Advanced Science and Technology Letters
Vol.90 (Mechanical Engineering 2015), pp.39-43
http://dx.doi.org/10.14257/astl.2015.90.09

# Numerical Evaluation of the Flow and Emission Characteristics in a Can-Combustor with Excess-Air Ratios

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**Abstract.** The main focus for the development of low emission combustor is to minimize the harmful emissions to atmosphere. In order to belittle the emissions, stable combustion conditions are required to completely burn a given amount of fuel. To evaluate this problem, two staged combustion is adopted to suppress the emission in the combustor by the provision of excess air for pollution free environment. Gas turbine combustor incorporates a modest amount of 5 to 10% excess air to burn the natural gas-fuel completely. In this work, the effect of excess air ratios on combustion gas temperature and emission characteristics of a gas turbine have been investigated. The main objective of this problem lies in preventing harmful emissions for high performance combustor without affecting the turbine performance.

**Keywords:** Excess Air Ratios, Gas Turbine Combustor, Harmful Emissions, Two Staged Combustion.

## 1 Introduction

With the growth in air traffic worldwide, pollution caused by aircraft jet engines can no longer be ignored. The residual unburned fuel in the gas turbine combustor after the stoichiometric combustion process encounters harmful emissions due to the insufficient availability of air to complete the combustion process. The motivation of the present work lies in the provision of excess air beyond stoichiometric proportion to establish the complete combustion process and prohibit the harmful emissions.

The previous work was accomplished with the emission characteristics for different flow configurations of various swirl angles and motility of holes in the secondary chamber [1]. To meliorate the performance of the can combustor, numerical evaluations are carried out in this work to mitigate the emissions with respect to the excess air ratios. Subsequently, the experiment conducted by Martinez et al. [2] assists to investigate the combustion gas temperature by the effect of excess air ratios. On the other hand, from the literature work of Reddy and Kumar [3],

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ISSN: 2287-1233 ASTL

computational analysis of the flow features were examined to measure the pollutant emissions of $NO_X$. The insight of the swirling flow to increase the combustor performance and preferring best swirler angle by CFD technique was predicted by Eldrainy et al [4]. Notably, the flow visualization measurement technique was experimentally investigated by Koutmos and McGuirk [5] to understand the complex flow events inside the combustor. To meet the needs of developing swirl combustion technology leading to low $NO_X$ emission, the turbulent swirling reacting flow in a combustor with staged air injection was experimentally studied by Jian et al [6]. In addition, a methodology was proposed by Levy et al [7] to reduce the combustion gas temperature by recirculation of the secondary air stream. As a matter of fact, Duwig et al [8] experimentally addressed the homogeneous temperature distribution for various equivalence ratios to reduce the harmful emissions and avert combustion instabilities. Finally, the can combustor was numerically investigated by Ghenai [9] to compare the performance of both natural gas and syngas fuels.

The main objective of this work is to minify the $NO_X$ emission by establishing the operational and effective excess air ratio. The present study aims to investigate the effect of temperature on the emission level, especially $NO_X$, for a selected type of methane fuel. The problem setup with excess air ratio depends upon the requirement to achieve the combustion outlet temperature. Temperature reduction is significant in lowering the levels of $NO_X$ being released into the atmosphere during combustion. Since the combustion temperature plays a key role in influencing the emissions, the diminution of temperature magnitude assists in controlling the harmful emission.

## 2 Numerical Methodology

The governing equations involving three-dimensional, steady state and turbulent reacting flow inside the combustor model are carried out in this work. The model has been created using CATIA V5R19 and analyzed in CFX solver. The three dimensional forms of the Navier- Stokes equations with eddy dissipation combustion model and P1 radiation model are exercised. A two stage swirl flow combustor configuration is considered in this study comprising of primary and secondary chamber as shown in Fig. 1. Four different flow configurations of stoichiometric air to fuel ratio (AFR) with 3%, 5% and 10% excess AFR are examined. Primary air is injected through centrally mounted pressure swirl injector of 60 degree swirl angle containing 16 vanes, while the liquid fuel is injected through five normal injection ports and air from the secondary inlets are introduced by five normal injection ports for cooling the combustion products.

In figure 1, the length of whole combustion chamber and primary combustion chamber are represented as 340mm and 220mm notified with $X_S$, while the $Z_S$ points the secondary inlet hole position of 210mm towards the downstream flow direction. For graphical perspectives, non-dimensional representation must be postulated to recognize the location in the combustor which are indicated as, $X/X_S=0$ (Main Inlet of the combustor), $X/X_S=0.7$ (Outlet of the primary combustor) and $X/X_S=1$ (Main Outlet of the combustor). The complete combustion of methane is enhanced by the main operating parameter called excess air ratio. The provision of excess air inside the can-combustor provides nominal estimation of emission characteristics.

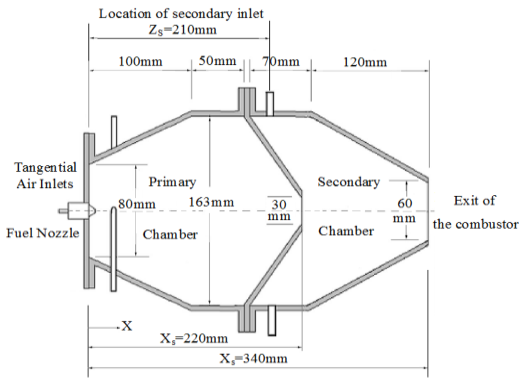
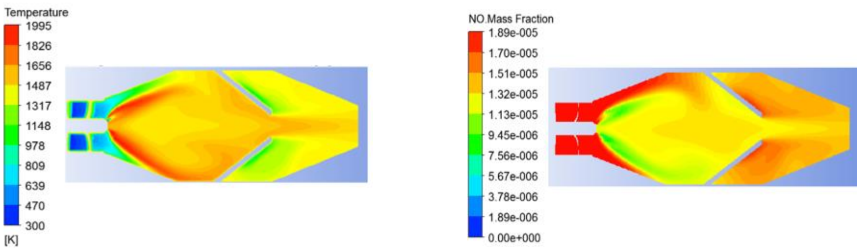



**Fig. 1.** Schematic diagram of the can combustor model



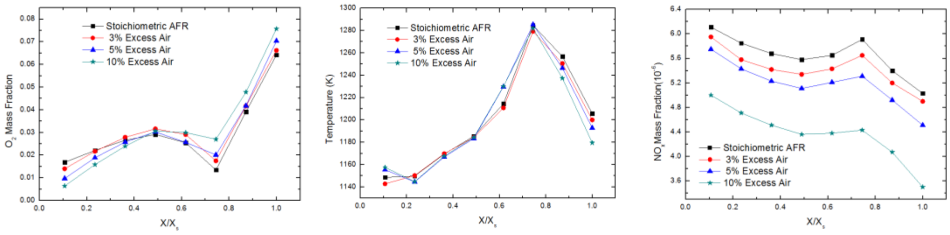

(a) (b)

**Fig. 2.** Flow visualization in can-combustor (a) Temperature contour & (b) $NO_X$ mass fraction

## 3 Results and Discussion

Fig. 2 demonstrates the flow visualization inside the can-combustor. The maximum temperature of 1995K is formed near the fuel injection region which is predicted on Fig. 2(a). The recirculation creates flame stability inside the combustor. The excess air ratio assists to burn the combustion mixture and reduces the temperature magnitude. The $NO_X$ mass fraction in Fig. 2(b) identifies the emission liberated during the combustion. With excess air, the cool air from the secondary inlet in the secondary chamber is supplied to put off the emission. Thus, the provision of excess air with the cool air from the secondary inlet mitigates the $NO_X$ concentration.

The graphical representation of the flow inside the can-combustor is pictured on Fig. 3. Fig. 3(a) shows the $O_2$ mass fraction plotted for different AFR. When the flow tends to go beyond $X/X_S$ =0.7, the oxygen mass fraction tends to increase due to furnishing of excess air. Thus for 10% excess air, the $O_2$ mass fraction is high at the exit of the combustor. Fig. 3(b) depicts the temperature magnitude of the can combustor drawn for different AFR. When the chemical reaction gets initiated, the temperature magnitude tends to increase slowly and rises to the peak value at the outlet of primary chamber at $X/X_S$=0.7. At the secondary chamber, cool air is provided to dilute the mixture temperature at the location of $Z_S$ =210mm. The most decrease in temperature value of 1180K for 10% excess air proves to be the optimum result. The $NO_X$ mass fraction of the can combustor for different AFR is explained on Fig. 3(c). The $NO_X$ value is found to be high for all AFR at the beginning of the process and gradually the $NO_X$ value diminishes at the secondary chamber. It is clearly predicted that $NO_X$ is mitigated by supplying excess air and the cool air from the secondary inlet also assists in diminishing the $NO_X$ magnitude. Depending upon the temperature magnitude, the $NO_X$ emission is determined by the species equation. Finally, the lower magnitude of $NO_X$ mass fraction is exhibited for 10% excess AFR due to the effect of combustion temperature and by the provision of excess AFR.




(a) (b) (c)

**Fig. 3**. Graphical representation of the flow in can-combustor (a) $O_2$ mass fraction, (b) Temperature magnitude & (c) $NO_X$ mass fraction of the combustor along the center line for different AFR

## 4 Conclusion

The primary excess air ratio is the most important parameter which can be optimized for maximum conversion of fuel, hence reducing the $NO_X$ level. The introduction of cool air at the secondary chamber can reduce the $NO_X$ emission level up to $3.6 * 10^{-6}$ at the optimum conditions. The two stage combustion is significant for reduction of $NO_X$ emission levels and the maximum $NO_X$ reduction happens when the primary air is injected at an excess air ratio of 10%. The simulation shows that also the total excess air ratio has an important effect on the $NO_X$ emission. An increase in excess air is needed to bring down the combustion gas temperature to allowable values at the turbine inlet. The temperature reduction at the exit of the combustor shows appropriate results in achieving low emission. Thus the numerical evaluation on can-type combustor shows that the 10% excess air aids in providing less $NO_X$ emission by diminishing the domain temperature. To reach a better contributing model, the harmful emission such as $NO_X$ should be mitigated for pollution free environment.

**Acknowledgments.** This research was supported by the CEFV (Center for Environmentally Friendly Vehicle) as Global-Top Project of KMOE (Ministry of Environment, Korea). Also, this research work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF- 2014R1A2A1A11052154).

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