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Combustion and emissions characteristics of dual-channel double-vortex combustion for gas turbine engines

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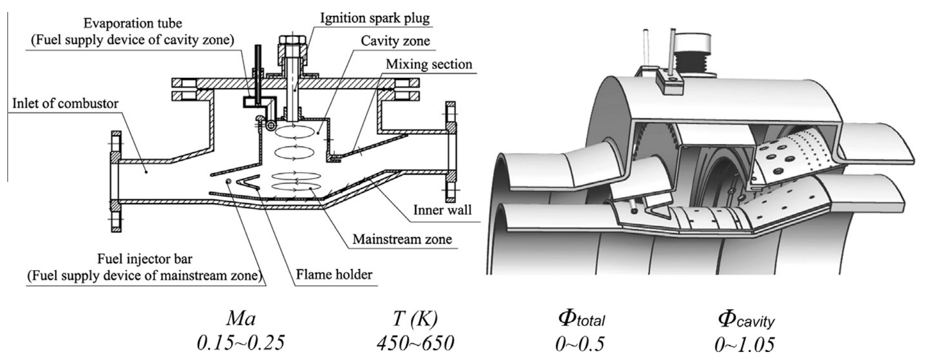
HIGHLIGHTS

- A novel double-vortex combustor with a dual channel was designed.
- The preheating effect of the evaporation tube is conducive to improving the combustion and emissions performance.
- The combustion organization method of the combustor is reasonable.
- The staged method significantly affects the performance of the combustor.

GRAPHICAL ABSTRACT



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ABSTRACT

A vortex combustor is a novel gas turbine combustor that uses staged combustion technology. Research examining the combustion organization method of the pilot combustion zone and the mainstream combustion zone is an important component of the design of the structure of a vortex combustor. In this paper, a new type of single-cavity vortex combustor fueled with aviation kerosene is presented. A double-vortex flow field structure and an evaporation tube for the fuel supply are used in the pilot zone. The flow-field structure of a double recirculation zone and a pneumatic atomization injector for the fuel supply are used in the mainstream combustion zone. The combustion experiment was performed under atmospheric pressure. The influence of the air-flow parameters, fuel parameters and staged method on the combustion performance and the characteristics of the pollutant emissions were studied in detail. Research indicates that the inlet temperature and the staged method primarily influence the ignition limit, lean blowout, combustion efficiency, temperature distribution of the outlet and pollutant emissions. The equivalence ratio primarily influences the temperature distribution of the wall and pollutant emissions. The inlet velocity influences the total pressure loss of the combustor.

Contents

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Nomenclature

Standard

d	diameter
EI	emission index
L	stoichiometric ratio
K	K number
Ma	inlet Mach number
Oh	Ohnesorge number
$OTDF$	outlet temperature distribution factor
Q	flow rate
Re	Reynolds number
T	temperature
V	velocity
w	velocity normal to the surface
Φ	equivalence ratio
η	combustion efficiency
λ	surface tension
μ	viscosity
ρ	density
σ	total pressure loss coefficient
C, M, a, m, n, x, y	constant

Sub and superscripts

cavity	cavity combustion zone
exp	experimental
inlet	inlet of the combustor
main	mainstream combustion zone
num	numerical
outlet	outlet of the combustor
wall	wall of the cavity

1. Introduction

With the development of aero gas turbine technology, the inlet temperature of the combustor and the temperature rise of the inlet and outlet of the combustor are gradually increased. Thus, control of the pollutant emissions in the combustor becomes more difficult. Studies show that the pollutant emissions of a gas turbine combustor can be effectively reduced using staged combustion technology [1–3] or flameless combustion technology [4–7].

The common staged combustion modes include lean premixed prevaporized (LPP) [8,9], variable-geometry combustor (VGC) [10], rich-burn, quick-mix, lean-burn (RQL) [11,12], twin annular premixing swirler (TAPS) [13] and trapped-vortex combustor (TVC) [14,15]. Among them, TVC has the advantages of a wide stable-combustion range and a compact structure [16,17]. Thus, vortex-combustion technology has potential in the field of aero gas turbines.

A vortex combustor is comprised of a cavity pilot combustion zone and a mainstream combustion zone. Fuel and air are injected into both zones in a specific way, and the injection can strengthen the stability of the vortex, which will help to improve the combustion performance [18–20]. Under low-power conditions, only the pilot zone is in operation. The main pollutants are carbon monoxide (CO) and unburned hydrocarbon (UHC). Under high-power conditions, the two zones are in operation simultaneously, and the main pollutants are nitrogen oxides (NO_x). By using an optimized air-inlet mode, fuel-inlet mode and fuel–air-mixing mode in the combustion zone, the pollutant emissions for both the low- and high-power conditions can be expected to be reduced [21–23]. These optimized modes should be able to reinforce the trapped vortex in the cavity zone, reduce the residence time in the cavity zone, and enhance the mass and energy transport between the cavity zone and the mainstream zone [2,16].

The traditional trapped-vortex combustor has a symmetrical, double-cavity structure. The cavity zone is the pilot zone. To further reduce the weight of the combustor, the number of pilot zones is reduced from two to one, thus forming an asymmetric structure with a unilateral cavity [24]. Compared with the double-cavity structure, the single-cavity structure is more compact. However, in this case, adjustment of the temperature-distribution field of the outlet of the combustor is more difficult.

For an aero gas turbine combustor, there are several requirements for the performance, which sometimes conflict with each other [1,14,25–28]. In research on the structure of a combustor, the overall performance of a new type combustor must be studied in detail. Through repeated optimization, all technical indexes of the combustor can meet the design requirements.

In this paper, a single-cavity double-vortex combustor is introduced. In the air supply of the cavity combustion zone, several rows of air jets are injected into the cavity zone to form a