Quantification of Gas Mixtures Using Imaging Fourier Transform Spectrometry

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Motivation
- The oil and gas industry needs to quantify gaseous emissions in various scenarios, e.g., reporting and mitigating fugitive emissions and assessing flared combustion efficiency.
- Optical gas imaging provides a two-dimensional representation of concentration in the camera field-of-view. It is passive and noninvasive, qualifying it for fence-line measurements.
- Most optical gas imaging techniques focus on quantifying a single species. However, many gas releases consist of mixtures (e.g., BTEX, natural gas, combustion gases, etc.). These can be quantified using an imaging Fourier transform spectrometer (IFTS).

Spectroscopic model
- The background intensity, \( I_{bg} \), was obtained from pixels that did not contain \( \text{CH}_4 \).
- The background temperature and ambient humidity were fitted assuming ambient temperature from meteorological data.
- Species molar fraction and temperature were parametrized as Gaussian profiles along the LOS, and the species absorption coefficient is simulated using the HITRAN spectral line database.

Flare combustion efficiency
- The IFTS can also infer flare combustion efficiency (CE), the ratio of the mass of carbon affiliated to \( \text{CO}_2 \) to the total mass of carbon in the fuel stream. Flare CE may be impacted by cross-winds (fuel stripping) and steam-assist.
- Synthetic MW Hyper-Cam data was generated from a CFD large-eddy simulation of a flare in a crosswind at a resolution of 4 cm.
- Peak species concentrations are inferred from nonlinear regression of modeled data to simulated measurements.

Optical flow velocimetry
- The velocity field is estimated by the evolution of brightness patterns in the interferogram data-cube.
- Changes in pixel brightness between successive timeframes are caused by the \( \text{CH}_4 \) flow.
- Image data-cubes are used to derive the temporal and spatial derivatives by the brightness constancy assumption.
- The underdetermined system of equations is solved by combining the gradient constraint with Laplacian priors on the flow velocities.

Flare emission from the Hyper-Cam LW were consistent with ground-truth data. More accurate results can be found using the Hyper-Cam LW Methane (more methane lines) or the Hyper-Cam MW (improved temperature sensitivity).
- The Hyper-Cam MW can also estimate \( \text{CO}_2 \) and \( \text{CH}_4 \) column densities in a flare, which can be used to assess combustion efficiency.
- The Hyper-Cam MW will be used to measure flaring CE in the Boundary Layer Wind Tunnel at Western University, and later in a flare at an industrial site.

References
[5] Flare LES provided by Jeremy Thomsen from the Department of Chemical Engineering at The University of Utah.