



Fundamental Studies to Enable Robust, Reliable, Low Emission Gas Turbine Combustion of High Hydrogen Content Fuels—University of Michigan

Background

The University of Michigan will perform experimental and computational studies which can provide an improved and robust understanding of the reaction kinetics and other fundamental characteristics of combustion of high hydrogen content (HHC) fuels that are vital to advancing HHC turbine design and to making coal gasification power plants environmentally sustainable and cost-competitive. The scope of work includes Rapid Compression Facility (RCF) studies of HHC ignition delay times and hydroxyl radical (OH) time-histories, flame speeds, and flammability limits. A range of temperatures, pressures, and test gas mixture compositions will be investigated experimentally and computationally. Accurate, detailed reaction mechanisms as well as simplified HHC mechanisms will be created. The reaction chemistry will be validated using the HHC RCF data and data in the archival literature. The computational work will include modeling studies of HHC flammability limits and flame auto-ignition interactions.

This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers. Both are managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from HHC fuels derived from coal that is clean, efficient, and cost-effective, minimizes carbon dioxide (CO₂) emissions, and will help maintain the nation's leadership in the export of gas turbine equipment.

Project Description

RCF experiments will be conducted to extend the high-quality, low-uncertainty experimental database of HHC combustion kinetic benchmarks over a range of operating conditions, including pressures (10–25 atmospheres), temperatures (700–1700K), and the effects of dilution with exhaust gases (where uncertainties in third body coefficients become particularly important). Flammability limits and flame/auto-ignition interactions will be determined computationally and experimentally. The RCF data will provide rigorous targets for development of accurate, well validated, detailed, and reduced chemical kinetic reaction mechanisms for HHC combustion, including nitrogen oxide (NO_x) chemistry.

NATIONAL ENERGY TECHNOLOGY LABORATORY

Albany, OR • Anchorage, AK • Morgantown, WV • Pittsburgh, PA • Sugar Land, TX

Website: www.netl.doe.gov

Customer Service: 1-800-553-7681

the **ENERGY** lab

PROJECT FACTS

Hydrogen Turbines

CONTACTS

Richard A. Dennis

Technology Manager, Turbines
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4515
richard.dennis@netl.doe.gov

Mark C. Freeman

Project Manager
National Energy Technology Laboratory
626 Cochran's Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-6094
mark.freeman@netl.doe.gov

Margaret S. Wooldridge

Principal Investigator
Mechanical and Aerospace Engineering
Departments
University of Michigan
2350 Hayward Street
Ann Arbor, MI 48109-2125
734-936-0349
mswool@umich.edu

PARTNERS

None

PROJECT DURATION

Start Date	End Date
10/01/2011	09/30/2014

COST

Total Project Value
\$635,561

DOE/Non-DOE Share
\$499,998/\$135,563

AWARD NUMBER

FE0007465



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ENERGY

Goals and Objectives

The primary goal of this project is to develop a thorough and quantitative understanding of important HHC fuel combustion properties at conditions relevant to gas turbine operation. Flammability limits and flame/auto-ignition interactions will be determined computationally and experimentally. The experimental data will provide rigorous targets for development of accurate, well-validated models for detailed and simplified chemical kinetic reaction mechanisms for HHC combustion, including NO_x chemistry. The efforts include distillation of the fundamental data into forms that will aid the rapid transfer of information into syngas turbine design and provide new quantitative assessment of HHC combustion at conditions directly applicable to gas turbines. Specific project objectives are as follows:

- To develop an accurate and rigorous experimental and computational database of HHC fuel combustion covering reaction kinetics, flame speeds, and flammability limits of HHC fuels, including mixtures with high levels of exhaust gases.
- To develop detailed and simplified models of HHC chemical reactions that accurately reproduce the new experimental data as well as data in the literature.
- To develop a quantitative understanding of the stability of HHC combustion in relation to fluctuations in the flow field, including the opportunities and challenges of exhaust gas recirculation (EGR) on extinction, ignition, and flame stability.
- To develop domain maps that identify the range of conditions (e.g., percent EGR) where HHC combustion can be effective in both positive and negative manners such as expanded or restricted flammability limits.

Accomplishments

- Experiments of syngas ignition targeted to identify criteria for weak and strong ignition were completed.
 - The results demonstrate that for experiments with strong ignition behavior the Li et al. (2007) chemical mechanism applied in a zero-dimensional homogeneous reactor simulation accurately predicts the measured auto-ignition delay times.
 - A close relationship between transitions in weak and strong ignition behavior and transitions across the classical and extended 2nd limits of H_2/O_2 explosion was demonstrated using a pressure/temperature map of ignition behavior.
- Uncertainties in the key reactions in the detailed reaction mechanism for syngas combustion were quantified in this study and shown to be significant at the conditions of interest to gas turbine combustors.

Benefits

This UTSR project supports DOE's Hydrogen Turbine Program that is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. Fundamental data from this project will provide a new quantitative assessment of HHC combustion at conditions directly applicable to gas turbines and aid the rapid transfer of information into syngas turbine design.

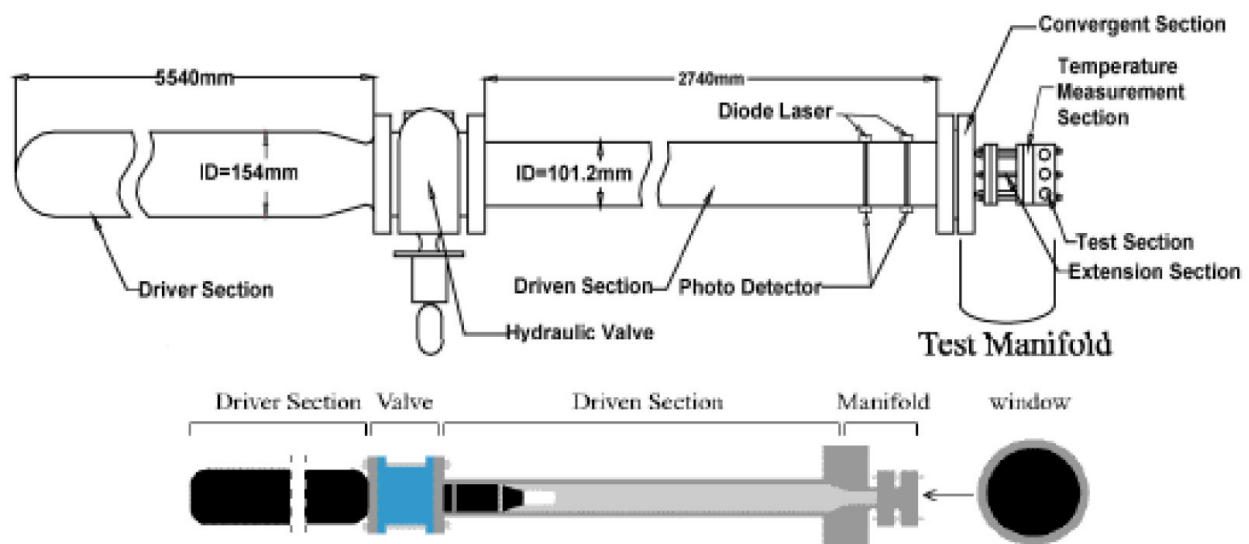


Figure 1. University of Michigan Rapid Compression Facility.

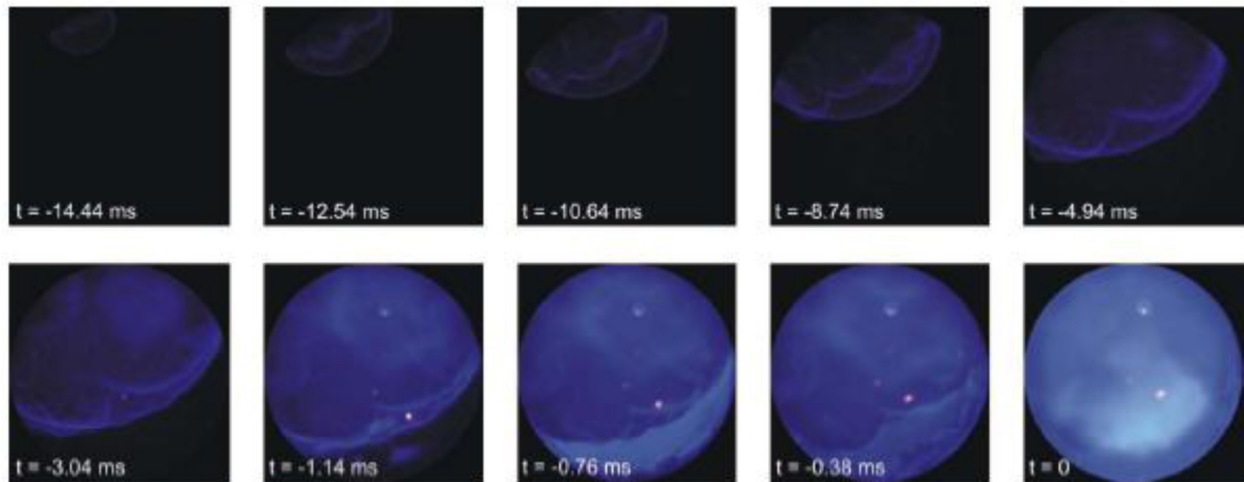


Figure 2. Example Time-Sequence of Images (Recorded with High-Speed Imaging Data Capability) that Documents a Weak/Localized Ignition Event Prior to Complete Combustion.

In Figure 2, notice how non-homogeneous the images are during the time sequence, which is indicative of some localized ignition event occurring at earlier stages before the remainder of the fuel mixture is observed to completely ignite. This localized ignition event is complex and influences the temperature, pressure, and thereby the reaction chemistry of the surrounding fuel mixture, and thus the entire experiment.

Figure 3 shows that the localized ignition event causes the pressure to increase (as the gas mixture temperature increases and more fuel gradually ignites) prior to complete combustion.

The RCF imaging capability provides a powerful diagnostic tool to evaluate fuel mixture behavior that is useful to interpret experimental data and provide insights pertinent to the underlying detailed reaction mechanisms governing ignition/combustion behavior of fuels.

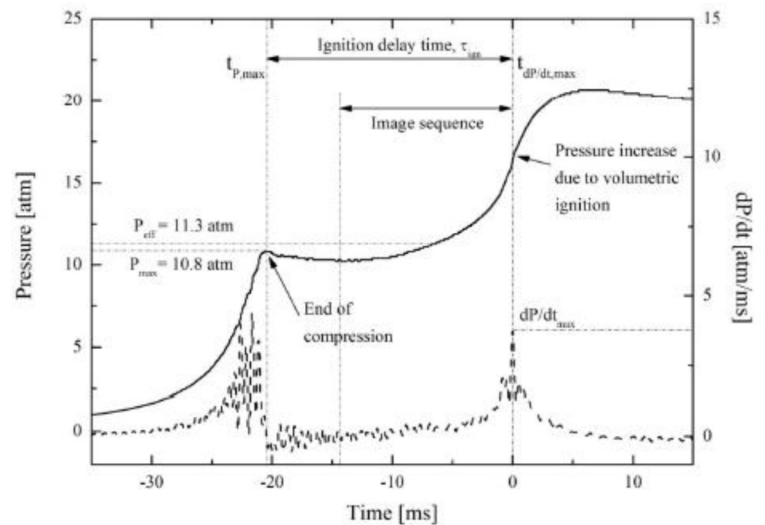


Figure 3. Pressure-Time History in RCF Experiment Where Localized "Weak" Ignition is Observed.

In the RCF experiment of Figure 3, a fuel containing 20% H_2 /80% CO at an equivalence ratio of 0.4 and inert: O_2 ratio of 3.76 was initially compressed to about 11 atm. and effective temperature of 1004 K.

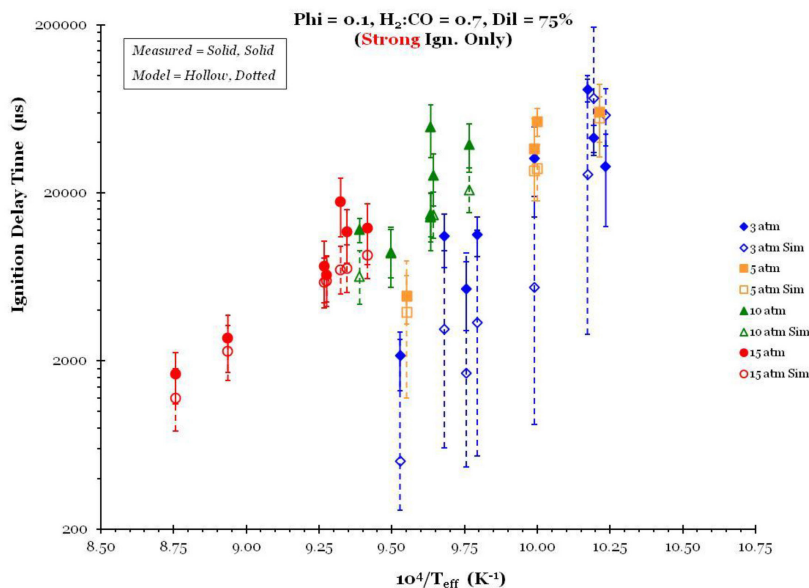


Figure 4. Comparison of experimental (solid symbols and error bars with solid lines) and modeling results (open symbol and error bars with dashed lines) for syngas ignition over a range of temperatures and pressures. There is excellent agreement between the experimental and predicted values at all conditions; however, the uncertainties in the syngas reaction chemistry are large at lower pressures as noted by the larger error bars.

Reference:

Kalitan, D.M., Petersen, E.L. et al., 2007. Ignition and Oxidation of Lean CO / H₂ Fuel Blends in Air. *Journal of Propulsion and Power*, 23(6), pp.1291–1303

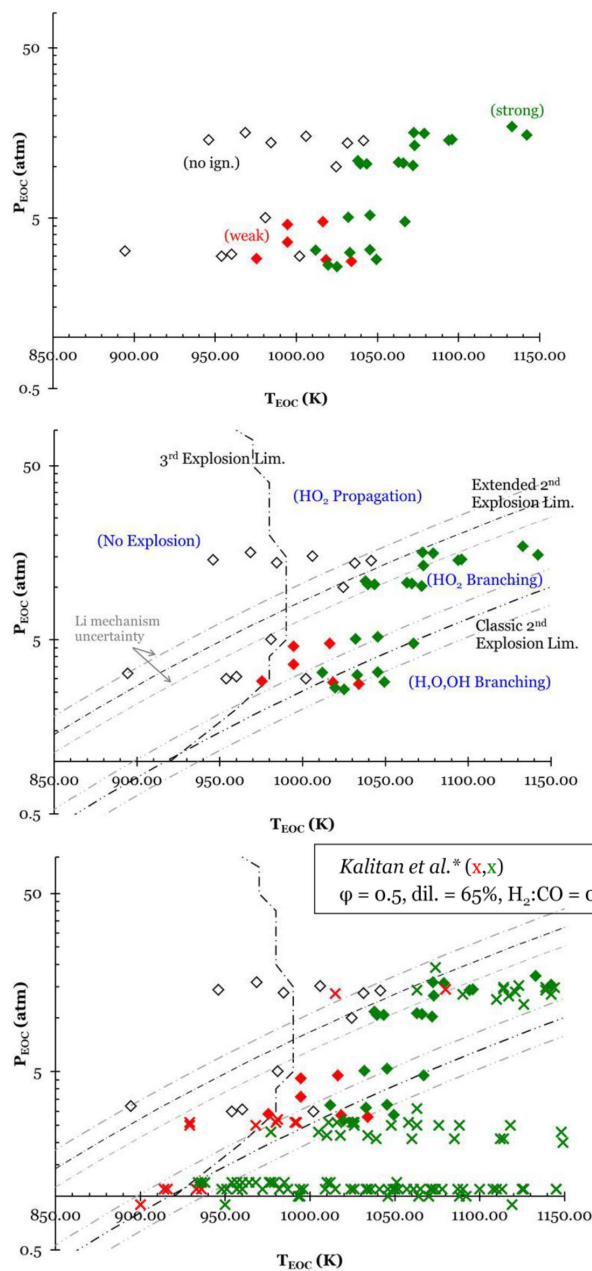


Figure 5. Pressure/temperature ignition maps. Top panel: results of ignition experiments showing the transition between weak and strong ignition as a function of fixed pressure. Middle panel: superposition of the H₂/O₂ explosion limits with the experimental data of the top panel. Note the close relationship between the transitions between ignition regimes and the explosion limits. Bottom panel: experimental results from current work and previous ignition studies by Kalitan et al. Consistent results are seen from different experimental facilities and spanning a broad range of conditions. Together the results indicate the changes in ignition behavior are not random and the relationship of the conditions to the explosion limits may be an indicator for predicting weak ignition behavior.

