Flame investigation of a gas turbine burner using OH PLIF and high speed chemiluminescence imaging

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Abstract

The design rules for gas turbine (GT) burners are always advancing toward achieving cleaner energy and improving fuel economy. Though, the progression in combustion efficiency, almost 100% oxidation of fuel, can reduce carbon monoxide (CO) emission significantly, the high combustion temperatures can yield high levels of nitrogen oxides (NO_x) and the regulation of which is continually tightened. NO_x can be reduced by premixed combustion at lower equivalence ratio. It can lower the temperature and hinder the thermal NO_x creation pathway. However, the lean premixed mode of operation may move the combustor towards unstable conditions that induce local extinction, poor combustion efficiency, and combustion instabilities. Inclusion of a diffusion pilot flame to the burner can help to stabilize the lean premixed combustion. However, this also increases the NO_x production. For retaining stability and reducing the NO_x, a premixed pre-chamber combustor can be used along with pilot. It improves the blowout characteristics by supplying radicals, arising from the products, and heat to the other burner sections for holding the main flame. A 4th generation dry low emissions (DLE) burner, developed by Siemens Industrial Turbomachinery, has a center body rich-pilot-lean (RPL) pre-combustor with pilot section. RPL can be operated from fuel lean to fuel rich conditions and the selection of lean or rich conditions depends on the optimization of the combustion stability concerning LBO and minimizing NO_x emissions. Improvements on the lean stability limit can be achieved by increasing the equivalence ratio in the RPL. For methane, increasing the equivalence ratio of RPL can lower LBO limit. On the contrary, it increases NO_x production.

Experiments were performed on the central pilot body (RPL- rich-pilot-lean) of Siemens prototype 4th generation DLE burner to investigate the flame behavior at atmospheric pressure condition when varying equivalence ratio, residence time and co -flow temperature. The burner assembly is composed of three concentrically arranged premixed burner sectors: a radial swirled outer main sector, an axial swirled intermediate sector (Pilot) and a jet swirled central body burner or RPL (Rich-Pilot-Lean) section. Fuel flow to each of these sections is individually controlled and the central body RPL has separate fuel and air feeds. The RPL burner has a mixing chamber where fuel and air enters tangentially and mixes. For

investigation, the RPL section has been mounted in an atmospheric pressure test rig using an adapter. The adapter throat has same diameter as the intermediate sector (Pilot), but lacks of swirl vanes. Fuel and air were supplied to the burner from gas tubes and the air was preheated to 650K. The test rig supports controls and operations as well as provides monitoring system of operating parameters.

The flame at the RPL burner exit was investigated applying OH planar laser-induced fluorescence (PLIF) and high-speed chemiluminescence imaging. OH PLIF measurement was taken by exciting the $Q1(8)$ transition of the OH radical with 283 nm. A frequency-doubled (532 nm) Nd:YAG laser was used to pump a tunable dye laser (operating with Rhodamine 590). The output wavelength (566 nm) of the dye laser was frequency doubled and tuned to the Q1(8) transition. Approximately 5 cm laser sheet was formed using sheet forming optics (-40 mm cylindrical and +500 mm spherical lens) and were passed through the mid-line of the burner exit. The laser pulse energy varied between 12mJ to 14mJ during measurements. The resulting OH fluorescence, at 310 nm, was collected perpendicular to the laser sheet with a high-speed camera (Phantom V7.1, Vision Research). It was fitted with an image intensifier and a UV sensitive lens (UV-Nikkor, f/4.5, f = 105 mm). To suppress scattering interference occurring from the laser light and background radiation, a combination of a UG11 filter and a WG305 long-pass filter was used in front of the camera. The detector was set to an exposure time of 50 ns to further limit the background contribution from flame chemiluminescence. For each flame condition, 1000 single-shot images were collected with 10 Hz frequency. No corrections for signal trapping, quenching and laser sheet energy distribution were applied. The same detector system used for OH PLIF, was used for the flame chemiluminescence imaging with no filter. The camera was used with an exposure time of 100 μs at a repetition rate of 3 kHz.

The results from chemiluminescence imaging and OH PLIF show that the size and shape of the flame are clearly affected by the variation in operating conditions. For both preheated and non-preheated co-flow cases, at lean equivalence ratios combustion starts early inside the burner and primary combustion comes to near completion inside the burner if residence time permits. For rich conditions, the unburnt fuel escapes out through the burner exit along with primary combustion products and combustion subsequently restarts downstream the burner at leaner condition and in a diffuse-like manner. For preheated co-flow, most of the operating conditions yield similar OH PLIF distributions and the flame is stabilizing at approximately the same spatial positions. It reveals the importance of the preheating co-flow for flame stabilization. Flame instabilities were observed and Proper Orthogonal Decomposition (POD) is applied to time resolved chemiluminescence data to demonstrate how the flame is oscillating. Preheating has strong influence on the oscillation frequency.