Heat Transfer Measurements in Hydrogen Enriched Flames

By Jules Cochard

Context and motivation

- Growing interest for renewable energies in the power generation industry has brought hydrogen to the forefront of alternative fuels for gas turbine applications.
- The utilization of hydrogen blended with natural gas may be a way of reducing pollutant emissions by improving lean flammability limits in combustion processes.
- Properties of hydrogen may however raise operating issues by enhancing risk of combustion instability, causing in certain cases large amplitude heat flux fluctuations that can damage the combustor walls.

Objectives

- Design and construction of a calibration facility for heat flux sensors.
- Calibration of a heat flux sensor and its integration into a combustor test rig.
- Radiative heat transfer measurements in swirl-stabilized hydrogen enriched flames.

Heat flux sensor description

The sensor used in this study relies on the thermoelectric effect and produces a voltage when exposed to a certain heat flux. The sensitivity of the sensor depends on its material properties that vary with temperature. Two Alumel leads connected on each side of the pad provide the output voltage proportional to the heat flux, the third one, made out of Chromel connected to the cold side of the pad allows to determine the temperature across the sensing element.

Calibration of the heat flux sensor

A class IV green laser served as a heat source, its beam was directed through lenses so that the diameter could be adjusted on the sensor’s surface. Air cooling was applied on both the laser head and the sensor. A reference sensor was firstly used to verify that the laser power output given by the power supply unit was correct. Thereafter, the working sensor was placed on the beam path and its output voltage and temperature were acquired by a multimeter connected to a computer. Finally, sensitivity of the sensor $S \ [\mu \text{V/mW}]$ was obtained in a desired temperature range.

Integration of the sensor and heat transfer measurements

The sensor was fixed on around a quartz cylinder so that the sensor was protected from convective heat flux and thus only flame radiation was measured. Non-premixed combustion was carried out due to high reactivity of hydrogen and risk of flashback.

Results and conclusions

- Two hydrogen enrichments of 10% and 20% by mass were performed and compared to the base case when only natural gas is injected in the combustion chamber.
- The influence of equivalence ratio $\phi$ [-] and thermal power input $P_{\text{fuel}}$ [kW] on radiative heat flux were also investigated.
- Based on the operating conditions, the combustion equation and a model for gas radiation, adiabatic flame temperature and theoretical flame radiation were calculated for each operating point:
  - At lean conditions, an increase in $\phi$ leads to an increase in heat transfer.
  - Flame radiation doesn’t depend on $P_{\text{fuel}}$.
  - The addition of hydrogen to natural gas reduces flame radiation.
- In practice, the evolution of the measured heat transfer is considerably more complex due to other factors that intervene in the flame stability, shape and position and that therefore affect the measured radiation.
- Particularly, fuel composition and equivalence ratio did not only affect the chemistry of combustion, but also the swirl intensity, and flame dynamics causing in several cases severe instabilities when hydrogen was mixed with natural gas.
- That resulted in a peak in heat flux for the 10% enrichment when $\phi = 0.7$.
- The analysis of the results revealed the need to couple heat flux measurements with flame imaging to account for the influence of flame position and structure on heat transfer measurements.

Supervised by Prof. P. Stathopoulos (TU Berlin) and Prof. S. Haussener (EPFL) Autumn 2017