International Journal of Pure and Applied Mathematics
Volume 119 No. 14 2018, 187-192
ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

Combustion Characteristics In a Can Combustor Fueled with surrogates of Gasoline and Jet-A using Numerical Methods

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Abstract

Numerical simulation plays significant role in providing good insight into the complex flow phenomena occurring inside a combustor. Hence present work focusses on descriptive study of flow and emission characteristics of surrogates of gasoline and Jet-A Fuel in a can combustor using turbulent non-premixed Flamelet combustion. The combustor configuration with liquid fuel spray jet interacting with the air stream is numerically compared to study the mixing effectiveness, maintaining air fuel ratio and velocity ratio constant for both the cases. The combustor characteristics like combustor efficiency, pressure loss factor and emission levels of both the fuels have been analyzed and results are compared with the available experimental results. Results show pressure loss in case of Gasoline combustion increases by 4 times in comparison with Jet-A fuel combustion.

Keywords—*Efficiency, Air fuel ratio, Mixture fraction, Pressure loss*

1. Introduction

Currently with the cutting edge technology and high speed computing, numerical analysis plays vital role in providing accurate flow predictions at a faster rate. Henceforth enormous numerical combustor studies are being performed to understand the turbulent mixing behavior of fuel and air and study the ways of controlling the flow characteristics for improved performance. Effective mixing reduces pollutant emissions and improves fuel efficiency. Recent industrial combustors use complex atomizers to generate fine spray for effective combustion. This phenomena can be numerically simulated which consumes lesser time and also cost effective. One such work is carried out by Zamuner et al [1] for kerosene spray combustion using in-house built numerical code. Author studied the effect of swirl number on exit temperature profile and also calculated the extra computational cost for droplet tracking. Similar study on droplet combustion simulation is performed by Wang et al [2] using Reynolds Average Navier Stokes Method (RANS) and Large Eddy Simulation (LES) predicting the temperature profiles and combustion characteristics closely with the experimental results. Parallel study on designing and testing of can combustor is done by Narayana Rao et al [3] to study the lean blow out limit for two swirler configurations. Alternately, study on the impact of alternate fuel such as syngas on combustion characteristics in can combustor is carried out by Chaouki Ghenai [4] showing reduction of CO_2 and NO emission using syngas. Recently Parag Rajpara et al [5] compared the emission characteristics of conventional and reverse flow can combustor and showed reduction in emission with the later combustor. Karim Mazaheri et al [6] worked on optimization of combustor geometry for NO suppression. He reduced the emission by 10% with optimized geometry. Study is done by Béla VARGA et al [7] to estimate the pressure loss in gas turbine combustors using Fanno and Rayleigh line flow and different empirical equations. Latest numerical study on comparison of Jet-A and hydrogen fueled combustion characteristics is performed by Nafiz Kahraman et al [8] and found out that hydrogen fueled combustor performs better in terms of pressure drop, emissions and outlet temperature profile.

Several numerical studies have been done in the field of spray emanation from nozzle jets to find the influence of spray parameters in combustor performance. In the present case combustor is fueled with Jet-A fuel normally used in aerospace applications. After several hours of stipulated flight operations, the gas turbine combustors will be utilized for power plant applications. Hence an attempt is made here to study the combustor characteristics using alternate fuel normally used in power plants such as gasoline. The gasoline used is the surrogate fuel, a blend of 47% of nheptane and 53% of isooctane. The present study emphasis on comparing the combustion characteristics of the two liquid fuel surrogates numerically.

2. Governing Equations

The governing mass, momentum and energy equations [9] for turbulent flows are shown in (1), (2) and (3).

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho U) = 0 \quad (1)$$

Momentum Equation

$$\frac{\partial (\rho U)}{\partial t} + \nabla.(\rho U.U) = -\nabla p + \nabla.\tau + S_M \quad (2)$$

Where stress tensor τ related to strain rate by

$$\tau = \mu(\nabla U + (\nabla U)^T - \frac{2}{3}\delta\nabla.U)$$

Energy Equation

$$\frac{\partial(\rho h_{tot})}{\partial t} - \frac{\partial p}{\partial t} + \nabla.(\rho U h_{tot}) = \nabla.(\lambda\nabla T) + \nabla.(U.\tau) + U.S_M + S_E \quad (3)$$

Where $h_{tot} = h + (1/2) U^2$ is the total enthalpy
$\nabla.(U.\tau)$ is the viscous work term
$U.S_M$ is the external momentum sources, currently neglected
S_M and S_E represents the source terms for particle momentum and energy

3. Computational Details

The schematic of the model can combustor used for the study is shown in Fig. 1. The geometry considered here for simulation study is the can combustor used by Jones et al [10] for experimental measurement of temperature and emission characteristics of the model can combustor. The geometry consists of domed cylindrical can combustor with swirled air entry. Primary and secondary holes are provided on the circumference of the can cylinder. The incoming jet of air through these holes helps in flame anchoring essential for complete combustion and reducing the temperature suitable for turbine entry temperature.

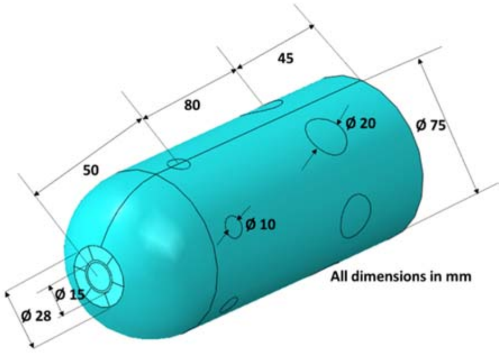

Fig. 1 Schematic of model can combustor

60^0 sector model with periodic boundary is created using 10 lac tetrahedral mesh for reducing computational time. Grid generation and distribution is done with the quality of mesh to be within acceptable range to have smooth convergence of results. Near wall boundary mesh size is chosen suitably to capture boundary flow phenomena.

Study is done for an air fuel ratio of 57 considering air mass flow rate of 0.1 kg/s. Air is preheated to 400 K before entering the combustor. 10% of total air enters swirler at an angle of 45^0, 13.7% enters primary holes, 58% enters secondary holes and remaining air is used for domain cooling. Hollow cone spray of Jet A fuel is sprayed at an included angle of 70^0. The Rosin Rammler distribution with sauter mean diameter of 50 µm is assumed for droplet distribution.

Non-premixed combustion modeling is done using flamelet combustion. The problem with extremely nonlinear kinetics associated with fluctuating flow fields is avoided by solving only two scalar equations in flamelet model. Also flamelet library is created for the fuel used for combustion which provides a large set of chemical equations involved in combustion. Statistical method such as probability density function approach is used to couple the turbulent equations with laminar chemistry.

4. Results And Discussion

Reacting flow steady state combustion analysis is performed for a can type model combustor for an air fuel ratio of 57. The present work is carried in two phases. In the first phase, the combustor is fueled with Jet-A fuel and the combustion characteristics in terms of mixture fraction is validated with the experimental work performed by Jones et al [10] at different axial locations. In the second phase, analysis is performed for the same geometry using gasoline surrogate fuel keeping air fuel ratio and velocity ratio constant for both the fuel combustion studies. The combustion characteristics for both the studies are compared in terms of combustion performance in this phase.

A. Validation Of Computational Model

Reactive two phase flow analysis is performed in a model can combustor with the injection of Jet-A fuel. The results obtained from the analysis is compared with the experimental results of Jones et al [10]. The mixture fraction values obtained from the experiment is compared with the analysis at different axial locations as shown in fig. 2. At x = 30 mm (primary zone) and x = 90 mm (secondary zone) the mixture fraction values matches well except at few locations. But noticeable variation is observed at x = 50 mm (primary hole location). Lack of sufficient information on spray details and geometry forced to make assumptions leading to variations at certain locations. However the flow pattern matches well with the experiment results.

It can be observed from the graph that peak mixture faction value of 0.32 is observed at x = 30 mm at the radial mid-section. This reduces tending to zero at x = 90 mm indicating reduction in fuel percentage axially, ensuring utilization of fuel in the process of combustion. The entrainment of primary air anchors the flame in the primary zone rising the temperature and turbulence of the air and fuel mixture to establish combustion.

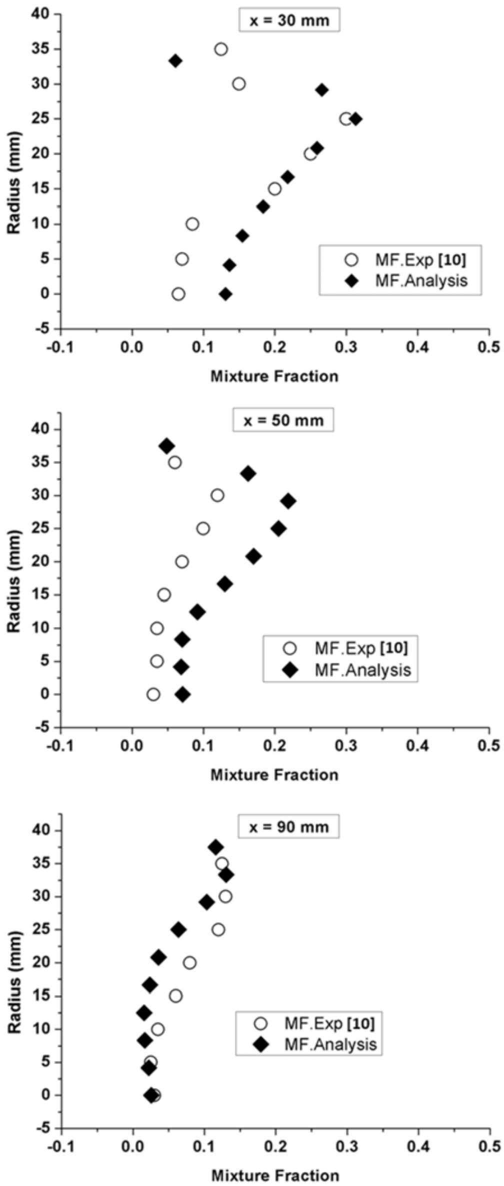

Fig. 2 Radial variation of mixture fraction results of experimental and analysis at different axial locations of the combustor along the plane of secondary hole: comparative study

B. Comparison Of Combustion Characteristics

Fig 3 and 4 clearly explains the temperature distribution and the flow phenomena occurring inside the combustor and compares the differences occurring between the two liquid fuels considered for study.

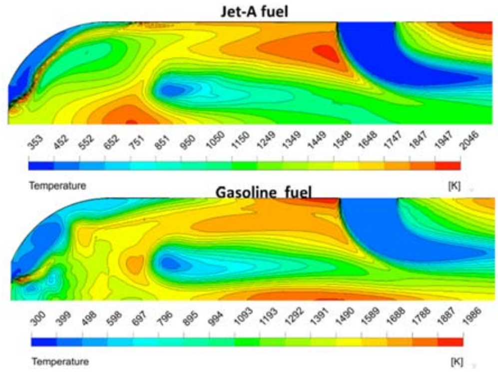

Fig. 3 Temperature contour plots along dilution jet plane

As seen in fig 3, Jet-A fuel ignites immediately as soon as it emerges from the injector reaching combustion temperature whereas there is delay in igniting in case of Gasoline as the fuel remain as droplets in the primary zone. This suggests that gasoline requires air with higher preheat temperature and reduced droplet size for effective combustion. Henceforth maximum temperature attained by Jet-A fuel combustion is higher compared to Gasoline combustion. Fig 4 shows the comparison of the mixture fraction values. Mixture fraction indicates the percentage of fuel involved in combustion phenomena. In case of Jet-A fuel combustion flame front gets lifted forming a recirculation zone whereas the same phenomena is not seen in Gasoline case, indicating insufficient fuel jet velocity.

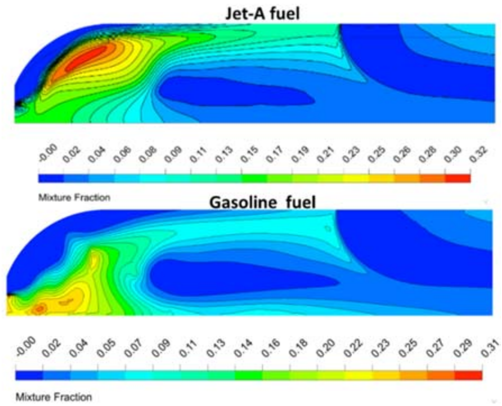

Fig. 4 Mixture fraction contour plots along dilution jet plane

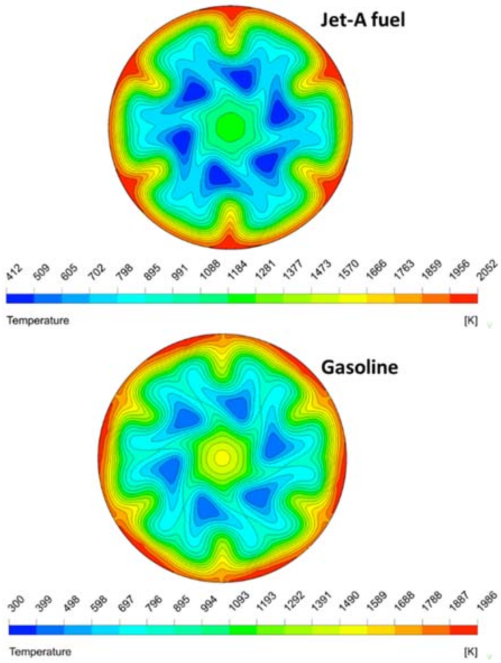

Fig. 5 Temperature contour plot at the exit of the combustor

Also the maximum temperature reached in Jet-A combustion is higher by 70^0 K compared to gasoline and average temperature by 120^0 K. This influences the combustor exit emission parameters. Gasoline combustion shows higher NO and unburnt fuel at the combustor exit indicating incomplete combustion as seen in table 1.

Table 1. Comparison of combustion characteristics at the exit of combustor

Fuel	Average Temperature (K)	NO mass fraction	CO mass fraction	CO_2 mass fraction	H_2O mass fraction	fuel mass fraction
Jet-A	1241	8.67 E-05	1.25E -02	7.41E -02	3.31E -02	1.10E -07
Gasoline	1112	9.96 E-05	4.90E -03	5.60E -02	2.80E -02	4.50E -07

Combustor efficiency and pressure loss are the major factors in evaluating the performance of combustors. Efficiency of the combustor is calculated as the ratio of increase in enthalpy of the gas due to combustion to heat input to the fuel. Efficiency calculated based on the above formula for both the fuels are compared in fig 6. Rise in temperature of the combustion gases in turn increases enthalpy of combustion gas leading to higher efficiency in Jet-A compared to Gasoline combustion.

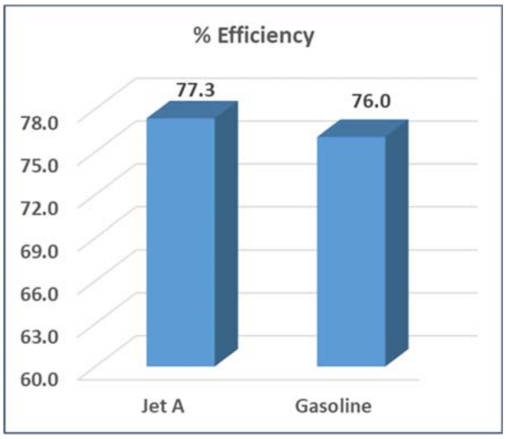

Fig. 6 Comparison of efficiencies of the combustor fueled with Jet-A and gasoline

Minimum pressure loss across the combustor is desirable for good performance of combustor. Two pressure loss parameters are of importance in combustor design [11]. One is the overall pressure loss as given in (4)

$$P_{overall\ loss} = \frac{\Delta P_{3-4}}{P_3} \quad (4)$$

Where $\Delta P_{3\text{-}4}$ is the total pressure drop across the combustor
P_3 is the total pressure at the inlet of the combustor.

The other is pressure loss factor as given in (5).

$$P_{loss\ factor} = \frac{\Delta P_{3-4}}{q_{ref}} \quad (5)$$

Where q_{ref} is the reference dynamic pressure. This is an important parameter which denotes the resistance offered by the flow of gases between compressor exit and turbine inlet which is nothing but the frictional loss and loss due to combustor heating. Comparison of these pressure losses occurring in the combustor fueled with Jet-A and Gasoline is shown in fig 7. Both the pressure loss parameters increase by 4 times in case of Gasoline combustion compared to Jet-A fuel combustion.

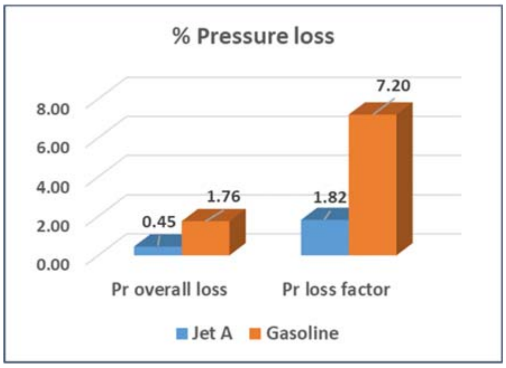

Fig. 7 Comparison of pressure losses in the combustor fueled with Jet-A and gasoline

5. Conclusions

The primary focus of the present work is to compare the combustion characteristics of the model can combustor fueled with two liquid fuels such as Jet A and gasoline operating under same inlet conditions. The conclusion of the present work is listed below.

- The combustion analysis fueled with Jet-A is validated with the experimental work conducted by the earlier author and the results agree well except at few locations.
- The comparative analysis suggests gasoline fuel requires higher jet velocities and finer droplets for efficient combustion compared to Jet-A fuel.
- With the current input parameters, gasoline combustion emits higher NO and unburnt fuel compared to Jet-A fuel indicating incomplete combustion.
- Gasoline has lower combustion efficiency and higher pressure loss compared to Jet-A with the given inlet conditions which is undesirable in terms of combustor performance.

References

[1] B. Zamuner, P. Gilbank, D. Bissières, C. Berat 'Numerical simulation of the reactive two-phase flow in a kerosene/air tubular combustor' Aerospace Science and Technology, 2002, Vol. 6, pp.521-529.

[2] Farhad Davoudzadeh, Nan-Suey Liu, Numerical Prediction of Non-Reacting and Reacting Flow in a Model Gas Turbine Combustor, Turbo Expo, NASA/TM—2005-213898.

[3] K. V. L. Narayana Rao, G Ramesha, N Ravi Kumar, M. Devathathan, Design And Testing Of A Can Combustor For A Small Gas Turbine Application, Proceedings of the ASME 2013 Gas Turbine India Conference.

[4] Chaouki Ghenai, Combustion of Syngas Fuel in Gas Turbine Can Combustor, Advances in Mechanical Engineering, Hindawi Publishing Corporation, Vol 2010, Article ID 342357.

[5] Parag Rajpara, Ankit Dekhatawala, Rupesh Shah, Jyotirmay Banerjee 'Thermal and emission characteristics of reverse air flow CAN combustor' International Journal of Thermal Sciences, Elsevier, 2018, Vol. 128, pp.175-183.

[6] Karim Mazaheri, Alireza Shakeri, Numerical optimization of laboratory combustor geometry for NO suppression, Applied Thermal Engineering, 2016, Vol. 102, 2016, pp.1328–1336.

[7] Béla VARGA, Gyula ÓVÁRI, László KAVAS, Gas Turbine Engine Combustors And The Estimation Of Their Pressure Loss, Scientific Research And Education In The Air Force – AFASES2017.

[8] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[9] Ansys incorporated Release 17, Ansys documentation, theory guide.

[10] W. P. Jones and A. Tober 'Measurements of Gas Composition and Temperature inside Can Type Model Combustor, International Union of Theoretical and Applied Mechanics' IUTAM Symposium Taipei, Taiwan, 1991, pp. 327-338.

[11] Lefebvre A. H, Dilip R Ballal, Gas turbine combustion: Alternative fuels and emissions, Third edition, Hemisphere Publishing Corporation 2013.