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Combustion of Cross Impinging Air-sheathed Spray Jets in Stagnation-Point Reverse Flow

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Extended Abstract

A unique lean-lean two-stage combustion concept was proposed by one of the present authors for achieving ultra-low NOx emissions from gas turbines over a wide range of power while maintaining high combustion efficiency and suppressing combustion oscillation. It is characterized by the reactions of lean to ultra-lean secondary mixtures injected into the combustion products from the lean-burn primary stage. Its advantages over the conventional two-stage approach have been demonstrated not only with gas-fueled gas turbines but also for liquid-fueled ones [1].

In the present study, for a further reduction of NOx emissions, a pair of air-sheathed kerosene spray jets were cross impinged in the primary stage at an angle of 60 degrees so that the resulting combined jet could develop along the centerline of the cylindrical flame tube (80 mm in diameter) towards the combustor dome to establish a reverse flow field. In the secondary stage, another pair of air-sheathed kerosene spray jets were opposingly impinged. In each injector, the fuel was atomized by pre-filming air-blast atomizer and the resulting spray was sheathed by the non-swirling air flow. The use of the sheath of straight air flow is the key in suppressing NO formation: it prevents fuel droplets from penetrating into the hot burned gas and pre-vaporization of fuel droplets and premixing of the resulting fuel vapor with the sheath air can be enhanced appreciably before combustion.

Emissions measurements were conducted at atmospheric pressure and at combustor inlet air temperatures of 293, 423 and 537 K for combustor dome lengths of 40 and 80 mm. Effects of the distance between primary and secondary mixture injection positions, 60 and 180 mm, was investigated. Planer imaging of Mie scattering by droplets in the spray, and OH and CH chemiluminescence in the quartz flame tube were recorded by using a high-speed camera. The flow rate of the sheath air for each injector was fixed at 10 g/s while the air flow rate to the atomizer, m_a, was varied from 0.4 to 1.5 g/s to change the level of atomization. The droplet size distribution of the sprays was measured at isothermal conditions by a laser diffraction droplet size analyzer and the derived correlations of mean diameters with m_a and fuel flow rate were used to estimate the level of atomization. Combustion efficiency greater than 99.9% were obtained when adiabatic flame temperature was higher than 1500 K at the combustor exit. The NOx emissions level for a fixed adiabatic flame temperature was decreasing monotonically with increasing level of atomization and was higher for the shorter combustor length. This trend of NOx emissions with level of atomization and combustor dome length are explained by improved fuel vaporization and premixing of the fuel vapor and air before combustion. The results of imaging of fuel spray, flame, and OH and CH imaging as well as local gas temperature measurements in the primary stage support the above reasoning for the higher NOx measured at lower atomization level and shorter time for pre-vaporization and pre-mixing of fuel and air in the shorter combustor dome length.

References

[1] H. Fujiwara, M. Koyama, S. Hayashi, and H. Yamada, “Development of a liquid-fueled dry low emissions combustor for 300 kW class recuperated cycle gas turbine engines,” *ASME Turbo Exposition*, ASME paper GT2005-68645, 2005.