Final Report on the Project

Advanced Concepts for High Efficiency and Low NO_x Gas Turbine Combustor Development

Submitted to

Advanced Gas Turbine Systems Research
South Carolina Energy Research and Development Center
386-2 College Avenue
Clemson University
Clemson, SC 29634-5181
Attn.: Dr, Dan Fant

By

The Combustion Laboratory
University of Maryland
Department of Mechanical Engineering
College park, MD 20742

Principal Investigator: Professor Ashwani K. Gupta
Co-Principal Investigator: Professor Mark J. Lewis

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Summary

During the performance period on the contract from August 15, 1994 to April 15, 1998 we developed a premixed/partially premixed swirl burner experimental facility which simulated a nozzle cup used in many gas turbine combustors. The burner could be operated in either the premixed mode or partially premixed mode. This burner allowed systematic variation of the distribution of swirl and flow in the burner. Data were obtained on the thermal and chemical behavior of the flames formed via various combinations of the radial distribution of swirl in the burner and momentum of the flow, and mixture equivalence ratio. The results showed significant effect of swirl and flow distribution on the thermal signatures of the flames. The burner dome geometry was also found to be important. Data were obtained at various spatial positions in the flames on mean and rms temperatures, integral- and micro-thermal time scales, probability density function of temperatures, thermal power spectra using high frequency compensated thermocouples. A total of 17 flames, formed with a suitable combination of swirl distribution, flow and momentum distribution in the burner, gas fuel chemical property, and equivalence ratio. Results have also been obtained with co- and counter-swirl distribution in the swirl burner. Emissions from the flames, obtained at the burner exit, have been correlated with the local thermal behavior of the flames. The results have shown good correlation between emissions and large value of thermal time scales. This in turn reveals that in order to have low emissions swirl distribution in the burner must be controlled so that one achieves low value of the integral thermal time scales at all locations in the flame. Planar Laser Induced Fluorescent (PLIF) studies showed increased fragmentation of the reaction zone under premixed flame conditions as the mixture was made leaner. In the PLIF studies OH was used as the marker for the reaction zone. Under leaner mixture conditions burning of the mixture as local flamelets was found. The presence of local flamelets can be viewed as local diffusion flames which are known to give high emission levels. The characteristic frequency generated by the flamelets under leaner flame conditions can also give rise to instability. A change of swirl distribution in the burner can reduce fragmentation of the reaction zone. As the mixture was less lean (i.e., richer mixture) the flame reaction zone appeared uniform from the PLIF images. The results from this study have, therefore, demonstrated that swirl can be used to enhance mixing and control instability in swirl stabilized flames used in gas turbine combustors. Poor distribution of swirl in the burner can increase emissions and enhance instability.

Experimental Facility

A schematic diagram of the swirl burner facility used here is shown in Fig. 1. It consists of a double concentric swirl burner having a central nozzle (without swirl). The swirl strength in the two annuli can be independently varied. The mixture ratio in the central nozzle and the two annuli can be independently varied. The flame formed from the burner was enclosed in a large size chamber which isolated the flame from external disturbances. Sample photographs for flames 1-5 is shown in Fig. 1a while those for flames 11-16 is shown in Figs. 1b. Photographs for flame 17 and 18 are given in Figure 1c. No flame could be obtained for flame 6 conditions. In figures 1a and 1b, in any row, the swirl is maintained constant while the momentum of the flow between annulus 1 and 2 is varied (keeping momentum in annulus 2 constant). In any column the momentum is maintained constant while the swirl is varied. The respective flow and swirl distribution for each flame is given at the bottom of the flame photo.

The stability limits of premixed flames could be significantly enhanced using partial premixing, see