The Effects of Fuel Distribution, Velocity Distribution, and Fuel Composition on Static and Dynamic Instabilities and NO_x Emissions in Lean Premixed Combustors

FACT SHEET

I. PROJECT PARTICIPANTS

Domenic A. Santavicca, The Pennsylvania State University, 132 Research Building East, University Park, PA 16802
(814) 863-1863
das8@psu.edu

Tom George, National Energy Technology Laboratory, P O Box 880, 3610 Collins Ferry Rd, Morgantown, WV 26507-0880
(304) 285-4825
tgeorg@netl.doe.gov

Richard Wenglarz, South Carolina Institute for Energy Studies, 386-2 College Ave., Clemson, SC 29634
(864) 656-2267
rwnglrz@clemson.edu

II. PROJECT DESCRIPTION

A. Objectives

The objectives of this research are (1) to determine the effect of combustor operating conditions on the static and dynamic stability characteristics of lean premixed combustors operating on natural gas and coal-derived syngas fuels, (2) to use this information to gain new insights and understanding of the causes of unstable combustion, and (3) to use this information to support the development of advanced numerical models and phenomenological-based models of unstable combustion.

B. Background/Relevancy

Background. Static and dynamic instabilities continue to be limiting factors in the development and use of lean premixed gas turbine combustors for achieving the NO_x emission levels required by current and future emissions regulations. These issues assume even greater significance with current interest in the effects of fuel variability, which includes variations in the composition of natural gas, the use syngas fuels, and the use of 100% hydrogen fuel, as well as recent interest in the use of "oxygen-combustion". To date, the only successful strategy for addressing these problems is through the application of passive and, in a few cases, active control systems after instabilities have been encountered. Such solutions are not always successful, can be expensive to implement and usually do not work over a broad range of operating conditions.

Relevance. This research program is intended to provide the detailed data and phenomenological understanding that is needed to improve our understanding of the factors affecting static and dynamic stability, to predict the occurrence of lean blowout and unstable combustion, and to formulate models that can be used as the basis of a methodology for designing stable lean premixed combustors.

C. Period of Performance. 7/01/03 – 06/30/06

D. Project Summary

Under the University Turbine Research (UTSR) program, The Pennsylvania State University is conducting research on the effect of combustor operating conditions on the static and dynamic stability of lean premixed combustors operating on natural gas and syngas fuels. The goals of this research are (1) to experimentally determine the effect of operating conditions and fuel composition variability on the static and dynamic stability characteristics of lean premixed combustors, (2) to use this information to gain new insights and understanding of the causes of unstable combustion, and (3) to use this information to formulate and validate phenomenological models for predicting the effect of operating conditions and fuel composition variability on the lean blowout limits and dynamic stability limits of lean premixed combustors.

III. PROJECT COSTS

$382,543

IV. MAJOR ACCOMPLISHMENTS SINCE BEGINNING OF PROJECT

Combustion Dynamics

- A variable length optically-accessible combustor has been constructed for the study of unstable combustion.

- Measurements of combustor pressure fluctuations, overall heat release fluctuations and flame structure have been made over a broad range of operating conditions in our variable length combustor operating on natural gas fuel and a range of natural gas – hydrogen – CO fuel mixtures. In all cases the fuel and air were premixed upstream of the choked inlet to ensure that there were no equivalence ratio fluctuations.

- It has been shown that a flame-vortex time-lag model and stable flame structure measurements can be used to predict the operating conditions at which unstable combustion occurs.

- It has been shown that stable flames having the same flame structure have the same preferred instability frequency, irrespective of the inlet temperature and fuel composition.

- A study of the potential of using Fluent to predict the flame shape, and therefore the preferred instability frequency, was initiated.

Lean Blowout

- An extensive set of experiments has been conducted to determine the effect of inlet velocity and inlet temperature on the lean blowout limit of hydrogen-natural gas-carbon monoxide fuel mixtures.

- It has be shown that both hydrogen and carbon monoxide extend the lean blowout limit to lower equivalence ratios, where the effect of hydrogen is greater.

- It has been shown that the lean blowout limits for the range of fuel mixtures tested can not be correlated with equivalence ratio, adiabatic flame temperature or laminar flame speed.

- Two-dimensional chemiluminescence images of the flame indicate that combustion in the dump plane recirculation zone plays an important role as lean blowout is approached.

- It has been shown that modeling combustion in the recirculation zone as a stirred reactor gives encouraging predictions of the lean blowout limits over a broad range of fuel mixtures.

• It has been shown that as the angle of the dump plane decreases, relative to the axis of the combustor, the lean blowout limit is extended to leaner conditions.

Chemiluminescence Measurements

• Experiments have been conducted to study the effects of equivalence ratio and velocity on the relationship between the overall chemiluminescence intensity and the overall rate of heat release in stable and unstable flames.

• It has been shown that the relationship between the overall CH* chemiluminescence intensity and the overall rate of heat release is independent of the velocity in stable and unstable flames if the background CO_2* chemiluminescence is subtracted from the CH* chemiluminescence.

• It has been shown that the overall CH* chemiluminescence intensity, after subtracting the background CO_2* chemiluminescence, provides a quantitative measure of the temporal variations in the overall rate of heat release during unstable combustion if there are no equivalence ratio fluctuations.

• It has been shown that in order to make quantitative chemiluminescence-based measurements of the overall rate of heat release during unstable combustion when there are equivalence fluctuations, it is necessary to make an independent measurement of the time varying equivalence ratio.

V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS

None – project completed.

VI. MAJOR ACCOMPLISHMENTS PLANNED IN OUTYEARS (6-18 MONTHS)

A proposal has been submitted to continue this work and in particular, to study the effect of equivalence ratio fluctuations.

VII. ISSUES

It should be noted that the actual tasks that have been worked on are significantly different from those in the original statement of work. In particular, the study of the effect of the inlet velocity distribution on static and dynamic stability has been replaced by two other tasks. The first is a study of the instability driving mechanisms which are most important in practical combustors, i.e., flame-vortex interaction and feed system coupling. The development of the variable length combustor, which was not part of the original statement of work, has provided a valuable and unique opportunity to investigate the relationship between the mechanisms of unstable combustion and the operating conditions. The second activity which was not in the original statement of work is the assessment of chemiluminescence-based quantitative heat release measurements in stable and unstable flames. The viability of this measurement had not been previously demonstrated, therefore it was deemed essential to address this issue before further studies of unstable combustion were conducted.

VIII. ATTACHMENTS

None