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Large eddy simulation and preliminary modeling of the flow downstream a variable geometry swirler for gas turbine combustors☆

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ABSTRACT

This work presents a novel swirler with variable blade configuration for gas turbine combustors and industrial burners. The flow dynamics downstream the swirler was explored using Large Eddy Simulation (LES). The resolved turbulence kinetic energy in the region where the flow exhibits the main flow phenomena was well above 80% of the total turbulent kinetic energy of the flow. It was evidently shown that the new swirler produces a central recirculation zone and a Rankine vortex structure which are necessary for swirl flame stabilization. Two Reynolds-averaged NavierStokes (RANS) simulation cases utilizing the standard and realizable k-ε turbulence models were also conducted for two objectives. The first is to demonstrate the validity of RANS/eddy-viscosity models in predicting the main characteristics of swirling flows with comparison to the LES results. The second objective is to comparatively investigate the flow features downstream the new swirler in both co-rotating and counter-rotating blade configurations. The results show that the counter-rotating configuration produces higher turbulence kinetic energy and more compact recirculation zone compared to the co-rotating configuration.

1. Introduction and new concept

Swirling flows are commonly used to improve and control the mixing process between fuel and oxidizer streams to achieve flame stabilization and heat release rate enhancement [1]. The key to attain homogeneity of fuel/air mixture and consequently low NOx emission, is chiefly dependent on the swirling flow field which governs the main flow structure and its matchup with fuel distribution.

Multiple swirlers with distributed fuel injection system characterize modern gas turbine combustors. The rotating direction of multiple swirlers has a large effect on the size, shape and strength of recirculation zone and turbulence intensity, and hence it has significant effects on the mixing process, temperature pattern and exhaust gas emission. Merkle et al. showed experimentally that the counter-rotating swirl brings up larger area of near-stoichiometric mixture of fuel and air, resulting in higher temperature field distribution within the stabilization zone compared with the co-rotating swirl case [2].

The appropriate arrangement of multiple counter-rotating or co-rotating air swirlers with distributed fuel injection system allows the control of mixing pattern, flame structure and temperature via air distribution, swirl strength, and fuel spray [3–5]. Lean Direct Fuel Injection (LDI) combustion is one of such arrangements that enables the control of fuel/air mixing via co-rotating and counter-rotating swirl configurations and fuel injection matchup, which was shown to be critical for NOx emissions and combustion efficiency. Terasaki and Hayashi [5] showed that the NOx emission for a double-swirler burner was only half or a quarter of the conventional small-hub swirler or the large-hub swirler, respectively. Correa [6] studies the LDI concept and noticed that very high turbulence intensity (up to 20%) was achievable in LDI systems. Variable swirler configurations are capable of providing a certain desired flow field. Results for swirl combustion [7] suggest that the mode of fuel entry and swirl air organization is a promising way to achieve low NOx emissions. Gupta et al. [8] used variable air swirlers to control both the initial fuel-air mixing and the flame structure in the dome zone of the combustor. The results showed that significant changes in NOx emission levels could be obtained by small changes in the swirler configurations and the operational parameters. Temperature field in a dual concentric swirl burner with premixed flame showed that the flame of co-rotating swirler had a wide and long area of low temperature fluctuations compared with more intense and smaller temperature fluctuations of a counter-rotating case [9]. Temperature measurements in a non-premixed LDI with co/counter swirl [2] showed that the counter-rotating swirl had larger high temperature region. For premixed combustion [10], it was shown that counter swirl case generated a more compact flame, lower temperature field and less NOx

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