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Multispectral Imaging of CO_2-free Hydrogen Combustion for Industrial Annealing Processes and Comparison to Natural Gas †

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The drive to transition towards greener methods for energy production and industrial processes is stronger every year. Typical combustion reactions create well known gas products (CO_2, H_2O, CO, etc…) and governments as well as the industry are pushing to limit the amount of greenhouse gases emitted every day. A great example of this effort is the research accomplished at the Instituto de Tecnología Cerámica (ITC) in Spain, focusing on a transition for ceramic annealing by a helium burner instead of a traditional natural gas one. Associated with the University of Jaume, their fundamental objective is to research, capitalize on knowledge, transfer technology, and design high-value services for companies. A demonstrative study was accomplished with a multispectral infrared camera to observe the difference in CO_2 and H_2O output from one type of combustion to the other as well as study the fire plume behaviour using high-speed infrared imaging.

Keywords: Infrared Camera, Hydrogen Combustion, CO_2-free, Multispectral

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The combustion application involves multiple types of observations requiring good temporal and spectral resolution. Thus, the Telops MS M3K is a perfect candidate for such a study. The camera was installed in ITC's helium combustion research facilities to analyze the flame produced by the state-of-the-art combustion system which perfectly controls and mixes the source gases for the desired reaction, see Figure 1.

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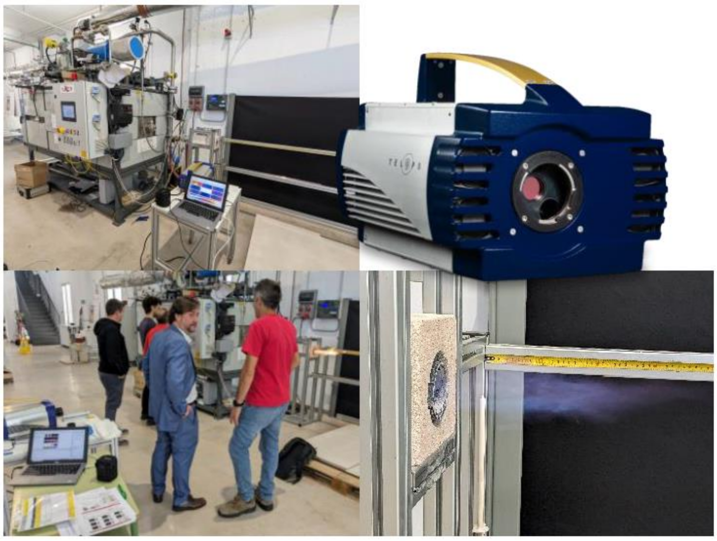

Figure 1. Combustion study system with controlled gas input in ITC'S facilities. The multi-spectral aligned in front the output flame.

The camera uses a 320×256 pixel cooled InSb focal plane array (FPA) detector. The camera benefit from the real-time radiometric and non-uniformity correction features using a patented calibration method[1]. This particular camera has an extended infrared midwave range of 1.5-5.4 µm, which is particularly important when doing a detailed analysis of water vapor. A standard midwave range between 3-5 µm does not cover much of the water absorption peaks that happen in lower wavelength (higher wave-number), as we can see in the Figure 2. The multispectral camera contain a wheel of 8 filters for a near-simultaneous imaging of various selective spectral regions. For this measurement, the ones of particular interest are the filters 3 to 5 representing the spectral windows: (3) 5.16-5.40 µm, water vapour, (4) 4.53-4.75 µm, CO_2 red peaks (low energy), (5) 4.26-4.54 µm, CO_2 blue peaks (high energy).

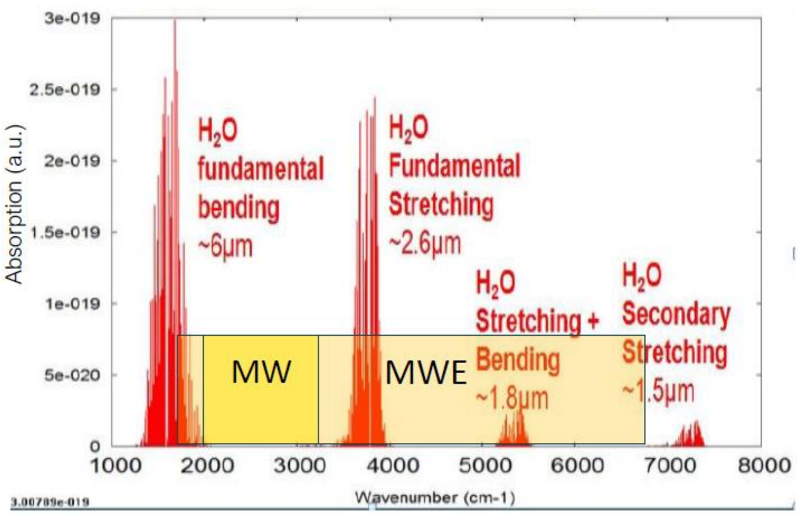

Figure 2. Water vibrational absorption bands with coverage offered by the imaging accomplished by the midwave (MW) and extended midwave (MWE) detectors. [Hitran database 2004].

A 50mm lens with an adjustable focus was used to observe the flame during the combustion process. The integration time was adjusted automatically by the acquisition software independently for each filter to avoid saturation and optimize signal intensity. The frame rate was set to the maximum for multispectral acquisition, 800Hz, which represents 100Hz per filter. The multispectral images below showcase the drastic reduction in CO_2 emission when using the hydrogen combustion, Figure 3. With the flame at a similar temperature for both cases, the emission from CO_2 is not visible anymore within its known spectral range which is expected due to the hydrogen combustion theoretically only producing water. The water is also more noticeable with hydrogen compared to the natural gas images. As the molar ratios of the reactions were not maintained as a known input for this demonstrative measurement, the relative intensity of the water signal could be due to a higher flux of hydrogen.

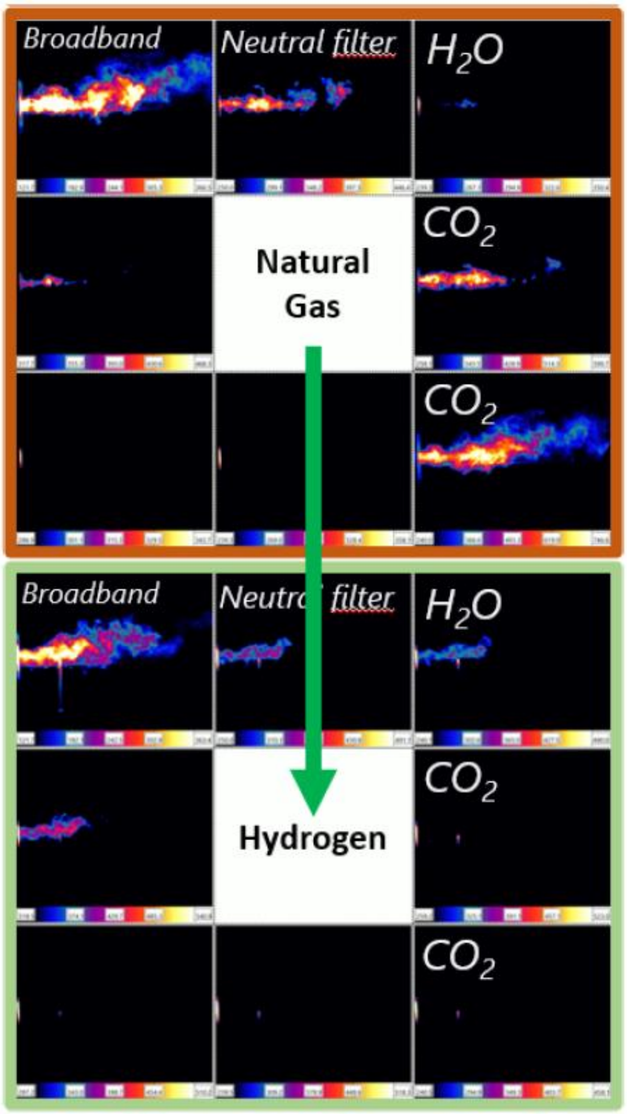

Figure 3. Multispectral images of natural gas and hydrogen flame. Frames 4-5 (clockwise rotation from broadband) represent CO_2 which is not detected in the hydrogen case. A slight increase in H2O detection (frame 3) is noticeable in the hydrogen combustion.

For high-speed imaging of the flame, the integration time was set to 14 µs at a frame rate of 3000 Hz, with the filter wheel fixed in the broadband position, while maintaining a full window size of 320x256 pixels. The general behaviour of the flame was easy to visualize at this frame rate, giving a clear view of the propagation and density of high temperature regions, Figure 4. As the process rapidly repeats itself, we can see the tip of the plume moving forward with the formation of eddies and the separation of localized high temperature areas. Each sub-window represents a time displacement of 1ms of the same region. This information is valuable to optimize the geometry of the annealing chamber, to obtain higher quality material at a more efficient rate.

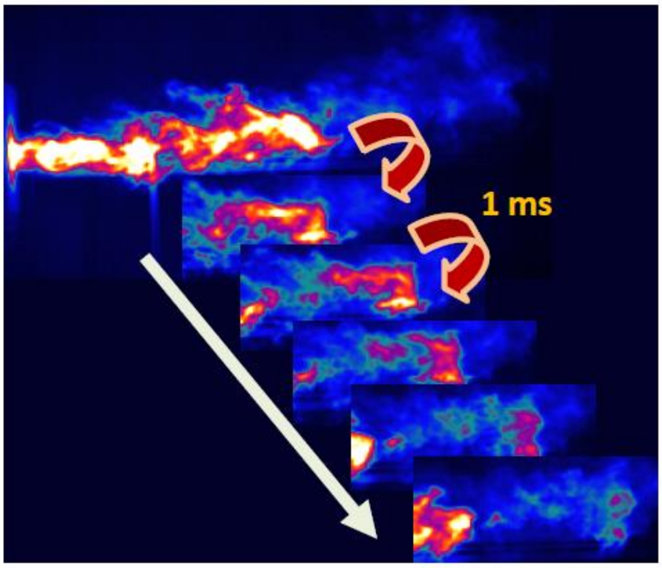

Figure 4. Broadband images of hydrogen flame plume with subwindows showing the propagation and density of the high temperature regions.

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