Topic number: no. 4.

BOUNDARY LAYER ANALYSIS IN AIR PLASMA BY LASER DIAGNOSTICS AND SPECTROSCOPY

Julien Annaloro[(1)], Damien Studer[(1)], Pascal Boubert[(1,*)], Pierre Vervisch[(1)]

[(1)] CORIA, UMR6614 CNRS, Université et INSA de Rouen, 76800 Saint-Etienne-du-Rouvray, France

[(*)] **boubert@coria.fr**

In the frame on researches about the plasmas created when a space probe enters a planetary atmosphere with a hypersonic velocity, the interaction of the plasma with the heat shield is a key issue in order to increase safety and payload. We studied the boundary layer above a metallic plate immersed in an air plasma and parallel to the flow. The plasma was created by an inductive torch and expended in a moderate pressure (38 hPa) wind tunnel. The plate is water cooled and its leading edge is protected from oxidation by a mullite coating.

Three kinds of experiments were carried out in order to measure densities and temperatures in the free jet and within the boundary layer. Spontaneous Raman spectroscopy (SRS) probed N_2 and O_2 ground states, broadband laser-induced fluorescence (LIF) probed NO ground state and optical emission spectroscopy probed NO excited state $A^2\Sigma^+$ [1-3]. The physical parameters are derived by comparison between experimental spectra and calculated spectra.

Fig. 1 presents the density results for NO and O_2 compared with calculations. Both experimental plots depart from equilibrium and frozen-chemistry calculations. Such differences is an evidence of NO production within the whole boundary layer and of O_2 production at the wall.

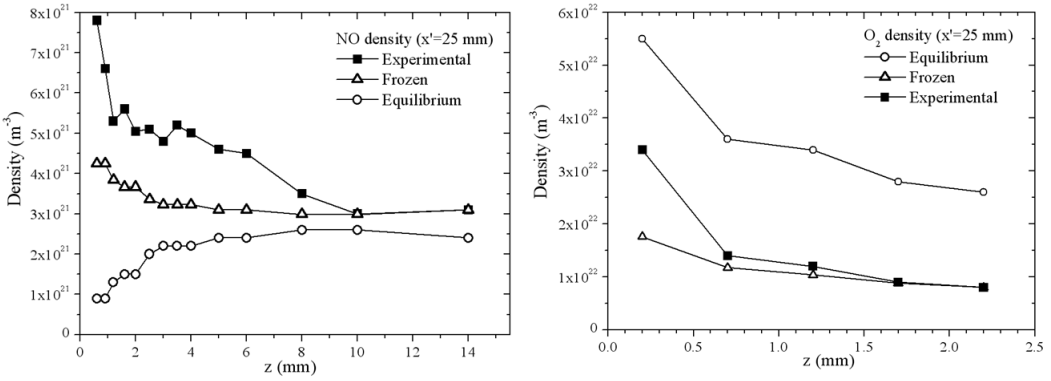

Fig. 1: NO (left) and O_2 (right) density transverse profiles in the boundary layer. The experimental profile is compared with an equilibrium calculation and a frozen-chemistry calculation.

Those results and similar analyses using molar fractions confirm the prediction of models [4] including catalytic NO production at the wall and NO production by Zel'dovich reaction $O_2 + N \rightarrow NO + O$ within the boundary layer. This last reaction is supplied by the oxygen recombination at the wall. Within the uncertainty of our measurements, no significant effect was demonstrated for N_2: the three plots are indistinguishable.

Fig. 2 presents some results obtained about temperatures with the three optical techniques. NO ground state results presents large differences between ground state rotational and vibrational temperatures within the boundary layer (including close to the wall) as well as in the free jet. The same observations were made for O_2 and N_2 with a systematic vibration-rotation non-equilibrium on the ground states. Moreover, if NO, N_2 and O_2 rotational temperatures are close, it is not true for vibrational temperatures. A multitemperature model should then deal with a vibrational temperature for each species.

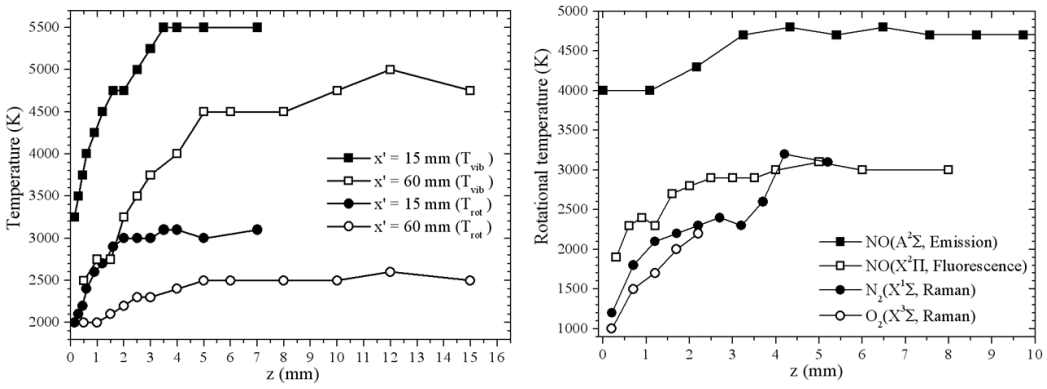

Fig. 2: Thermal non-equilibrium within the boundary layer between NO vibrational and rotational temperatures (left) and between ground and excited state rotational temperatures (right)

Furthermore, the rotational temperatures measured on the NO first excited state by OES were found to be much higher than those measured on ground states by laser techniques. This phenomenon means that emission spectroscopy cannot be used to estimate the kinetic temperature in such plasma conditions. Otherwise, the overpopulation of high rotational levels is due to an excitation of NO by energy transfer from the metastable state of N_2. Another process may occur at the wall: desorption of excited molecules resulting from catalytic reactions involving adsorbed atomic nitrogen. The dissociative adsorption probability of nitrogen is especially high with $N_2(X,v)$ – not suitable here - and $N_2(A)$ that is present in the free jet..

As a conclusion, our works brought a better understanding of the interaction of metallic partially catalytic surfaces with air plasmas. It highlighted several interesting features:

- O_2 recombination at the wall.
- Large NO production within the boundary layer.
- One vibrational temperature for each species.
- General vibration-rotation non-equilibrium.
- Thermal non-equilibrium between excited and ground states.
- Role of $N_2(A)$ in the excitation of NO(A) whatever the process.

A comparison with a Navier-Stokes calculation is now needed to complete the physical analysis.

Reference

D. Studer and P. Vervisch, 2007 *J. Appl. Phys.* **102**, 033303
D. Studer, P. Boubert and P. Vervisch, 2010 submitted to *J. Phys. D: Applied Physics*
D. Studer, P. Boubert and, P. Vervisch, 2010 submitted to *Appl. Phys. B: Lasers and Optics*
M. Barbato and C. Bruno, 1996 *Molecular Physics and Hypersonics Flows*, (Mario Capitelli Ed., NATO ASI Series) **C482** 139-160