QUALITATIVE DESCRIPTION OF THE STRUCTURE OF A BOUNDARY LAYER TYPE DIFFUSION FLAME IN NORMAL AND REDUCED GRAVITY ENVIRONMENTS

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1 Position of the problem

A fire onboard spacecraft is one of the scenarios with the highest damage potential for crew and hardware. Thus fire and flammability testing of all materials used in space structures and equipment is strictly required. Extensive research carried out under microgravity indicate that the basic idealization of the problem consisting of a wall fire in a convective flow on the ground is still appropriate, but leads to results which are sometimes at variance with those obtained under microgravity conditions. For several years[1,2] we attempted to characterize the structure of a boundary layer type diffusion flame developing over a burning surface using the combustion chamber presented on Figure 1.

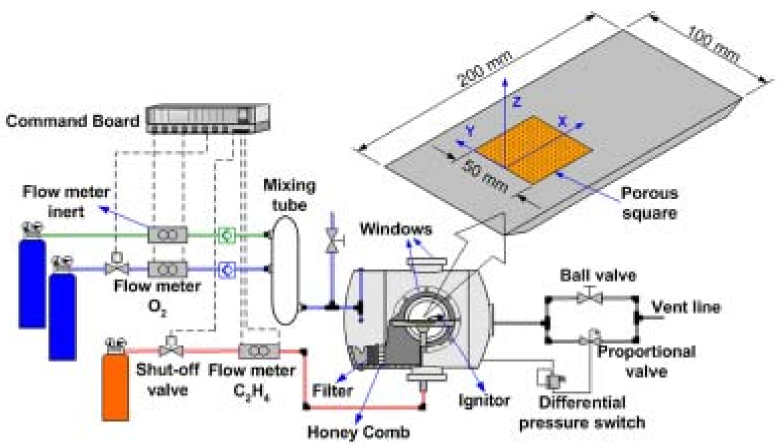


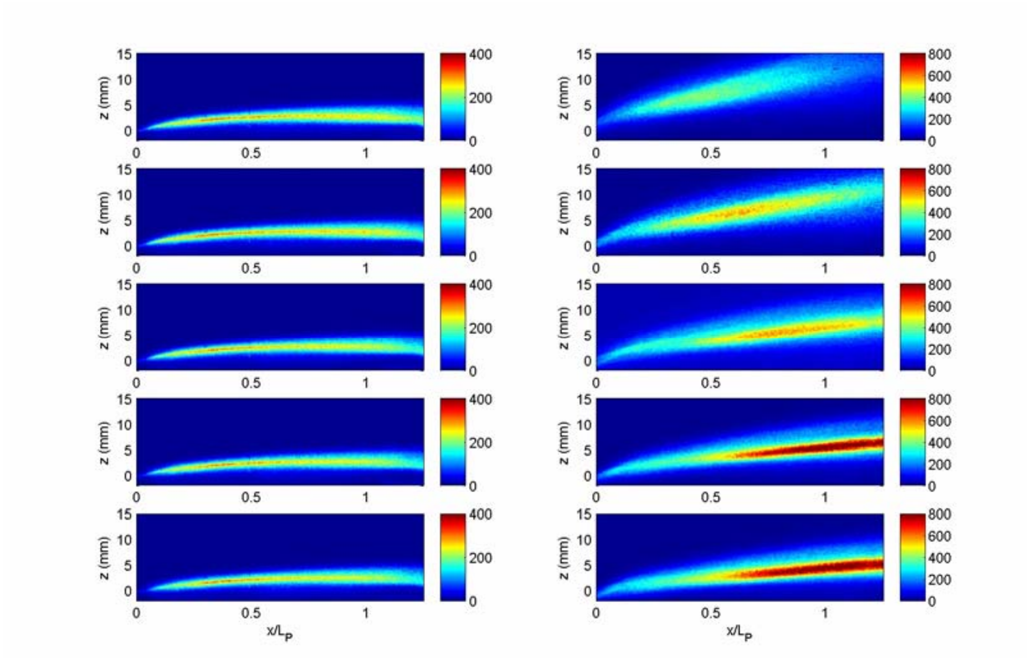
Figure 1: Schematic of the flat plate boundary layer laminar diffusion flame combustion chamber.

The flames are obtained using the system ethylene-oxidizer flow containing 21, 35 or 50% of oxygen. The oxidizer velocity V_{OX} ranges from 0.1 to 0.3m/s and the fuel injection velocity V_F between 0.002 and 0.006m/s. One should notice that at normal gravity the oxidizer velocity is enhanced by an order of magnitude due to the buoyancy forces induced by the flame.

The comparison between the structures of the flame obtained at reduced and normal gravity is based on visualizations obtained using non intrusive diagnostic techniques: CH* and OH* radicals' spontaneous emission to get flame geometric characteristics (flame stand-off distance, length, width, thickness) Planar Laser Induced Fluorescence (PLIF) for the localization of the formation of the Polyaromatic Hydrocarbons (PAH) and the Laser Induced Incandescence (LII) to determine the soot formation and oxidation domain. All this parameters are essential at the evaluation of the radiative properties of the reacting mixture then at the evaluation of radiation and its contribution to material flammability and combustion.

2 Flame geometric characteristics comparison through radicals' spontaneous emission visualisation

Figure 2 provides an example of the visualizations obtained using CH* radicals spontaneous emission.

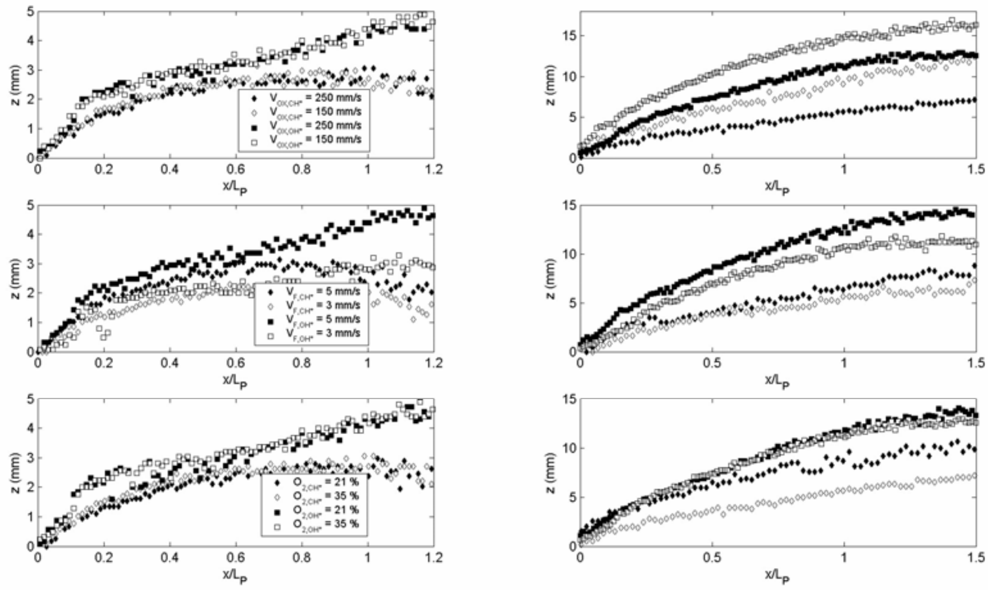


a) Normal gravity b) Reduced gravity

Figure 2: CH* spontaneous emission at normal and reduced gravity for O_2=35%, V_F=0.005m/s and V_{ox}=0.125, 0.150, 0.200 and 0.300m/s.

All the visualizations, based either on OH* or CH* spontaneous emission underline the expected trends as the velocity of the buoyancy induced flow is one order of magnitude larger than the velocity of the forced flow: the flames are longer and closer to the reacting surface at normal gravity. One can also easily notice that the oxidizer velocity (V_{OX}) has no influence on the integrated intensity at normal gravity but has a significant one under microgravity. Then increasing V_{OX} the flame geometric characteristics as the integrated intensity for both OH* and CH* radicals tends asymptotically to the normal gravity characteristics.

In a previous work doing surrogated hydrodynamic experiments [3] we noticed the existence of a mixing zone of the two orthogonal flows which should corresponds to the most intense reaction zone, i.e. the flame zone, located inside the main flow boundary layer. This zone is bounded by a lower limit below which you find only the injected fuel and an upper limit above which you have only the oxidizer. Assuming that the lower limit corresponds to the locus of the maxima of the CH* spontaneous emission and the upper the OH*ones, we are able to define a similar zone in which the flame is always located. One should also remark the so-called mixing or reaction zone is thinner and closer to the reacting wall at normal gravity than at reduced gravity, due to the influence of the buoyancy induced flow. All this appears clearly on figure 3. It is also evident that the thin flame assumption is not valid at all. Moreover at reduced gravity the influence of V_F at V_{OX}=constant and of V_{OX} at V_F=constant are more noticeable.



a) Normal gravity b) Reduced gravity

Figure 3: Influence of V_F, V_{OX} and $\%O_2$ on the localisation of the reaction zone defined by the domain between the locus of the maxima of CH* spontaneous emission (lower limit) and the locus of the maxima of OH* spontaneous emission (upper limit).

3 PAH and soot formation and oxidation domains

Using the PLIF and LII diagnostics we have been able to get original data concerning the structure of this kind of laminar diffusion flame. More especially a calibration procedure has been developed allowing the determination of the evolution of soot volume fraction along the flame. The parametric study underlines that the locus of the maxima of the LII signal is very sensitive to V_{OX}, especially under reduced gravity. The maxima are close to the trailing edge and the signal tends to decrease faster while increasing V_{OX}. One should notice that soot is mostly present downstream of the burner. Figure 4 is an example of the results concerning the LII and soot volume fraction signals. This figure illustrates the important role of the oxidizer flow on soot oxidation at the flame tail. We also notice the concentration of oxygen plays a very important role (increase the amount of oxidant available for the oxidation). Again the oxidation process is important downstream of the burner and consequently the amount of soot decreases rapidly at the flame tail especially when you increase significantly the amount of oxygen. However, the fuel injection velocity has nearly no influence on soot volume fraction. At reduced gravity there is more soot for large x/L_P that means longer flames. Figure 5 provides the distribution of the PAH and their location. They are located closer to the burner and disappear very quickly when the soot is formed. The trends observed at normal and reduced gravity are very similar for PAH and soot, the PAH as soot precursors decrease earlier. The PAH disappear completely at the flame tail and of course prior to the soot volume fraction peak. The PAH are produced on the CH* radical side. One should noticed the peak of intensity for the PAH is closer to the flame tail than the CH*spontaneous emission peak. Along the flame and in flow direction we can assume soot formation occurs according to the following path:

Ethylene $\longrightarrow$ CH* $\longrightarrow$ PAH $\longrightarrow$ SOOT

A phenomenon follows by an oxidation process. This process leads to the decrease of soot volume fraction at the flame tail.

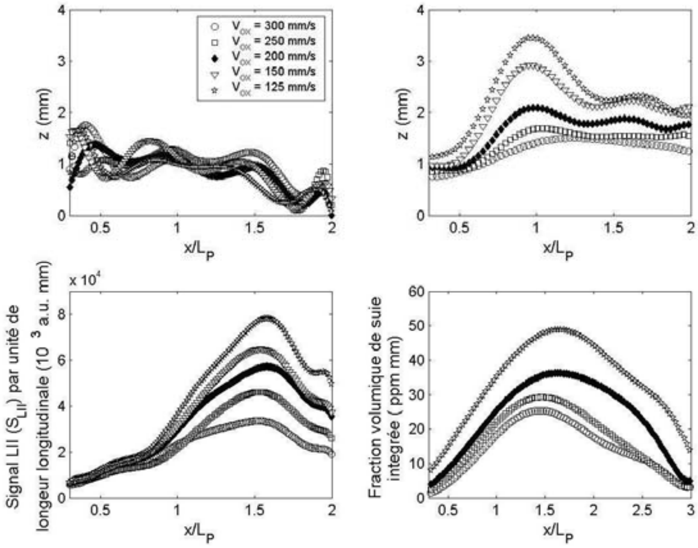


Figure 4: Comparison normal/reduced gravity of the LII signal at different V_{OX} for V_F=0.005m/s and 35% O_2

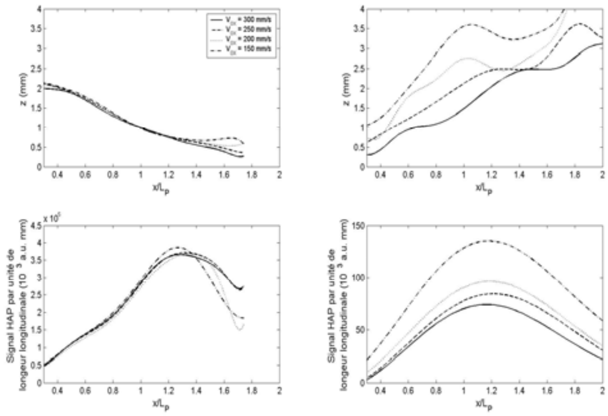


Figure5: Comparison normal/reduced gravity of the PAH (PLIF) signal at different V_{OX} for V_F=0.005m/s and 35% O_2

References

[1] Legros G., *« Etude du comportement radiatif d'une flamme de diffusion établie en micropesanteur »* Thèse de l'Université de Poitiers, 9 Décembre 2003.

[2] Fuentès A., *« Interaction entre la zone réactionnelle et le champ de concentration des suies : Cas de la flamme de diffusion laminaire au sein d'une couche limite »* Doctorat de l'Université de Poitiers, 8 Décembre 2006

[3] Brahmi L., Vietoris T., Rouvreau S., Joulain P., David L., Torero J., *«Microgravity laminar diffusion flame in a perpendicular fuel and oxidizer streams configuration»* AIAA Journal Vol.43, No.8, pp. 1725-1733, August 2005.