Laser induced ignition and plasma spectroscopy in non premixed hydrogen-air burner

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1 Introduction

Ignition is still one key problems for many piratical applications. Several exists to ignite a mixture with a laser, either focussing a laser with any wavelength so as to create a breakdown ([1]), or by choosing properly the wavelength of the laser so as to excite thermally one molecule [2]. The first approach has been so far favored because of the relative simplicity in the laser source. Many applications have already been proposed, from static test cell at ambient pressure [3], to laminar burners [4], or static cells at higher pressures using hydrogen ([5]). Recent review articles have been published [6, 7]. Many applications have focussed to cases where the mixture is perfectly uniform in time. For many practical approaches, the local mixture fraction may vary with time, due to turbulence. The ignition results will highly depend on those variations (together with variations of turbulence for instance) and one should be able to provide a tool giving the mixture fraction at the ignition point. This is the combined laser induced ignition and plasma spectroscopy ([8]). Recently, a new approach allowing a quantitative measurements of the equivalence ratio independently of the laser source has been proposed ([9]). The present article shows new results obtained in an hydrogen-air burner for which the local equivalence ratio is actually measured for each spark.

2 Description of the experimental facility

The laser used to ignite is a Nd:YAG emitting at 532nm with an overall power of 100mJ in single cavity mode and about 180mJ for double cavities. To focus the laser, a lens (NADL-30-80PY2 from Sigma Koki) with a focal length of 80mm is used. The spectrometer used is a MS-257 from Oriel together with an intensified ICCD (Andor). Timing between laser pulse and acquisition is set at 300ns with an integration of 3,000ns. Procedures to educe the equivalence ratio from the spectra are similar to those presented previously ([9]) and are briefly reported here. The emission of each element is taken as being the total emission of the spectra (after background subtraction) with a wavelength within 3nm of the peak. The present burner, based on hydrogen-air mixture, is depicted in figure 1.

Hydrogen is injected through small orifices perpendicular to the main airstream. Typical massflow rate was 7 g/s for the air with variable injection of hydrogen. The typical velocity field (obtained by using 1,000 PIV images in non-reacting conditions without injection of hydrogen) for this condition is shown in Figure 2. The points used after for ignition tests are clearly represented. One can see that some points close to the center of the nozzle will be in the main recirculation zone whereas points located 5mm from the center will be in a region with a strong velocity. Looking at this velocity field, one may estimate that the inner points will have a higher probability to ignite that those located within the main air stream. Basically, two different hydrogen flow rate have been used, one with 10.7 mg/s and the other

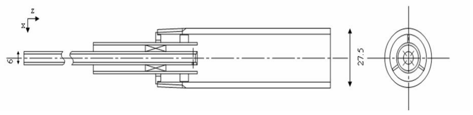

Figure 1: Schematic representation of the injector.

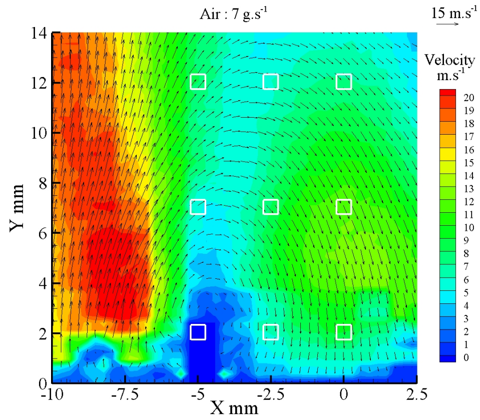

Figure 2: Schematic representation of the burner and its associated velocity field.

one with 13.5 mg/s. The overall mixture fraction corresponds respectively to 0.0015 and 0.0019, much lower than the stoichiometric value of 0.0284. This flame can not be generated in premixed mode, as leaner than the flammability limit of hydrogen under ambient conditions and it has been seen that when ignition is successful, the flames are stabilized in the vicinity of each injector, hence forming a series of small diffusion flames. Typical lean blow out for an air mass flowrate of 7g/s was around an equivalence ratio of 0.045.

3 Results

The results are first presented as the probability to properly ignite the burner. As seen in Figure 3, the probability is a strong function of space for the same overall equivalence ratio.

The present application does not intend to give minimum ignition energy but rather to obtain a map of the ignition probability using 200mJ. The energy of the spark is measured by the difference between power meters before and after the spark, with proper calibration to take into account the presence of the burner and so forth. A very high probability to ignite is observed for a position of 2mm above the exit of the burner, in the center part. On the other hand, it is impossible to ignite with the maximum laser power (over 200mJ). It is quite clear that the differences in the probability shows also the usefulness of the laser ignition approach for which a different position can be easily achieved compared to more conventional spark. Similar results were presented also for a laminar diffusion flame with methane ([10]).

Differences between radius of 0 and 5mm may be due to either a strong velocity for the position at 5mm, whereas 0mm lies in the recirculation zone. Another possibility is that hydrogen has not enough momentum to penetrate deep inside the airflow and remains limited to the inner side of the burner. Obtaining flow measurement would require the use of seeding particles, which would modify the ignition property. However, using the spectroscopy from the plasma could reveal the local equivalence ratio, hence some hints about chemical processes.

As far as Laser Induced Plasma Spectroscopy is concerned, each individual spectra is processed to yield quantitative measurement of the local mixture fraction within the created spark. The uncertainty is estimated to be less than 5% for single shot cases. Figure 4 shows a typical spectra where one can see the presence of hydrogen atoms (at 486 and 656nm), as well as nitrogen (744-748nm) and oxygen (777nm). For each spectra, the emission of both hydrogen, nitrogen and oxygen is measured. Calibration previously obtained for methane are presently used in this study. As in LIPS, all molecules are decomposed into atoms, the main difference will be a factor 2 when dealing with hydrogen-air rather than methane-air for the correspondence between the atomic ratio of hydrogen versus oxygen and the mixture fraction. Local background is subtracted to yield only intensity due to the atomic emission under consideration. Intensity is integrated over 5nm for each emission.

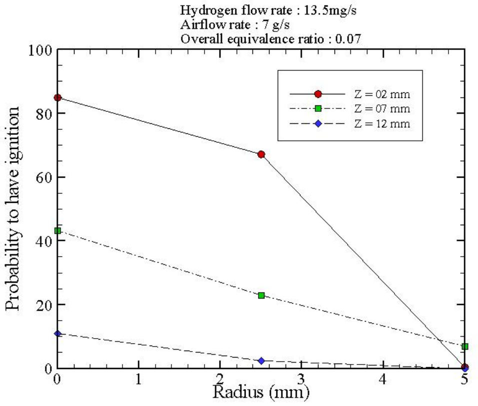

Figure 3: Probability for ignition as function of position of the plasma.

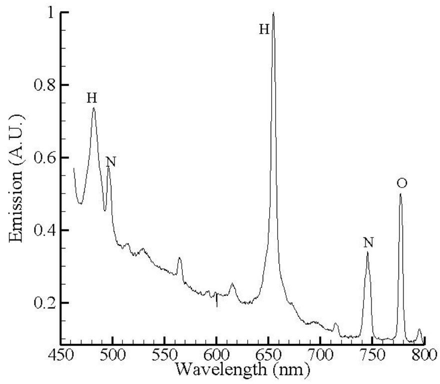

Figure 4: Typical spectra obtained when using laser induced plasma spectroscopy. Delay of 300 ns with an integration of 3,000ns.

To show the information provided by LIPS on the actual mixture fraction, an example is chosen for which ignition could occur only in 10.9% of the cases. The point of interest is taken 12mm from the exit of the burner, at a radial position of 0mm.

The measurement of the true equivalence ratio at the ignition is given in 5 versus the center of the plasma. The center is measured through an ICCD gated with the laser pulse and after image processing. The most important information comes from the LIPS measurements. It is seen that the equivalence ratio is higher than 0.1, whereas the overall equivalence ratio used in this case was limited to 0.07. This higher value enables ignition to occur. On the other hand, no definite conclusions can be drawn on the impact of the equivalence ratio on ignition. Ignition could be achieved for equivalence ratio as low as 0.117 but not for cases with values close to 0.18. The differences are certainly due to differences in the local velocity that changes a lot with time. Therefore, for a fully description of the ignition phenomena within this burner, it is important to couple velocity and mixture fraction measurements.

4 Conclusions

Experiments of laser ignition applied to a non-premixed hydrogen-air burner have been presented. Through the probability of ignition, it was clearly shown that one may take of the advantage of spatial non-uniformity in the fuel distribution to ignite even under very lean conditions. The plasma spectroscopy measurements confirmed those findings and it is expected that those combined measurements may reveal interesting information for ignition of other non-premixed flames. Further extension may include the simultaneous determination of the gas velocity by LDV to record both effects of mixture fraction and turbulence, or using PIV measurements to have a view of the velocity field at the ignition time. This induces problems of particles modifying the position of the plasma and strong light coming into the LDV sensor or into the PIV camera. Effects can be attenuated using liquid crystals that can be triggered with respect to the laser induced plasma to block light emitted by the plasma.

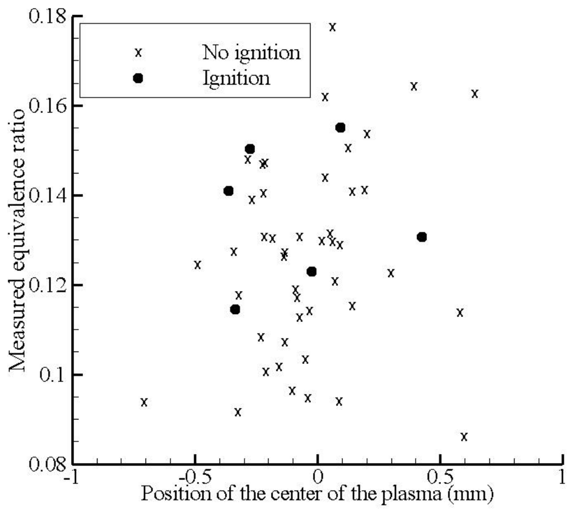

Figure 5: Measurements of local equivalence ratio for ignition and non-ignition events for an overall equivalence ratio of 0.07.

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