Influence of Staging Ratio on a Premixed Swirled Burner

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Introduction

An experimental study has been carried out on a lean-premixed swirl-stabilized combustor, using the recent technology of two-staged fuel distribution (Sattelmayer *et al.* (1992)). This technology developed to reduce NO_x emissions is known to be very sensitive to acoustic coupling (Paschereit and Polifke (1996)). The influence of the staging ratio has been studied, both in terms of acoustic waves (spectral analysis has shown coupled longitudinal oscillations in the combustion chamber) and pollutant emissions. Visualization of the flame structure (radicals chemiluminescence and OH Laser Induced Fluorescence) enables to explain the phenomena involved.

Fondamental issues

The concept of lean premixed swirled combustion in gas turbine has been widely developed in the last years to meet stringent environmental standards on $\mathrm{NO_x}$ emissions. As premixing is improved and the local flame temperature is decreased, $\mathrm{NO_x}$ formation is reduced exponentially at the expense of significantly higher pressure fluctuations (Richards and Janus (1998)). A new technique, called staged premixing, relies on modifying the distribution of fuel-air concentration in the burner in order to fix the position of the flame at a location which is optimum, both for the lowest emissions and acoustic fluctuations (Lefebvre (1995)). This is achieved by dividing the premix fuel supply in two or more stages, which can be independently controlled. The overall objective of our work is to demonstrate the concept of this fuel-staged combustor, as an enhancement of current lean premixed technology with very low $\mathrm{NO_x}$ emissions. Within this objective, the burner behaviour is characterized through pressure fluctuations, flame structure and pollutants emission measurements.

Influence of staging on flame properties

Figure 1 schematically presents the experimental device used in the present study. The staging process is realised with two similar injection blocks, controlled independently. For each stage, compressed propane and air are delivered to a cylindrical plenum, where the two gases are mixed. A porous material, placed there to avoid flashback in the plenum, homogenizes the mixture. This mixture enters the premixing tube via two opposite tangential slots, which create an important swirl movement. Conditions inside the burner are expected to be fully premixed in each stage. Cold flow experiments have been made for an accurate assessment of the premixing level between the two stages. The staging parameter, α, is defined as the proportion of propane injected in the upstream stage, $\alpha = \dot{\mathrm{m}}_{\mathrm{p},1}/(\dot{\mathrm{m}}_{\mathrm{p},1} + \dot{\mathrm{m}}_{\mathrm{p},2})$, where $\dot{\mathrm{m}}_{\mathrm{p},1}$ and $\dot{\mathrm{m}}_{\mathrm{p},2}$ are respectively the mass flux of propane in first and second stage. A small axial air injection has been implemented in the rear plane of the premixing tube to prevent the flame stabilization in

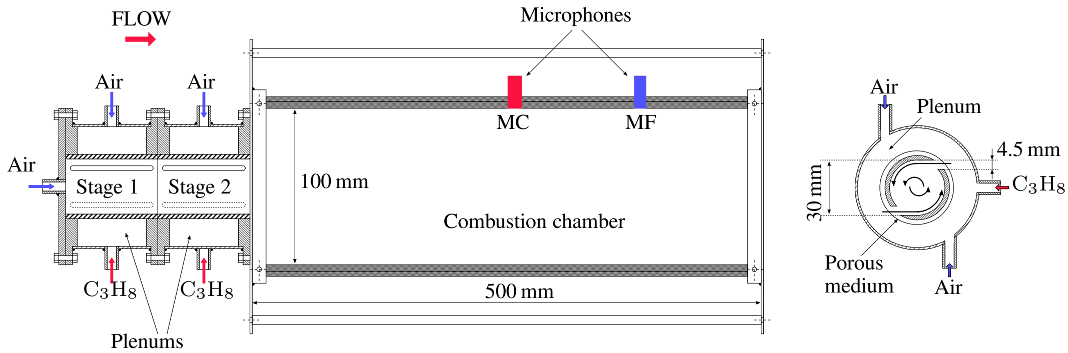


Figure 1: *Schematic of experimental device - Left side: global set-up - Right side: detailed transverse view of gas distribution in one stage.*

the premixing tube, predicted by LES calculations.

Production and consumption of key combustion species such as NO_x, CO_x, O_2 and unburnt hydrocarbons (C_xH_y) were carefully monitored using gas analysers, with Infra-Red (IR) spectroscopy or paramagnetic technique. Static measurements have been performed in the middle of the combustion chamber in burnt gases. Major pollutant emissions are illustrated on Figure 2. Additional measurements have also been made while moving the sampling probe along a vertical line on half the chamber height, to check the burnt gases homogeneity. Measurements

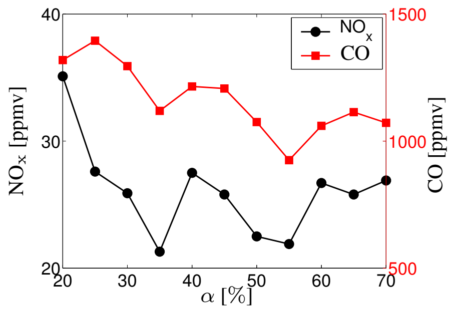


Figure 2: *Pollutant emissions (NO_x and CO concentrations) of the burner measured in the middle of the combustion chamber*

show relatively low pollutant emissions. Even though an overall tendency is not evidenced, local minima are found.

The stability map of the burner was determined using flame intensity signals delivered from a photo-multiplier tube (PMT) centered on CH^* emission at $\lambda = 431.4$ nm and pressure oscillations. Two water-cooled microphones, MC and MF, were placed respectively at 250 and 375 mm downstream the injector, on the upper wall. Detailed spectral analysis was carried out. The effect of the staging parameter, α, is presented on Figure 3. The maximum value of the power spectral density (PSD) and the corresponding frequency are extracted for each value of

α. A maximum of instability appears for values of α between 35 and 45 %. The frequency

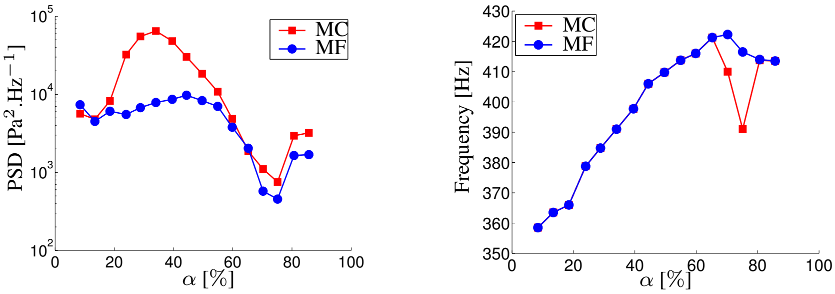
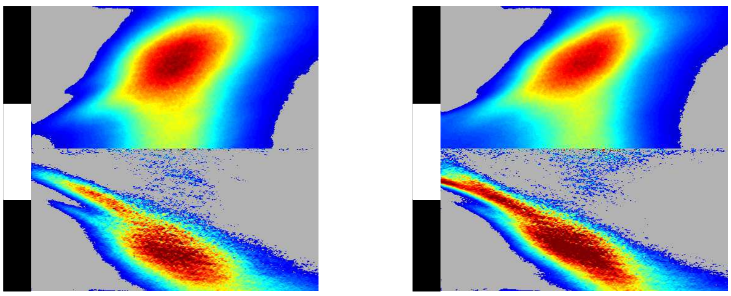


Figure 3: *Spectral analysis of the burner of both microphones - Q_{air} = 40 Nm^3.h^{-1} - ϕ = 0.82. Left side: maximum peak of PSD - Right side: frequency of the peak*

increases with α to a maximum value around 410 Hz. Differences between microphones are numerical errors due to small levels of the PSD.

Influence of staging on flame structure

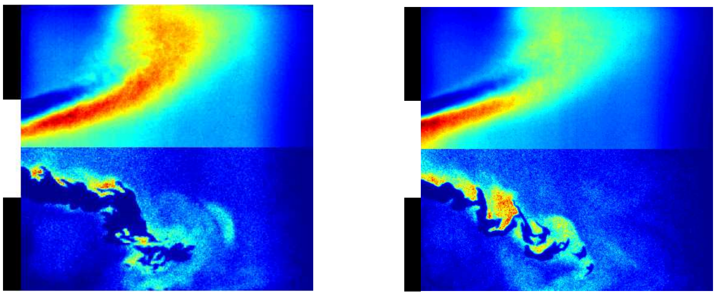
The flame structure explains the influence of the staging factor α. Two different diagnostics have been used: radical chemiluminescence (CH* and OH* radicals respectively at $\lambda = 431.4$ nm and $\lambda = 308.9$ nm) and PLIF (Price *et al.* (2001)) of OH molecules (excitation of $Q_1(5)$ band at $\lambda = 282.67$ nm and light collection around $\lambda = 310$ nm). Examples of OH* emission are given in Figure 4 for two operating points $\alpha = 35$ % and $\alpha = 75$ %. The deconvo-



(a) $\alpha = 35$ % (b) $\alpha = 75$ %

Figure 4: *Influence of the staging parameter on the flame structure (OH* emission) - Q_{air} = 40 Nm^3.h^{-1}, ϕ = 0.82. On top: mean images - On bottom: Abel transform.*

lution of these images reveals that the global position and shape of the flame strongly depends on the staging parameter. As α increases, the flame stabilizes upstream in the premixing tube. As a consequence, the reaction zone seems to be thiner and the opening angle is smaller. PLIF is illustrated on Figure 5 for $\alpha = 35$ % and $\alpha = 75$ %. The picture intensity permits to precisely visualize the turbulent flame front, with the propagation of large-scale vortices. It also confirms the position and the width of the cone of fresh gases entering the combustion chamber.



(a) $\alpha = 35\,\%$ (b) $\alpha = 75\,\%$

Figure 5: *OH PLIF in a longitudinal view -* Q_{air} *= 40 Nm*^{3}*.h*$^{-1}$*,* ϕ *= 0.82. On top: mean image - On bottom: instantaneous (25 ns) shot.*

Conclusion

The staging coefficient α appears to be a fundamental parameter of the burner behaviour. This parameter controls the position and the shape of the flame and locally modify the composition of the fresh mixture. Therefore, there is a strong interaction between the mixing of the two stages, the position of the recirculation zone and coupling with acoustics of the system. Aerodynamics and mixing analysis of the burner are planned for next months to confirm these hypothesis. The strong influence of staging on pollutant emissions and acoustic behaviour requires a robust control algorithm to operate the burner in stable conditions.

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