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Thermal and emission characteristics of reverse air flow CAN combustor

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ABSTRACT

Relative assessment of thermal and emission characteristics of conventional and reverse air flow CAN type gas turbine combustor is reported. Large Eddy Simulations (LES) are carried out with Wall Adaptive Local Eddy (WALE) viscosity model for sub grid scale stresses. Turbulence-chemistry interaction is modelled using presumed shape Probability Density Function (PDF) approach. Discrete Ordinates (DO) model is used for radiative heat transfer. Experimental measurement of temperature and NO_x emission level at the exit of combustors are reported. Flow pattern and flame shape obtained from numerical analysis for conventional and reverse air flow combustor are correlated to combustor liner wall heating, exit temperature characteristics and NO_x emission. The liner wall region of conventional combustor is dominated by hot combustion gases whereas the location of hot flame in reverse air flow combustor is in the vicinity of centreline. The exit temperature measurement shows that the wall side temperature in reverse air flow combustor is relatively low compared to conventional combustor. Reverse air flow arrangement in combustor eliminates the hot spots of high temperature gradient from primary region of combustor which results into significant reduction in NO_x emission level in reverse air flow combustor as compared to conventional combustor. Thermal imaging of outer wall of combustors demonstrates that the radiative energy transfer from liner wall to outer wall is small in reverse air flow combustor compared to conventional combustor. This depicts that the wall-cooling requirement decreases in reverse air flow combustor.

1. Introduction

The conventional combustor under consideration shown in Fig. 1 is roughly three/fourth scale model of a CAN type gas turbine combustor representative of the Rolls-Royce Tay gas turbine [1]. It features a fuelling device, air swirler, hemispherical head (dome) followed by cylindrical barrel with two rows of discrete air jets and circular to rectangular exit nozzle. Swirler, which is used to promote fuel-air mixing, is positioned in the annulus region surrounding the fuel injector on upstream end of the dome. CAN combustors, due to their simple design and ease of maintenance, are popularly used in aero industry in turboshaft engines and in industrial land based stationary gas turbines for power generation.

Several numerical and experimental studies demonstrating the performance assessment of conventional CAN type gas turbine combustors are reported in literature [1–8]. Study of literature revealed that the interaction between swirl and primary air jets mainly govern the combustion and emission characteristics of CAN combustor. In such combustors, the shape, size and stability of flame regime is controlled by a central toroidal recirculation region formed due to strong interaction between swirling flow and flow from primary jets. However, strategy of controlling flame by swirl-induced recirculation in conventional combustor has drawback that it forces the high temperature gases to flow in the vicinity of liner wall region in combustor. The flow pattern created by swirl and primary jet impingement sets the liner wall of the combustor to a very high temperature. There exists a large number of pockets of high temperature gradients in the primary region, which favours the evolution of large amount of NO_x from the conventional combustor. Studies [9–13] have revealed that the accurate assessment of wall temperature is essential in gas turbine combustor to choose optimum air required for cooling. A major part of heat transfer in combustor occurs by radiation from flame to wall and vice versa. The total radiative intensity is maximum in regions where temperature is maximum. Jones and Paul [12] and Paul and Jones [13] reported that the total radiative intensity was maximum near the liner wall region of combustor. This shows that liner wall of conventional CAN combustor is dominated by high temperature burnt gases which results into large heating of combustor liner.

In the past decades, several solutions have been proposed to reduce wall-cooling requirements of gas turbine combustors. These include thermal barrier ceramic coating and various other cooling techniques such as film cooling, jet impingement cooling etc. Ali et al. [14] reported that the liner wall temperature could be reduced by 800 °C when cooling holes were provided on liner wall of combustor. Li et al. [15,16]

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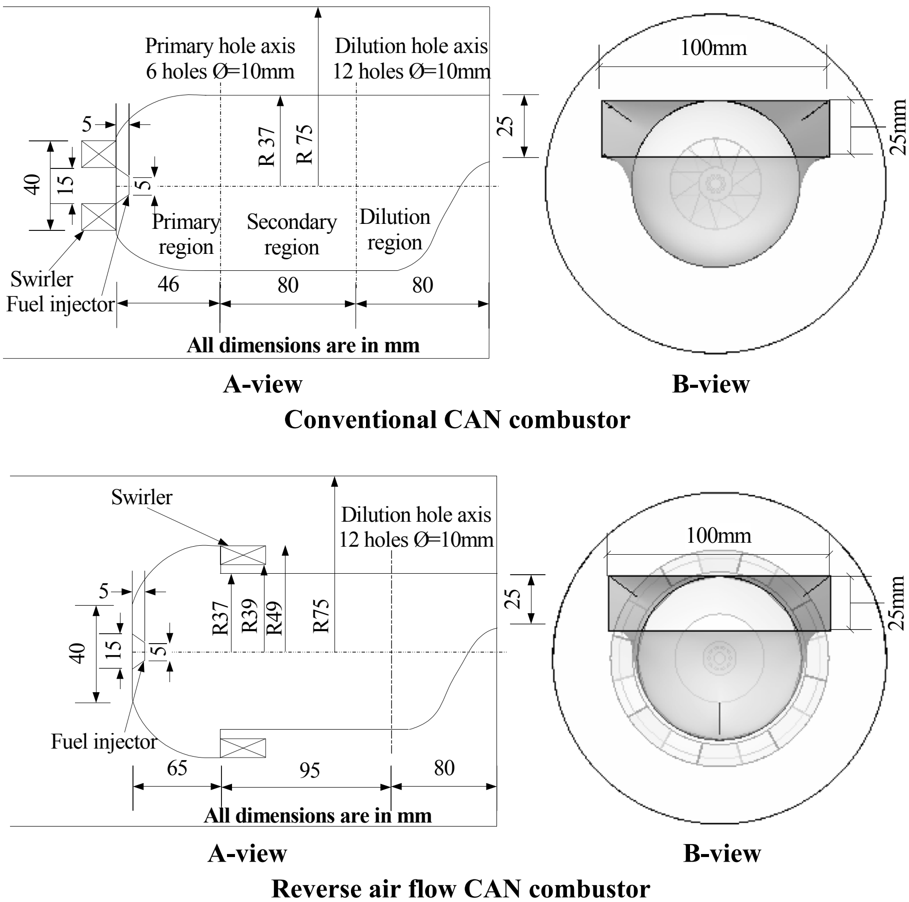

Fig. 1. CAN combustor configurations.

and Scrittore et al. [17] investigated the effect of dilution jets on film cooling performance. They found that dilution jets disrupted the film cooling performance. An increase in dilution jet depth reduced the effectiveness of cooling jet. Para et al. [18] studied the effect of mist concentration and blowing ratio on film cooling effectiveness. They stated that film cooling effectiveness was improved by 11% by mist injection of 2%. However, the film cooling method found less efficient when pressure and temperature of air at compressor outlet are high. To compensate for this, large amount of total air is required for liner cooling. This results into rich burning in primary zone of combustor, which favours higher emissions of CO and UHC. The combustor liner wall cooling technology has advanced over the years. Composite matrix liner was reported to require least amount of cooling air [19]. However, production cost for composite matrix liner is significant compared to film cooling technique. Ribbed structure also reported to enhance the heat transfer from the heated liner surface and keeps the liner wall at relatively low temperature [20]. However, ribbed structures results into increase in overall weight of the engine.

Arai et al. [21] and Furuhata et al. [22] introduced a new low NO_x combustor based on the philosophy of upward swirl (reverse air flow) for micro gas turbine. In this combustor, the position of swirler was set between primary zone and secondary combustion zones. The combustion air was forced to flow in reverse axial direction towards the combustor bottom from where the fuel spray was injected through a fuel injector. Due to the alteration in the swirling air entry, lean and non-luminous flame was produced in the primary region of combustor. The burned gas recirculation and highly turbulent shear flow in the primary zone caused by the upward swirl resulted into lower value of NO_x emission from combustor. Measurements of CO and NO_x emission indexes showed that the upward swirl combustor keeps the emission indexes very low for wide range of flow conditions.

The philosophy of reverse air flow is used here for CAN type gas turbine combustor in order to minimize the wall cooling requirements and NO_x emission. The present work reports numerical and experimental studies towards relative assessment of thermal and emission characteristics of conventional and reverse air flow CAN type gas turbine combustor. Experimental measurement of temperature and NO_x emission level at the exit of both combustors are reported. The numerical predictions of flow and flame characteristics in both combustor configurations are correlated to liner wall heating, exit temperature characteristics and NO_x emission generation. Thermal imaging of outer wall of combustors is performed to analyse the wall temperature distribution in both combustors along with comparison between simulated temperature contours and experimentally captured thermal images.

2. CAN combustor models

The CAN combustor configurations selected in the present work shown in Fig. 1 are reported in Shah and Banerjee [23]. The conventional combustor presented in Fig. 1 comprises of fuel injector, swirler followed by hemispherical head (dome), one row of primary holes and one row of dilution ports on cylindrical barrel and circular to rectangular nozzle. Fuelling device is a conical shaped fuel injector where fuel jets are arranged on 90° cone. It injects gaseous fuel through ten 1.7 mm diameter holes circumferentially placed on pitch circle diameter of a 90° cone located centrally at the upstream end of hemispherical head. A swirler with 10 flat vanes at 45° angle to the flow is placed circumferentially around the fuel injector on the head of the combustor. In conventional combustor, one row of primary holes and one row of dilution holes are located in the intermediate barrel section. There are 6 primary holes and 12 dilution holes having diameter of 10 mm pierced through the liner surface in conventional combustor.