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Numerical analysis of a gas turbine combustor fueled by hydrogen in comparison with jet-A fuel

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ABSTRACT

The interest in alternative fuels has increased in recent years. Because, the conventional fuels have the danger of extinction in the near future and these fuels harm the environment. Therefore, in this study, the availability of hydrogen as an alternative fuel has been investigated in the tubular combustion chamber of a gas turbine engine fueled by jet-A fuel. For this purpose, the combustion characteristics in the combustor of a Rolls-Royce Nene turbojet engine fueled by gas jet-A and hydrogen have been numerically studied at different excess air ratios (EAR) for a given thermal power values. Temperature distributions in the combustor, combustion efficiency, pressure drop and velocity change have been numerically analyzed at 1480 kW (10000 rpm), 2290 kW (11000 rpm) and 2980 kW (12000 rpm) thermal power in the combustion chamber. The RNG k- turbulence and eddy-dissipation combustion models have been used for 2D axisymmetric geometry with swirling flow.

The combustion efficiency and the pressure drop values are increasing with an increase in the EAR values. But, the outlet temperature values of the combustion chamber, the CO_2 emissions and unburned HC emissions are decreasing by increasing of the EAR values. Moreover, it is observed that the NOx emission values are increasing and then are decreasing with the EAR values. The combustion of hydrogen is seen as advantageous in terms of pressure drop, temperature values at the combustion chamber outlet and CO_2 and unburned HC emissions. In addition, it can be seen that as advantageous in terms of the NOx emission values at low EAR values but as disadvantageous at high EAR values.

1. Introduction

In recent years, air travel has become the preferred means of transport. The most important part of an aircraft is its engines. Chemical energy stored in the fuel is converted into the propulsion force in the engines. This transformation begins with the reaction between fuel and air within the combustion chamber in the engine. The performance of the combustion chamber directly affects the economic viability and reliability of aircraft.

Lately, standard aircraft fuels have ceased to be economic due to rapidly increasing oil prices and to the fact that these fuels are quickly becoming depleted. Moreover, it is important to consider the use of alternative fuels because standard aircraft fuels damage the environment. Hydrogen could be used as an alternative fuel in the combustion chamber because it has a high combustion temperature, and its combustion does not produce carbon-based emissions. Additionally, hydrogen provides stable combustion in a wide range of mixtures and is common in nature. So, this study can contribute to improve the performance and emissions of a combustor.

The analyses of combustion chamber performance are very important as the combustion chamber is used to provide optimum thrust in a gas turbine engine. Analysis of combustion processes and testing of different fuels have been carried out by many researchers. Huntley [1] experimentally studied the effect of operational variables on temperature distribution at the combustion chamber outlets of a Rolls-Royce Nene turbojet engine in an altitude chamber. He obtained a significant amount of temperature data on the combustion chamber outlet at different revolution speeds and presented the figures. Barson and Wilsted [2] experimentally studied the performance of the combustion chamber of a Rolls-Royce Nene turbojet engine with different jet nozzles. They presented results for simulated conditions varying from sea level to an altitude of 65,000 feet and for ram pressure ratios ranging from 1.0 to 3.5. Furthermore, many researchers have worked to increase the performance of combustion chambers. To this end, they have studied different combustor geometry and different fuels. For example, Eldrainy et al. [3] studied described the flow dynamics inside a novel swirler conceptualized for gas turbine combustors. The results of four numerical simulations were presented and discussed to study the central

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Nomenclature

$(A/F)_a$	actual air-fuel ratio at combustion chamber inlet
$(A/F)_s$	stoichiometric air-fuel ratio at combustion chamber inlet
D_H	hydraulic diameter, m
EAR	excess air ratio
I	the intensity of turbulence
l	length of combustor, m
m_{fi}	fuel mass flow at combustion chamber inlet, kg/s
m_{fo}	fuel mass flow at combustion chamber outlet, kg/s
P	pressure, Pa
PDP	pressure drop percentage
ppm	parts per million
r	the radial coordinate
rpm	Revolution per minute
S	Swirl number
$(TCFD)_{Pair}$	The tangential component of primary air
$(TCFD)_{fuel}$	The tangential component of fuel
$(TCFD)_{Sair}$	The tangential component of secondary air
UHC	Unburned hydro-carbon
v_x	The axial velocity

recirculation zone, turbulence intensity, and pressure drop at different swirl numbers. Mare et al. [4] studied temperature and species concentrations in a model can-type gas turbine combustor operating in a non-premixed combustion regime using large eddy simulation. Lysenko and Solomatnikov [5] studied the numerical modeling of turbulent heat exchange in the combustion chambers of gas-turbine engines with the use of the Fluent package. Shehata [6] performed experiments on a gas turbine combustor. He studied the emission and wall temperature of a traditional gas turbine combustor converted to a lean premixed prevaporised combustor.

Recently, many researchers have studied about combustor fueled by Jet-A which is commonly used in aviation sector. To illustrate, Frenillot et al. [7] studied the effect of H_2 addition to Jet A/air on flame stability and pollutants. They compared the stability domains and pollutant emissions when combustion occurs with and without the addition of H_2 in Jet A1/air premixed prevaporised mixture injected into a lean gas turbine combustor. Iannetti et al. [8] studied emission changes with some spray initial conditions (as number of droplet groups and initial droplet temperature) fueled by Jet-A ($C_{12}H_{23}$). They used the National Combustion Code on a single swirler Lean Direct Injection flame tube and compared the result with experimental data. As these studies, many scientists research about combustor efficiencies and emissions with jet-A fuel [9–12].

In addition, many numerical and experimental researches are conducted using alternative fuels in a combustor. For example, Juste [13] experimentally worked on the control of pollutants produced in a tubular combustor, by the injection of hydrogen in small quantities. This study included hydrogen premixed with air which was introduced in the primary zone. Khelil et al. [14] numerically studied the combustion of strong swirling confined reacting natural gas/air flow in a gas turbine combustor. Their aim was to obtain predictions of chemical species concentration and temperature fields using the PDF model coupled with the Reynolds stress model. The numerical calculation was performed using the commercial code Fluent. Habib et al. [15] numerically investigated the problem of NO_x pollution using a model furnace of an industrial boiler utilizing methane. Ilbas et al. [16] experimentally studied the laminar-burning velocities of hydrogen-methane-air mixtures. Moreover, many researchers have carried out research on hydrogen or hydrogen mixtures in a combustor [17–21]. Furthermore, in this study, the authors have been purpose to investigate the use of hydrogen as an alternative fuel in a gas turbine combustor and to improve the data about the issue in literature.

2. Mathematical model

2.1. Combustor geometry

A cross-section view of the engine used in this study is shown in Fig. 1 [22]. The two-dimensional model and grid structure of the combustion chamber are shown in Fig. 2. The geometry model was formed using the original dimensions and fifteen different faces in the Gambit software. The faces were classed as quadrilateral and triangular types with a total of 23170 grid cells. Due to get best balance between the computer time and accurate converging solutions, mesh independence study were carried out by using 12250, 17650, 23150, 28300 and 33550 different mesh sizes. The temperature values obtained from the mesh independence study and the values of reference temperature taken from literature for different engine speeds are given in Table 1. As can see from the table, the best balance between the computer time and accurate converging solutions is obtained at 23150 mesh size.

The physical values used in combustor modeling were selected as: length of combustor L = 620 mm, maximum radius of combustor R_{Cmax} = 145 mm, radius of primary air inlet R_{Pair} = 35 mm, radius of combustor inlet and combustor outlet R_{Cin} = R_{Cout} = 90 mm. The fuel inlet was fitted on a symmetric axis, and the radius of the fuel inlet was

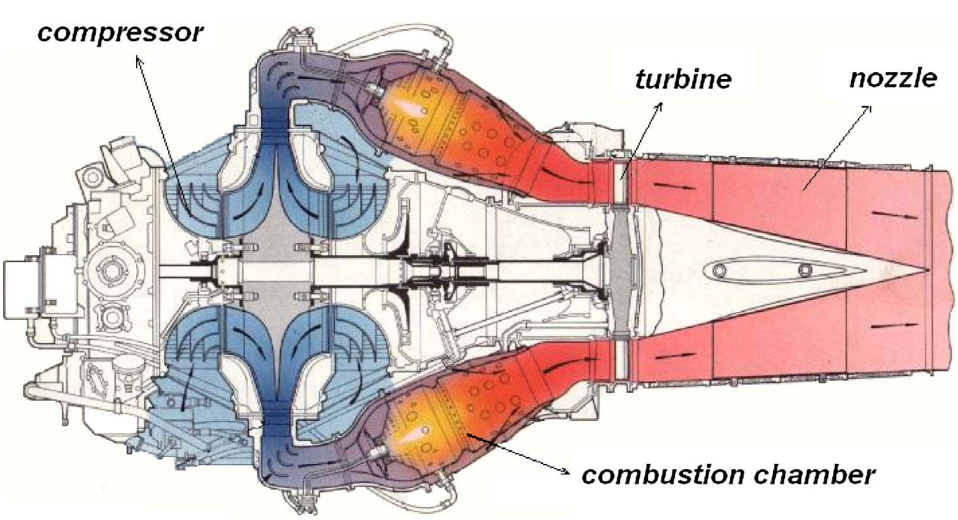

Fig. 1. Nene turbojet engine [16].