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Research paper

Numerical study of influence of biofuels on the combustion characteristics and performance of aircraft engine system

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HIGHLIGHTS

- Influences of biofuels properties on combustion characteristic are explored.
- Effects of biofuels on cycle parameters of aircraft engine are discussed.
- Viscosity and caloric value are key factors affecting combustion of biofuels.
- NO emission becomes lower when biofuels with low caloric value is adopted.
- The performance of aircraft engine becomes worse for biofuels with low caloric value.

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ABSTRACT

The atomization and combustion flowfield of the combustion chamber with swirl-nozzle were simulated using different biofuels; the thermodynamic cycle of the aircraft engine system were also analyzed, influences of biofuels on the combustion characteristics and performance of aircraft engine system were explored. Results show that viscosity and caloric value are key factors affecting the atomization and combustion characteristics of biofuels, and then dominate the distribution of the temperature and NO concentration. Due to the characteristic of low viscosity and low caloric value for biofuels adopted, the biofuels accumulate near the head of combustion chamber, and the corresponding NO emission is lower than that it has for conventional kerosene. When biofuels with low caloric value are used under the operation condition which is same as the condition for the conventional kerosene, lower turbine inlet temperature, lower thrust and higher specific fuel consumption would be achieved for the aircraft engine.

1. Introduction

Forced by the crisis of fuel shortage and environmental pollution, the development and utilization of alternative energy sources has become a global sensitive strategic technology. Due to the good quality of renewable property, friendly to environment, and repression to the global climate anomaly for biofuels, it is meaningful to develop the biofuel to replace conventional fuel products as gas turbine and aircraft engine energy [1].

Franco [2] performed the aerodynamics analysis on different biofuels, and pointed out that the biofuel was a kind of fuel with great application foreground. Yamasaki [3] carried out the experimental investigation on gas turbine with biofuels, and found the combustion chamber should be redesigned in order to obtain the higher combustion efficiency and the lower NOx emission. Pascale [4] simulated the combustion characteristic of the biofuels with component of CH_4, CO and H_2, and got the better temperature distribution. Francesco [5,6] compared the combustion characteristic between biofuels and natural gas, results showed that the hot spot in the combustion chamber was decreased when the biofuels were adopted, and the flame of the primary combustion zone already became stable near the region of the fuel injection position, which was beneficial to reduce the pollution emission. Sadamasa [7] measured the emission of the combustion chamber using biofuels, it was found that CO_2 in the biofuels could restrain the NO formation through slowing the combustion reaction, and became more notable under high temperature condition.

Li [8] denoted that the fuel components, excess air coefficient and chamber configuration all affect the axial temperature

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distribution in the combustion chamber when biofuels were adopted. Li et al. [9] pointed out that methanol was one of liquid fuels with good performance, and could be feasibly used to replace the conventional fuels used in the combustion chamber in the future. Zhao [10] simulated the combustion performance of GE-F101 combustion chamber, in which methanol and synthetic gas with low caloric value were adopted. Results showed the combustion stability was reduced when the caloric value of the fuel became smaller, and NOx emission also decreased. The combustion stability could be improved through increasing the nozzle diameter and swirl number of the cyclone. Wang et al. [11] found that the temperature at the chamber exit became lower when the fuel with low caloric value was used, the fuel supply should be increased at this case in order to obtain the same power output with conventional fuel adopted. Besides investigations of the influence on the combustion characteristic, the biofuels effect on the startup method, power output and corrosion to the turbine blade were massively concerned [12–16].

From the above investigations mentioned, it could be found that the stable operation range and pollution emission induced by the fuel type were related to the important energy conversion component — the combustion chamber, the key technology of the gas turbine system with biofuels adopted was crucially dependent on the combustion chamber. Now, along with the crisis of the oil shortage and increasingly stringent environmental regulations, aviation biofuels will also become a fundamental way for aviation industry to get the sustainable fuel source and realize greenhouse gas emission reduction targets. Therefore, in order to successfully apply the aviation biofuels on aircraft engine, it is necessary to deeply explore the atomization and combustion characteristic of the biofuel, and analyze the corresponding influence pattern on the thermodynamic cycle parameters of the aircraft engine, then provide the foundation to the technical development and application of the biofuel on aircraft engine system. In this paper, ethanol and methanol are chosen as aviation biofuels, the atomization and combustion flowfield of the three-dimensional combustion chamber with swirl nozzle were simulated, and the atomization and combustion characteristics were compared between biofuels and conventional kerosene. The performances of the aircraft engine system were predicted by GSP (Gas turbine Simulation Program) which is a professional software to simulate the aircraft engine performance, and the effects of the biofuels on the thermodynamic cycle parameters of the aircraft engine were discussed in detail.

2. Influence of biofuels on aircraft engine system

As compared with conventional kerosene, the biofuels such as ethanol and methanol are characterized by lower caloric value and different combustible components. These features would induce several impacts on the aircraft engine system, which can be described as follows:

1) The physical properties and proportions of the combustible components of the biofuels such as CO, H_2 and CH_4 are different with the conventional fuel, which would change the combustion characteristic.
2) The difference of the caloric value between biofuels and conventional kerosene can reflect on the thermal energy released by the fuel in the combustion process, which would affect the flow boundary condition after the section of combustion chamber in the aircraft engine, and the thermal cycle parameters and performance parameters of the system would be altered under the same condition.

The influence of fuel properties on the aircraft engine performance can be summarized in Table 1. It can be found that the combustion characteristic, emission and stability are all affected by fuel properties. When the biofuel is applied to the combustion chamber which is designed for the conventional fuels, the operation of the aircraft engine system would be altered due to the change of fuel properties.

3. Calculation method and model

3.1. Calculation method

Numerical simulations were performed for the combustion chamber using the FLUENT software. The equations solved are the fully three-dimensional, steady, compressible, Reynolds averaged, Navier–Stokes equations. The implicit density-based algorithm is used to solve the equation. Standard k-ε turbulence model is chosen as the turbulence model. The equations are discretized in finite volume form on each control volume. Second order upwind scheme is used in the spatial discretization. The eddy-dissipation model is adopted as the combustion model, with P-1 radiation model used to concern the influence of radiation. DPM discrete model is employed to investigate the atomization characteristic of the fuels, the trajectory of the fuel droplet, split and combination of the droplet, the couple effect between the fuel droplet and the main flow can be obtained by DPM discrete model. NOx emission mainly comprises with NO, and also includes a small quantity of NO_2 and N_2O, thermal NOx-Zeldovich and prompt NOx-Fenimore mechanism are considered for NOx emission.

3.2. Boundary conditions

Mass flow inlet conditions are applied to air inlet and fuel inlet of which the mass flow rate, total temperature and flow angle are prescribed. At the outflow boundary, the static pressure is imposed and the other variables are extrapolated from the interior. The material of the solid wall is aluminum; the boundary of the wall used for fluid-solid couple is specified as the default value. No-slipped wall boundaries are applied on the other solid walls. In the simulation process of the atomization characteristic of the fuels, the pressure-swirl atomizer model is used, the ejection position, ejection direction, fuel mass flow rate, pressure of fuel supply, fuel temperature, ejector diameter of the nozzle, ejection semi-angle are specified for the ejector.

Table 1
Influence of fuel properties on aircraft engine performance.

Fuel characteristics	Influence on the combustion characteristic	Influence on the aircraft engine performance
Component	Propagation velocity,	Emission, combustion efficiency, stability
Caloric value	Evaporation characteristic, flammability limits	
Freezing point	Characteristics of phase transition	Startup in cold weather
Lubricity	Transport characteristic	Fuel system
Material compatibility	Corrosion	Fuel system, pipeline
Viscosity, tension	Atomization characteristic, transportation	Combustion characteristic, fuel system