Effects of Exhaust Gas Recirculation (EGR) on Turbulent Combustion and Emissions in Advanced Gas Turbine Combustors with High-Hydrogen-Content (HHC) Fuels

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LES Modeling

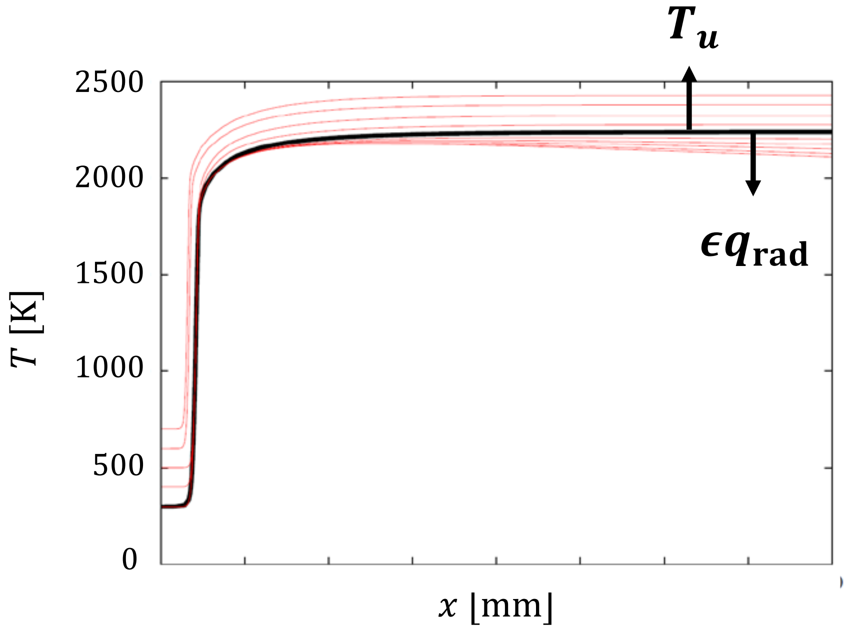
- Model Development
  - Premixed Flamelet Model
  - Radiation Heat Losses
- RATS Burner Simulations
  - Computational Details
  - Effects of Diluents
- Future Work

Model Development

- Premixed Flamelet Model
  - Use one-dimensional premixed flamelet solutions to map thermochemical state onto a progress variable
    - $\rho_u S_L \frac{dY_k}{dx} = -\frac{d}{dx}(\rho Y_k V_k) + \dot{m}_k$
    - For example: $\dot{m}_k(Y_k, T) \rightarrow \dot{m}_k(Z, C)$
  - Solve for progress variable (and mixture fraction) in LES
    - $\frac{\partial \bar{\rho}\tilde{C}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_j\tilde{C}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\bar{\rho}\widetilde{D}\frac{\partial \tilde{C}}{\partial x_j}\right) - \frac{\partial}{\partial x_j}\left(\bar{\rho}\widetilde{u_j C} - \bar{\rho}\tilde{u}_j\tilde{C}\right) + \overline{\dot{m}}_C$
    - Retrieve local thermochemical state from flamelet solutions
  - For radiation, introduce heat loss parameter H (solved for in LES and flamelets) and flamelets at variable enthalpy
    - $\dot{m}_k(Y_k, T, H) \rightarrow \dot{m}_k(Z, C, H)$
  - Additional transport equation solved in LES for NO mass fraction

Model Development

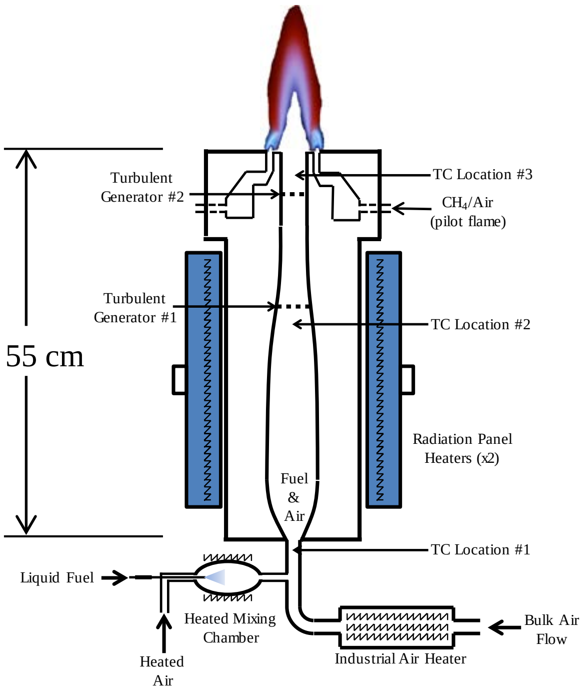
- Radiation Heat Losses
  - Heat losses
    - Compute steady flamelets with a fraction ϵ of the radiation source term
    - Avoids unphysically small unburned gas temperatures and/or product dilution
  - Heat gains
    - Increase unburned gas temperature



Shift
Ctrfl

RATS Burner

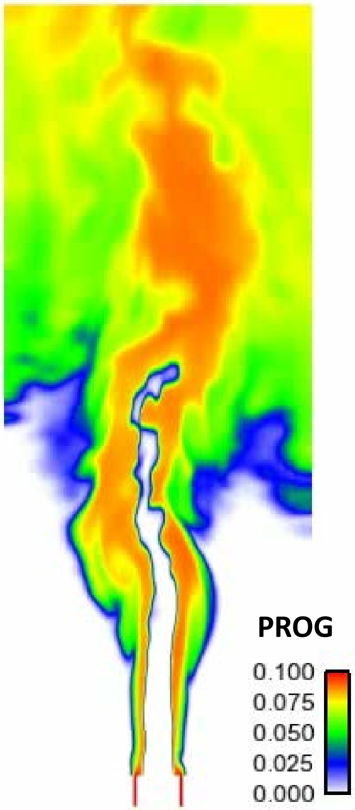
- Configuration: RATS Burner[1]
  - Methane/air: $\phi = 0.9$
  - $U_{\text{jet}} = 15 \text{ m/s}$
  - $\text{Re} \approx 8{,}500$
  - Varying water dilution
    - 0%-10% by volume
    - N2 dilution to maintain constant flame temperature of 2025 K
  - Pilot
    - Stoichiometric methane/air without dilution with $U_u = 1 \text{ m/s}$



[1]C.B. Reuter, S.H. Won, S. Nakane, Y. Ju, 9th U.S. National Combustion Meeting, 2015, Cincinnati, OH

RATS Burner

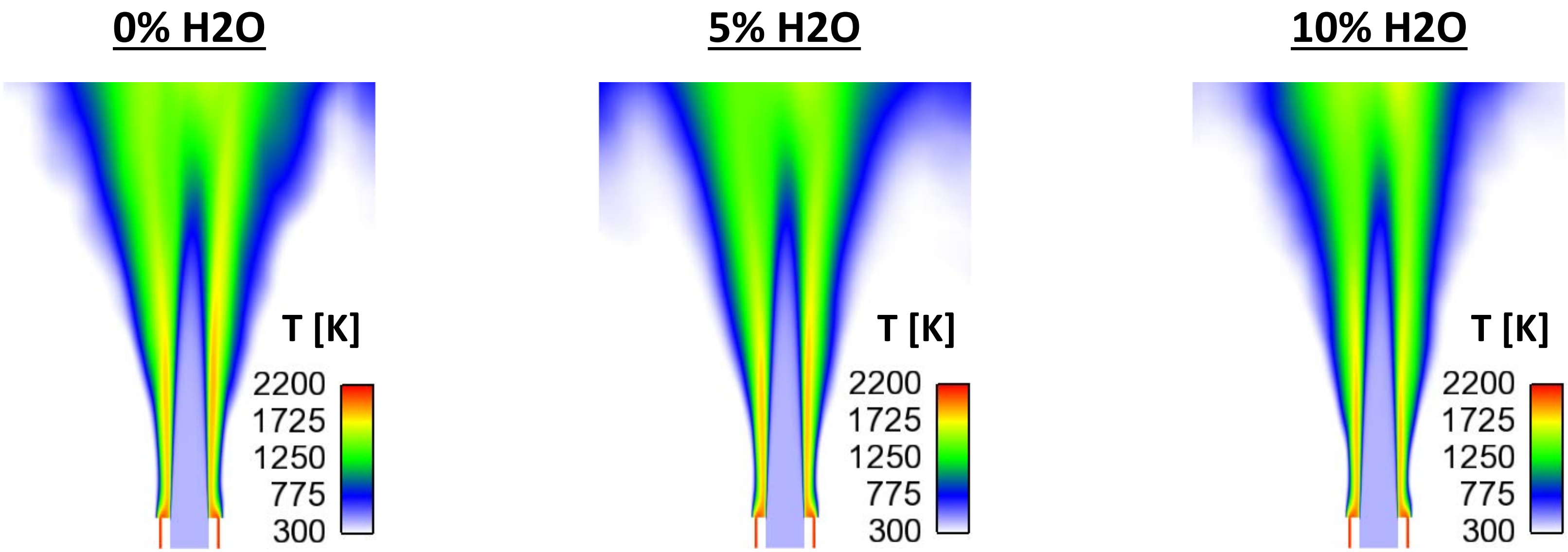
- Code: NGA[1]
  - Numerical Methods and Turbulence Models
    - Space: Second-order velocity; third-order scalars
    - Time: Second-order semi-implicit
    - Dynamic Smagorinsky models for turbulent transport
  - Computational Domain
    - 1.6M grid points $(256 \times 192 \times 32)$
    - Domain length: $20H$
  - Boundary Conditions
    - Jet: Forced isotropic turbulence with matched integral scale and turbulence intensity
    - Coflow: Weak to mimic entrainment
    - Pilot: Stoichiometric mixture with consistent dilution and unburned velocity of $1\ \text{m/s}$ (little sensitivity)



[1]O. Dejsardins, G. Blanquart, G. Balarac, H. Pitsch, J. Comp. Phys. 227 (2008) 7125-7159

RATS Burner

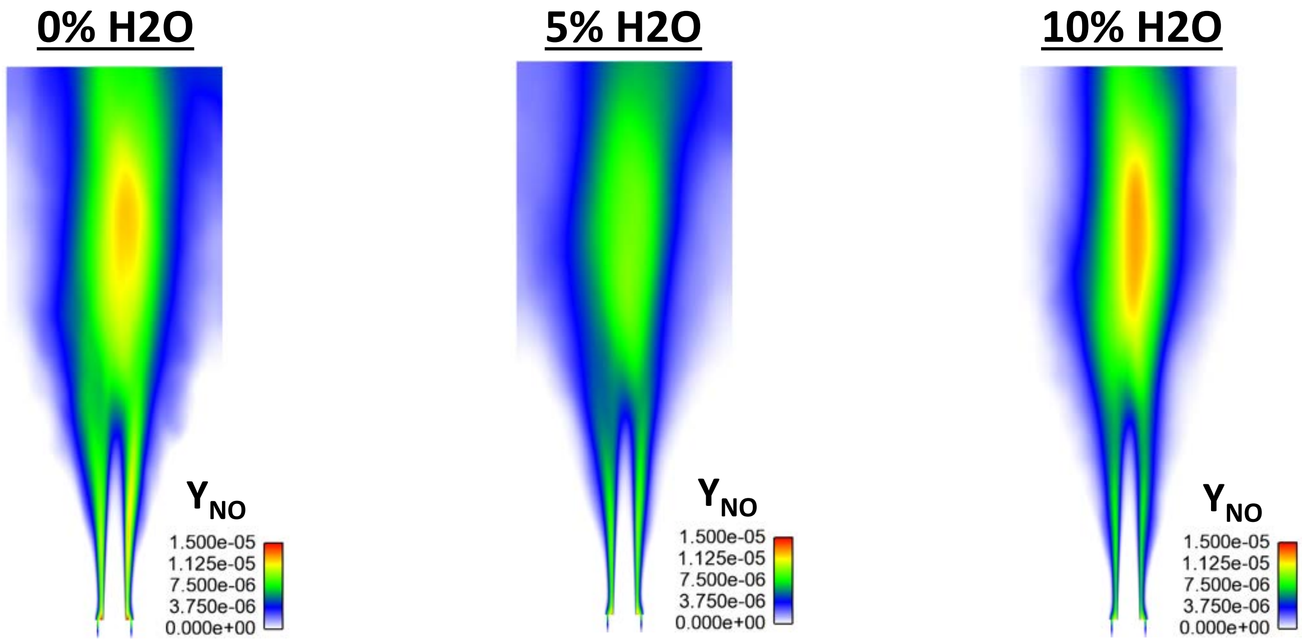
- Effect on Flame Structure



  – Little change in flame height with increasing water dilution, consistent with experimental measurements

RATS Burner

- Effect on Emissions

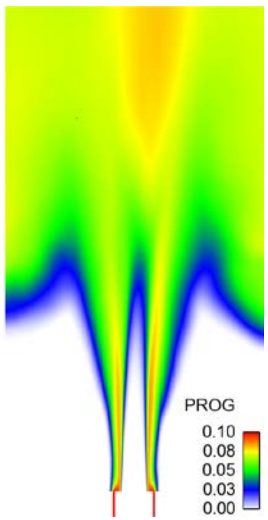


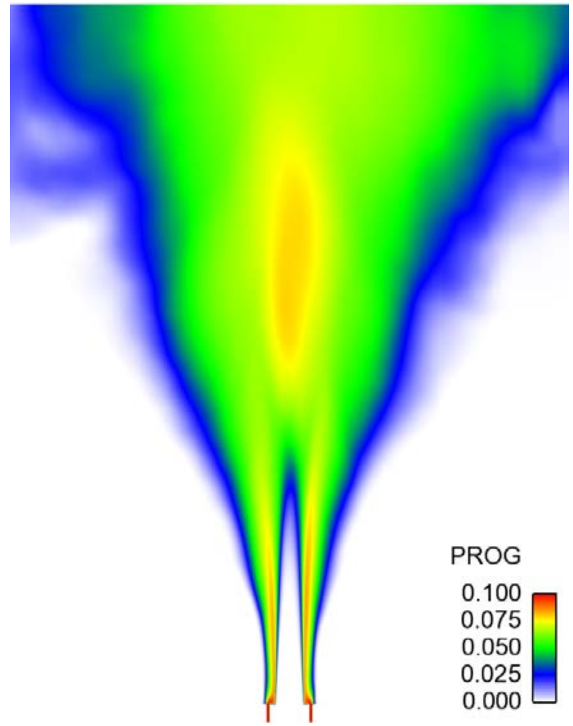
  - Decrease then increase in NO consistent with temperature
    - Correlation with temperature does not indicate chemical effect
    - Temperature a result of product recirculation in 0% and 5% flames

RATS Burner

- Effect of Domain Size

No Water Dilution





Flames on same physical scale

  - Larger domain reduces recirculation from the outflow
  - Little effect on flame height but significant downstream

Future Work

- Model Development
  - Detailed radiation modeling implementation
    - Discrete ordinates method
    - Start with weighted sum of gray gases for optical properties
  - Coupling with premixed flamelet model
- (PA)RAT(S) Burner Simulations
  - Better entrainment boundary condition
    - Unconfined flames without coflow are computationally challenging!
  - High-pressure simulations of PARAT burner
    - Effect of radiation model
    - Effects of diluents on emissions