pressure-driven and thermally-driven rarefied gas flows, by using an non-intrusive experimental technique that provides local velocity profile measurements. In particular, our work is aimed at applying the molecular tagging velocimetry (MTV) technique, which is an optical measurement technique that employs a molecular tracer able to produce light emission when excited by a UV laser. The possibility of using vapor acetone as molecular tracer has been analyzed. In the considered range of pressure and temperature, this tracer is characterized by an initial intense and short lifetime luminescence, known as fluorescence, and a weaker but with longer lifetime luminescence, the so-called phosphorescence [5]. Since the fluorescence signal lasts only a few nanoseconds, only the phosphorescence emission can be used to track gas flow displacements, as its lifetime is on the order of one millisecond. Recent works [6]

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have demonstrated the successful application of the technique for gas flows in a rectangular channel at atmospheric pressure and ambient temperature. However, its application to the case of thermal transpiration or viscous slip flow presents some difficulties that require the design of an optimal experimental setup that works at low pressures and with temperature gradients. Since the reduction of the channel height is limited by the smallest obtainable diameter of the laser beam (on the order of 30 μm), the Knudsen number, and thus rarefaction, can be increased only by lowering the gas pressure. Unfortunately, low pressure conditions increase diffusion and reduce both the acetone molecular density and the quantum yield efficiency, which leads to a lower accuracy and a decrease of the phosphorescence signal, respectively [7, 8, 9]. Moreover, regarding the thermally-driven flow case, technological limitations in the temperature gradient intensity can determine limits in the thermal creep velocity speed. Therefore, the choice of the optimal pressure and acetone concentration conditions needs to take into account these practical limitations and the available phosphorescence lifetime at the chosen gas mixture condition.

In this work, we provide new experimental data on the acetone's fluorescence and phosphorescence signal emission as a function of the total pressure of the system and the partial pressure of acetone. This preliminary study has been done in order to investigate the limits of our experimental setup in terms of achievable signal strength, as well as to corroborate previous experimental data [9, 10]. Existing theoretical models on acetone fluorescence and phosphorescence [10, 11] available in the literature will be used in combination with numerical simulations of gas flows in straight channels at low pressure and with temperature gradient to find the best experimental setup configuration to be designed in order to successfully employ the MTV technique on rarefied gas flows in confined systems.

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