Measurement of Convective and Radiative Heat Transfer in Flame Impingement

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Further details in the Proceedings for IMECE 2015

UTSR Workshop 2015

Motivation: Characterize complex heat loads within gas turbine combustors

Demands on gas turbine combustors:

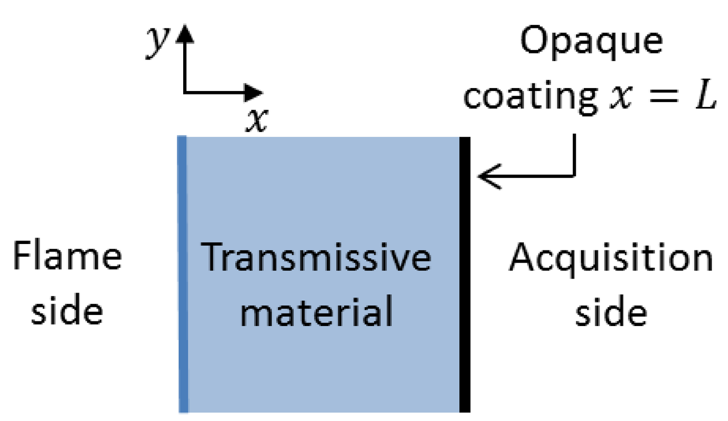
- Durability (~ 30 000 hours)
- Flexibility: Fuel and variable loads
- Emission limits: 15-42 ppm NOx (new stationary gas turbines)
- Efficiency: Higher compressor pressure ratios, higher turbine inlet temperatures

Problem: Develop a technique to measure the relative contribution of radiation and convection

Lack of experimental data for empirical design correlations:

- Convective loads estimated from adjusted correlations for straight pipes
- Radiative loads estimated from correlations derived for heavier fuels and non-premixed systems
- No measurements of liner wall heat loads under realistic conditions.

Physical model: Simultaneous conduction and radiation through an optically thin material

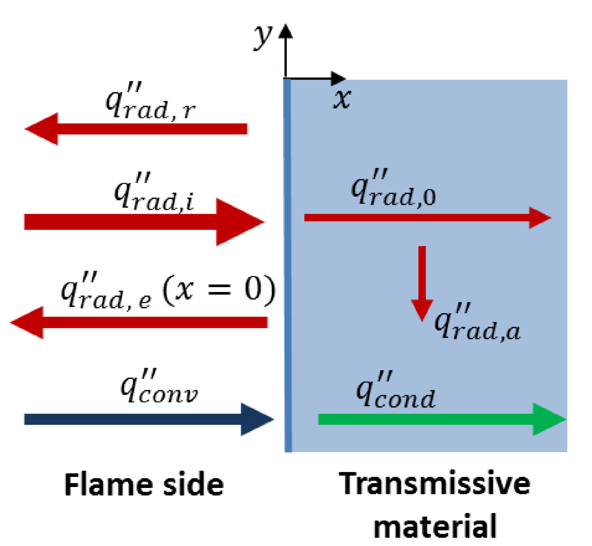


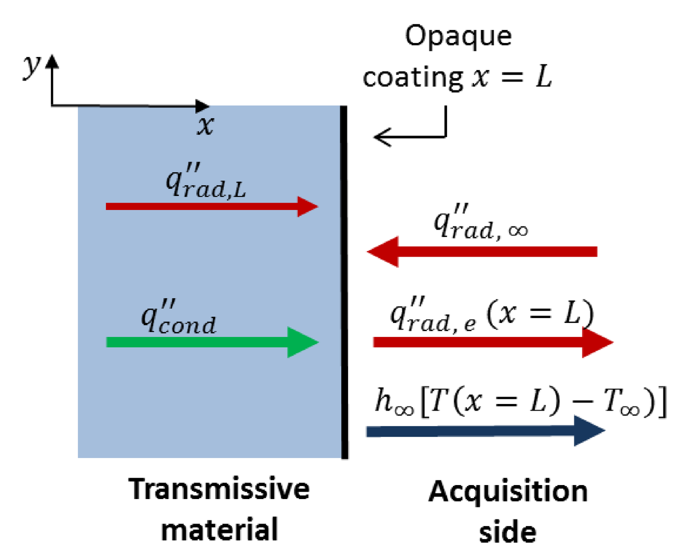
Flame side: No obstruction or coating.
Acquisition side: Coated with a high emissivity, opaque paint.

IR camera on the acquisition side captures temperature history as the target wall interacts with the flame.

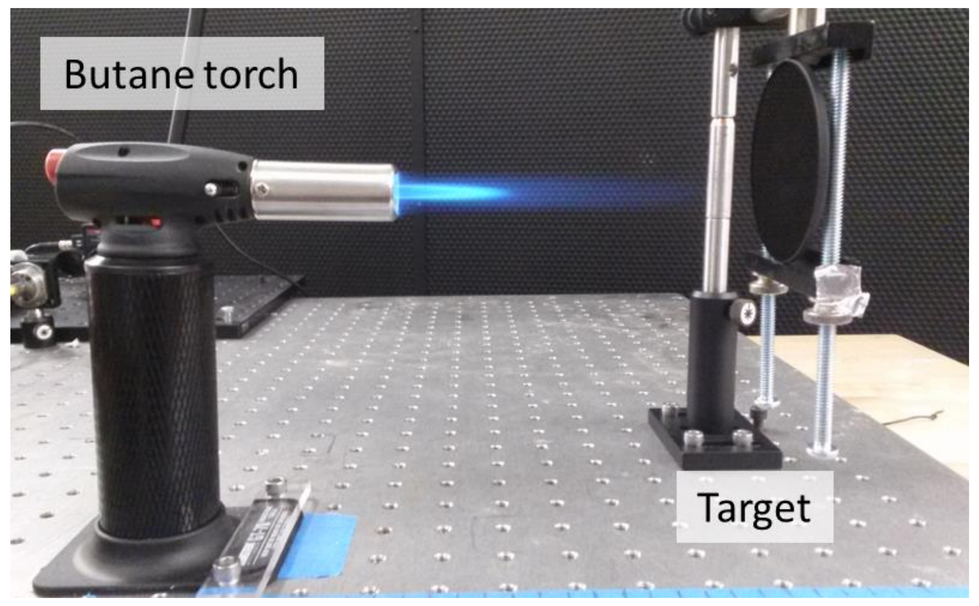
Concept of the measurement:
Radiation transmits through the material and heats the opaque coating instantaneously, while the convective load takes a finite amount of time to conduct through the material and reach the coating.

1D finite difference direct model was coded. The model is evaluated iteratively with different convective and radiative heat loads on the flame side ($q''_{rad,i}$, q''_{conv}) until the backside modeled and measured temperature histories match.



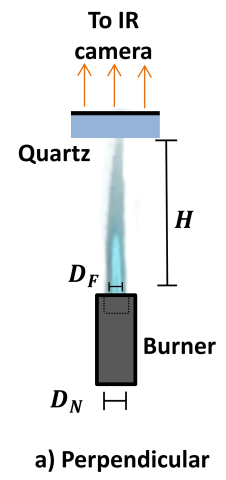


Proof of concept experiment: Flame perpendicular and parallel to the target surface, using a commercially available butane torch.

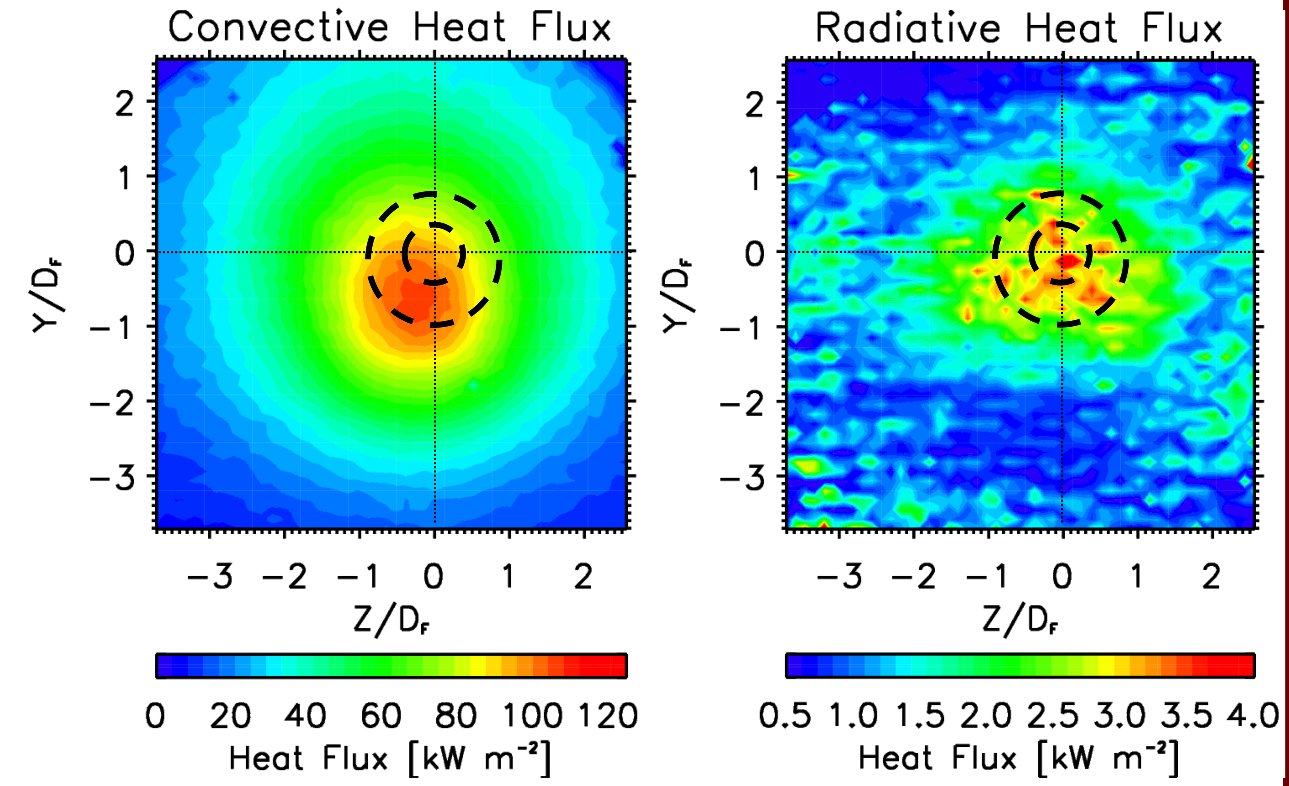


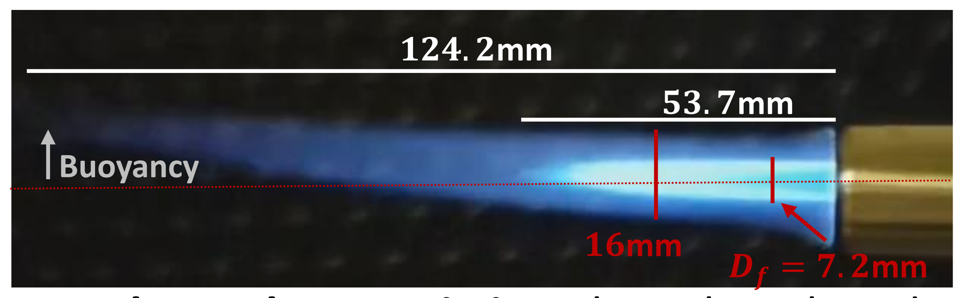
Experimental setup: Shown for the perpendicular impingement case.

Flame perpendicular to target



- Radiation <5% of heat flux
- Correlations [1] yield 124kW/m² at the stagnation point (14% larger than observed)
- Measurements by Dong et al. [2] reported 140kW/m² peak at similar conditions.



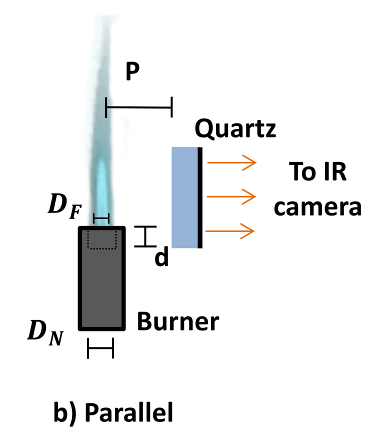


Flame characteristics: Flame length and diameter.

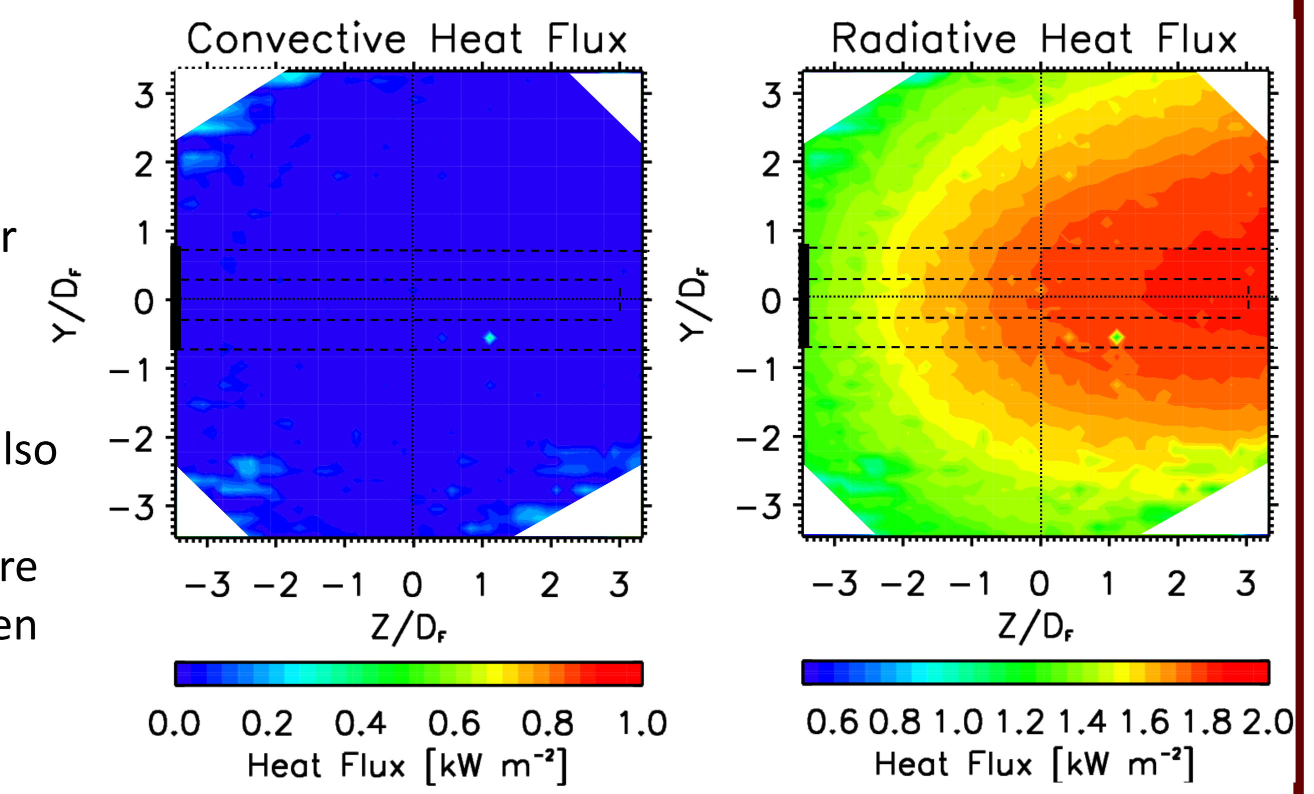
- Quartz as target material, high transmissivity, low conductivity.
- Non-luminous, premixed flame (minimal soot formation)
- Flame Reynolds # = 1580
- Uncertainties $< 15\%$ for convective heat flux and $< 11\%$ for radiative heat flux

Flame parallel to target

- Dominated by radiation
- Radiative load is similar in magnitude to that obtained for the perpendicular case



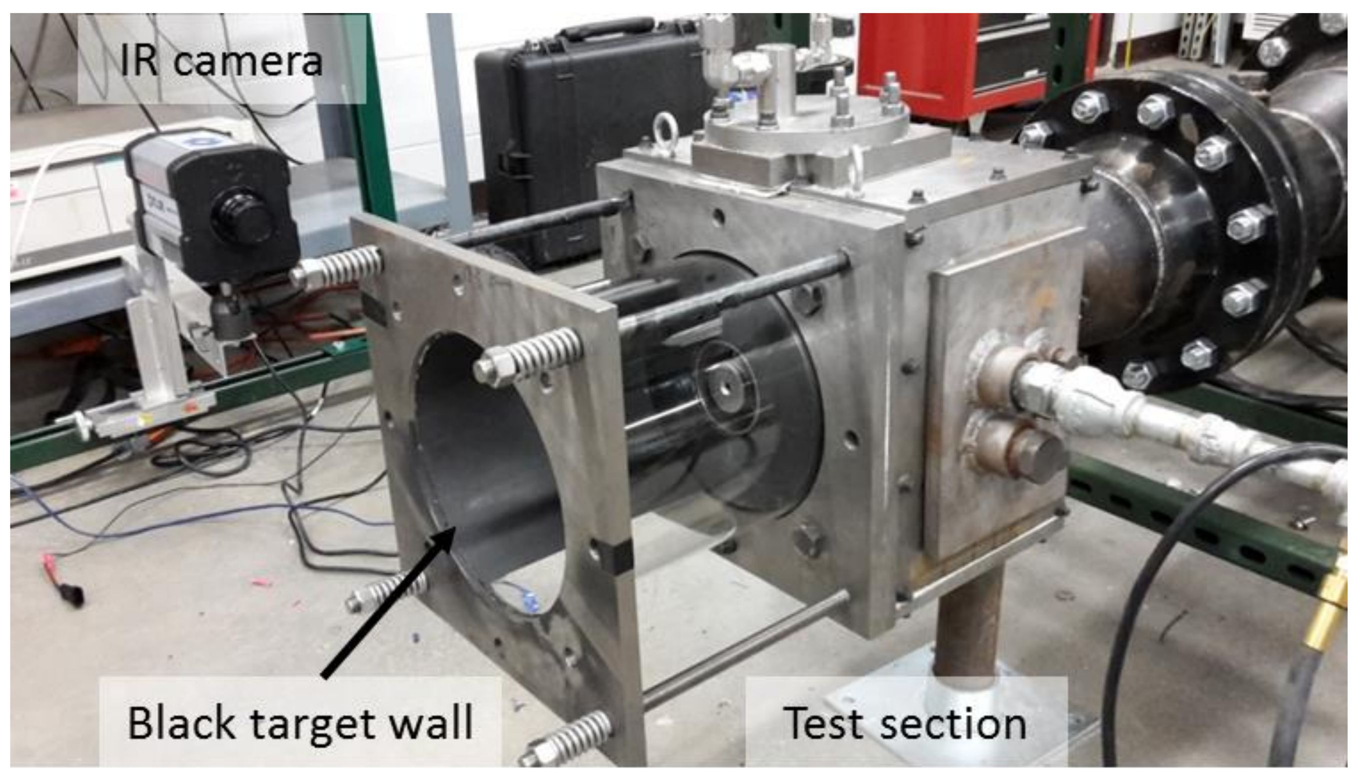
Absorption coefficients were also obtained in the algorithm and were consistent between cases.



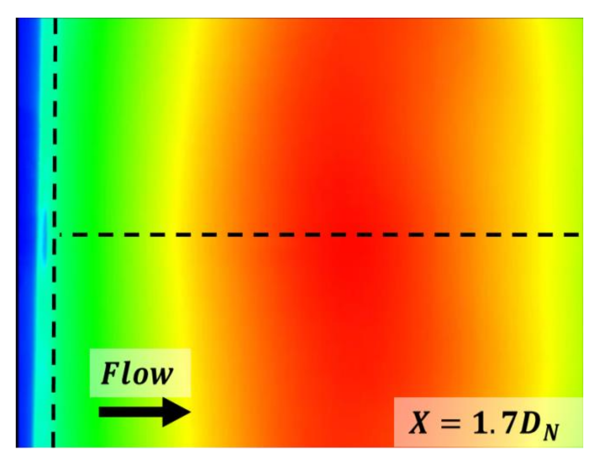
[1] Popiel, Cz. O., Van der Meer, Th. H., and Hoogendoorn, C. J.,"Convective Heat Transfer on a Plate in an Impinging Round Hot Gas Jet of Low Reynolds Number" *International J. Heat Mass Transfer* 23(1980): 1055-1068.
[2] Dong, L.L., Cheung, C.S., and Leung, C.W., "Heat Transfer Characteristics of an Impinging Butane/Air Flame Jet of Low Reynolds Number" *Experimental Heat Transfer* 14(2001): 265-282.

Current work: Applying these ideas to an optical combustor and a dedicated small scale impingement experiment.

Optical combustor with internal wall coated with high emissivity/optically opaque paint.



Atmospheric optical combustor setup

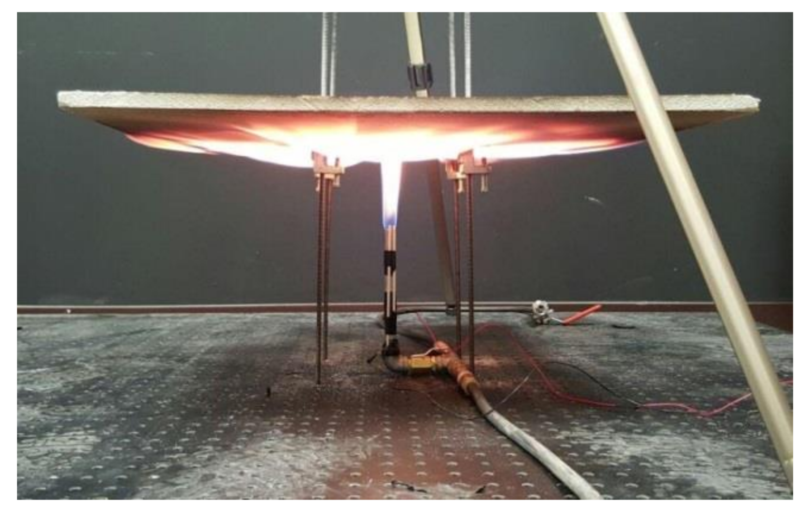


Isothermal measurement of liner temperatures.

2D finite difference code written to predict instantaneous heat fluxes. (varying in time)

Challenges:

- Varying heat fluxes with time: fuel ramp-up
- Soot accumulation on the surface impacting transmission
- Determination of adiabatic wall temperatures to obtain heat transfer coefficients.
- 3D conduction effects



Flame impingement setup, allows for finer control of Reynolds #. equivalence ratio, impingement distance

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