Experimental study of combustion and flow dynamics in a meso-scale whirl combustor

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Combustion may constitute an interesting solution for small-scale power generation. Using hydrocarbons high energy density at small scales is still a scientific and technological challenge. Driven by industrial applications such as the replacement of existing batteries by a lighter system or the design of miniature propulsion device, successful development of such small scale systems requires an extensive understanding of combustion behavior while scaling down conventional combustors to a miniaturized size. For this purpose, a meso-scale whirl combustor is designed (Fig.1) and experiments are performed.

1. Objectives

In the present work, we aim to demonstrate the interest of hydrogen-enriched methane-air combustion in a meso-scale whirl combustor inside which the flow configurations appear to be much more complex. At first, the internal flow field under isothermal conditions will be studied aiming to investigate the flow motions inside the combustor. Then, emphases will be put on the analysis of the global performance of the meso-combustor, including establishment of stability diagrams coupled with flame structure observation and estimation on the combustion efficiency. Finally, the effect of hydrogen addition on flame stability and pollutant emissions will be discussed in detail.

2. Experimental Approaches

The internal flow fields have been studied by Particle Image Velocimetry (PIV) in non-reacting conditions. Pressure fluctuation data have been analyzed for the purpose of exploring the combustion instability. Pollutant emissions have been measured not only in order to detect the exhaust species, but also to estimate the combustion efficiency. At the same time, CH* chemiluminescence flame imaging has been carried out by an intensified CCD camera to observe the flame location inside the combustor and instantaneous flame structures corresponding to different total flow rates and different equivalence ratios. High-speed imaging has also been implemented and synchronized with pressure acquisition to study the thermo-acoustic coupling.

3. Results and Conclusions

We are restricted to 2D PIV measurements which are performed in consecutive planes and in two orthogonal directions. By assuming implicitly the flow field as fully stationary, a time-averaged 3D and 3C velocity field can be reconstructed from a series of 2D measurements. Whirl flow structure has thus been studied.

The combustor demonstrated its ability to operate with different gaseous hydrocarbon fuel mixtures. Combustion stability diagrams have been established which evidenced quite wide flame stability limits (Fig.2).

A first step to thermo-acoustic analysis has been achieved to evaluate the relevance between local heat release and pressure fluctuations by means of Rayleigh Index.

Considered as a promising way to improve the combustor performance, the fuel mixture is enriched by hydrogen at different rates. The injection of hydrogen has been proved to largely extend the lean blow-out (LBO) limits. In addition, both CO and unburned hydrocarbon (THC) emissions have been significantly reduced by adding hydrogen. Moreover, the thermo-acoustic analysis showed that hydrogen is able to reduce thermo-acoustic instabilities. So far, the beneficial effects of hydrogen enrichment on the flame stabilization and the reduction of pollutant emissions have been pointed out, which provides a potential alternative to fuel utilization in meso-scale combustion.