Consideration of Non-Ideal Detonation Regimes Influenced by Wave Modes in a Water-Cooled Rotating Detonation Engine Using OH* Chemiluminescence

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Outline

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• Method
  • OH* chemiluminescence anatomy
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  • Summary data generation
• Global Comparisons
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  • Galloping waves
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Introduction

• Rotating detonation engines (RDE) offer an alternative strategy for advancing the thermodynamic efficiency of gas turbine engines
• RDE technology has matured to mechanism research
  • Large volumes of experimental data are available
  • The presence and proportion of ideal and non-ideal combustion regimes should be compared across a variety of process conditions and wave modes

• Objective: Large-scale data analysis seeks to summarize proportional heat release associated with commensal, parasitic, and detonative combustion averaged across individual traces of OH* chemiluminescent data acquired at the detonation plane

[2] Nordeen
Water-Cooled NETL RDE

- Water-Cooled NETL RDE
  - Uncirculated water
  - Run times exceeding 30 seconds

- OH* Chemiluminescence Probe
  - Port A1 (0.683 cm downstream injector tip)
  - 1-mm diameter fused silica core aluminum buffer Accu-Glass Products fiber optic
  - Cleaved end of the fiber is exposed to the detonation channel, recessed 2 mm
  - Edmond Optics UG11 narrow band pass filter with center wavelength of 325 nm and full width half-max of 110 nm
Method – OH* Anatomy

- Systematic approach for large-scale data processing (no manual annotation)
  - Anatomy derived from University of Michigan
- OH* traces normalized across 10-11 second window
- Sample window width initialized according to dominant fast Fourier transform (FFT) frequency
- Adaptive window widths:
  - Peak OH* value is found within window
  - If peak lies outside 40-60% of window width, the window is shortened or broadened, respectively
Method – OH* Anatomy

- Regimes:
  - Parasitic combustion: begins as first sample
  - Detonation front: maximum second derivative
  - Commensal combustion: magnitude of first derivative falls below 40% of minimum
  - Commensal continues to end of sample window
- Each section integrated via trapezoidal integration
- Integrated values of each section are added to a 10-wave sum to generate relative percent combustion values
Method – Evaluation of Process

- Less ideal OH* traces due to operating conditions
  - Method addresses varying degrees of parasitic and commensal combustion as well as small magnitude detonations
- Individual vs. phase averaging
Method – Summary Data

- Sets of 10 concurrent waves are used to generate a single value for average relative combustion proportions.
- Values are found at 20 timesteps throughout the 10-11 second window.
- The average across the 1 second window is used as a datapoint representing the given operating condition.
Global Comparisons – Equally Spaced Waves

- Percent detonation vs. equivalence ratio at constant backpressure
  - Somewhat inverse relationship shown

- Percent detonation vs. wave count at various process conditions
- A clearer correlation between wave count and percent detonation
Global Comparisons – Equally Spaced Waves

- Percent detonation vs. wave velocity at varying process conditions
- Wave velocity extracted from FFT, divided by wave count

- Percent detonation vs. detonation time at various process conditions
- Detonation time is time from passing of wave front to commensal, multiplied by wave velocity
Global Comparisons – Galloping Waves

- Percent detonation for galloping waves should be considered
- Values are plotted alongside equally spaced waves

- Galloping waves show fairly comparable proportions of percent detonation
- Any short-timescale variations are not captured by averaging technique
Conclusions

• A method to analyze individual wave traces in experimental OH* probe data was proposed.

• Summary data points representing averages across 200 waves, comprised of 10-wave groupings were sampled at 20 successive time intervals throughout a 1 second window.

• Trends showed improved percent detonation for decreasing equivalence ratios, increasing wave counts, decreasing wave velocities, and increasing detonation time.
  • Suggesting that lower equivalence ratios, known to lead to lower wave velocities and increased wave counts at a given process state, result in extended detonation times, leading to increased percent detonation.
  • It is believed that an increasing wave number reduces the surface area of the fill region, thereby reducing contact burning which dominates parasitic combustion.

• This study has shown that larger wave numbers consume higher proportions of reactants through detonation, a primary goal of RDE design.
References


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