Experimental study on kerosene injection directions in a cylindrical air-breathing rotating detonation engine

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Abstracts

An experimental investigation was conducted on a centerbody-free Rotating Detonation Combustor (RDC) using kerosene as the fuel under an air total temperature of 900 K with normal oxygen content. The setup included one axial injector and one radial injector, with tests conducted by adjusting the equivalence ratio (ER). Results indicated that stable rotating detonation was achieved within a wide ER range of 0.3 to 1.2 using radial injector, whereas using axial injector only sustained stable detonation within a narrow ER range of 0.3 to 0.4. Under both injection configurations, the detonation wave consistently propagated in a single-wave mode. At an ER of 0.73, the average peak pressure of the detonation wave reached 0.6 MPa, with a wave velocity of 1300 m/s. High-speed imaging revealed that at low ERs, the kerosene jet penetration depth rapidly decreased after the detonation wave swept through, recovering to its original height before the wave's next sweep. However, at ERs exceeding 1.0, the jet penetration depth fluctuated at a frequency lower than that of the detonation wave, correlating with the detonation wave pressure. When using axial injector, intermittent detonation occurred at an ER of 0.2, while at an ER of 0.3, the average peak pressure reached only 0.3 MPa, with a wave velocity of 1138 m/s. Additionally, combustion efficiency under axial injection was consistently lower than that of radial injection at equivalent ERs.

1 Sample of Introduction

Among various detonation engine configurations, rotating detonation engine (RDE) demonstrate distinct advantages, including a wide operational range, simplified structural design, and the capability for self-sustained detonation propagation[1,2].

Previous investigations on air-breathing RDEs have predominantly focused on annular combustor configurations. Wang et al. [3] tested a air-breathing RDE under Mach 4 inflow conditions, using hydrogen as the fuel, and successfully achieved stable rotating detonation waves. Frolov et al. [4] conducted a series of experimental studies on annular ramjet-type RDEs,

using hydrogen as fuel and simulating Mach numbers ranging from 4 to 9. They achieved a maximum specific impulse of 3600 s and a thrust of 2200 N at Mach 5, however, stable rotating detonation could not be achieved at Mach 8.

In contrast, Peng et al. [5]examined the Rotating Detonation Wave (RDW) propagation characteristics in hollow combustors, employing hydrogen and ethylene as fuels and varying the inner cylinder length. Their findings indicated that combustor width is a key factor influencing RDW propagation. They suggested that rapidly initiating rotating detonation waves within short distances can mitigate parasitic deflagration-to-detonation combustion, thereby enhancing RDW stability. Subsequently, extensive experiments were conducted in hollow combustors [6–8], comparing hydrogen, ethylene, and methane as fuels under different nozzle contraction ratios. The tests achieved low velocity deficits and high detonation wave stability within the same hollow combustor. Wang et al. [9] proposed a hollow combustor with a cavity and no centerbody to enhance the performance of RDEs, and its feasibility was validated using ethylene as fuel. In air-breathing RDEs, most studies have focused on gaseous fuels, while research on high-stability liquid fuels remains limited. Liu et al.[10] conducted a study using hydrogen as fuel in a centerbody-free combustor, employing annular-slit and central injection methods. Their research revealed that sufficient fuel accumulation in the outer wall region of the combustor is one of the necessary conditions for the formation of detonation waves.

There has been limited research on centerbody-free rotating detonation combustors fueled by liquid kerosene, and the impact of kerosene injection direction on rotating detonation warrants further investigation. This study focuses on comparing the effects of injection direction on rotating detonation in a cylindrical combustion chamber and analyzes the injection characteristics under different equivalence ratios.

2   An Example of a Simple Equation

The flow coefficient of injector equation:

$$\dot{m}_{\mathrm{ker}} = nA_{holes}C_v\sqrt{2\rho\triangle P}$$

where $\dot{m}_{\mathrm{ker}}$ is Kerosene flow rate, n is the number of holes, C_v is the flow coefficient, ρ is the density of kerosene and $\triangle P$ is the pressure drop across the injector.

The instantaneous velocity of detonation wave, average velocity of detonation wave and wave velocity deviation equation:

$$V_i = \pi D_o \Delta t_i / N$$

$$\overline{V} = \pi D_o \overline{f} / N$$

$$\delta_v = \frac{V_{CJ} - \overline{V}}{V_{CJ}}$$

where V_i is instantaneous velocity of detonation wave, $\overline{V}$ is the average velocity of detonation wave, $\overline{f}$ is the frequency of detonation wave, δ_v is the wave velocity deviation and V_{CJ} is the CJ velocity.
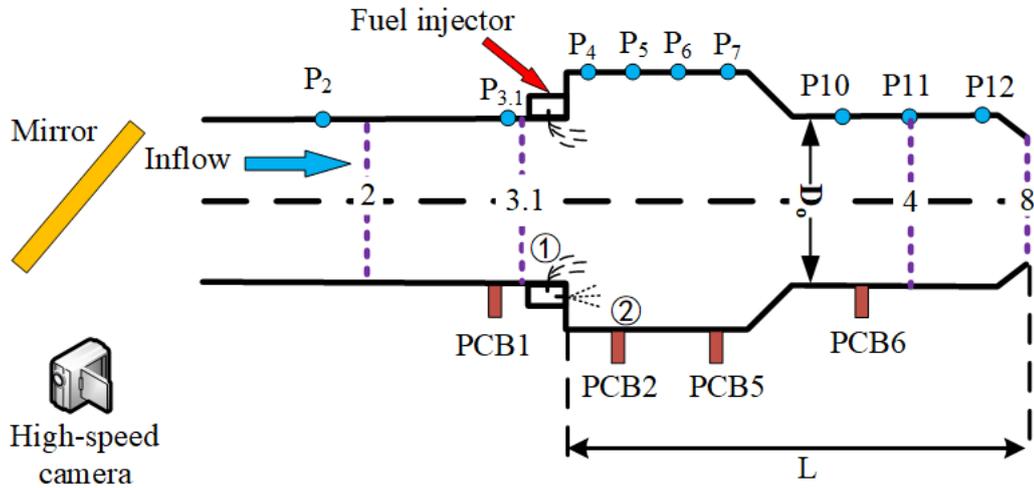
3   Examples of Figures

Sample figure:

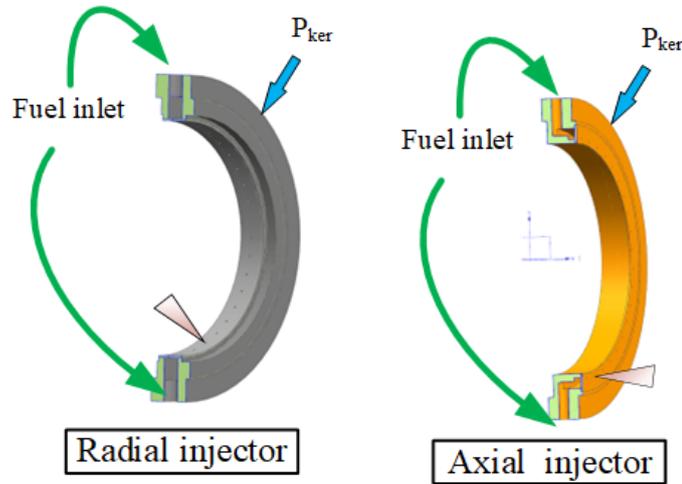Figure 1: Simplified diagram of cylindrical combustion chamber and schematic of injection locations.

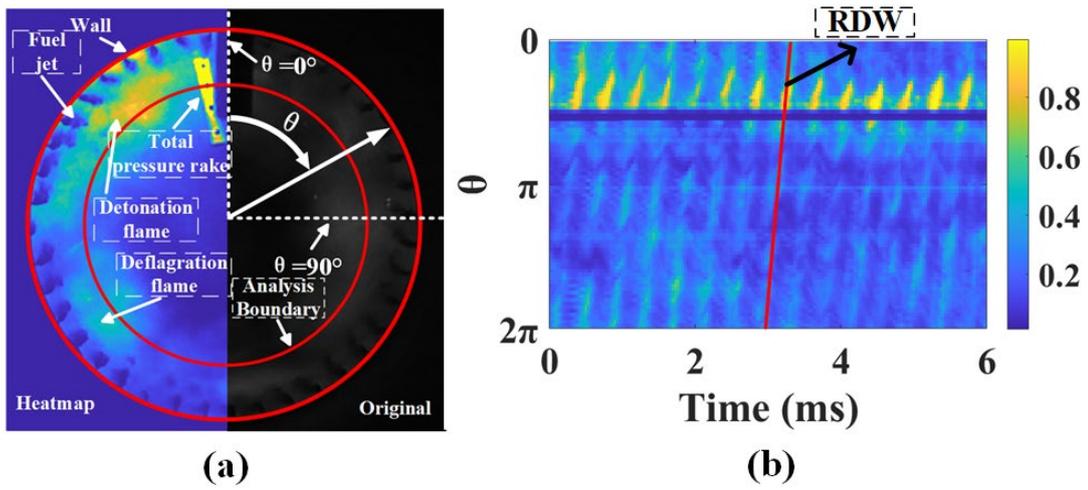Figure 2: Schematic of radial injection device and axial injection device.

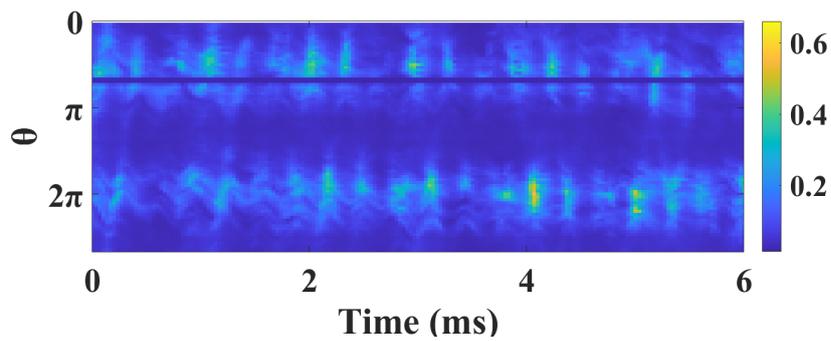Figure 3: Schematic of θ-t analysis method (a) and analysis results of ER=0.4 for radial injector (b).
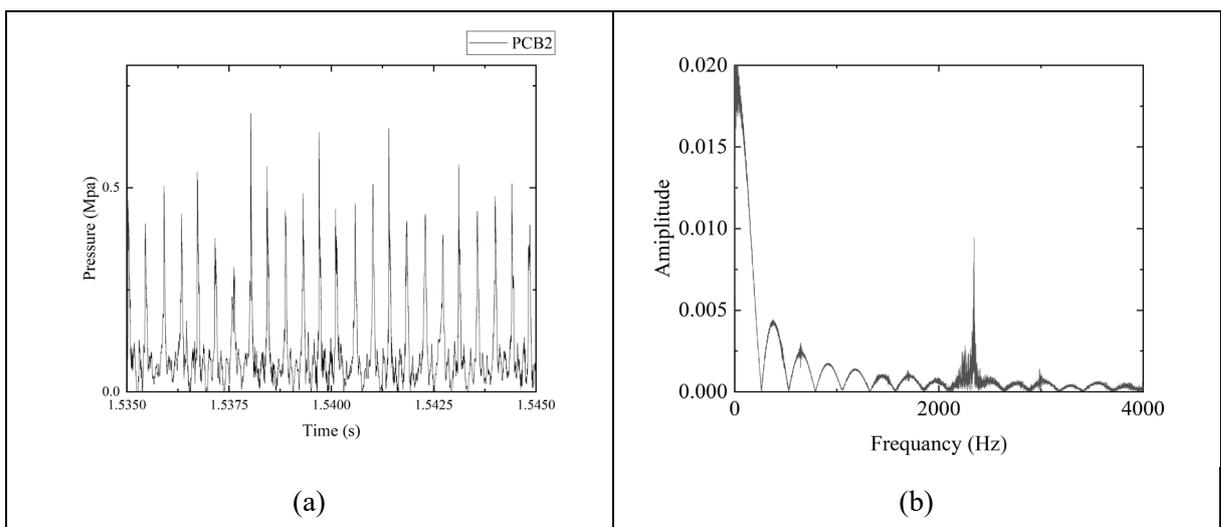

Figure 4: θ-t of ER=0.4 for axial injector.

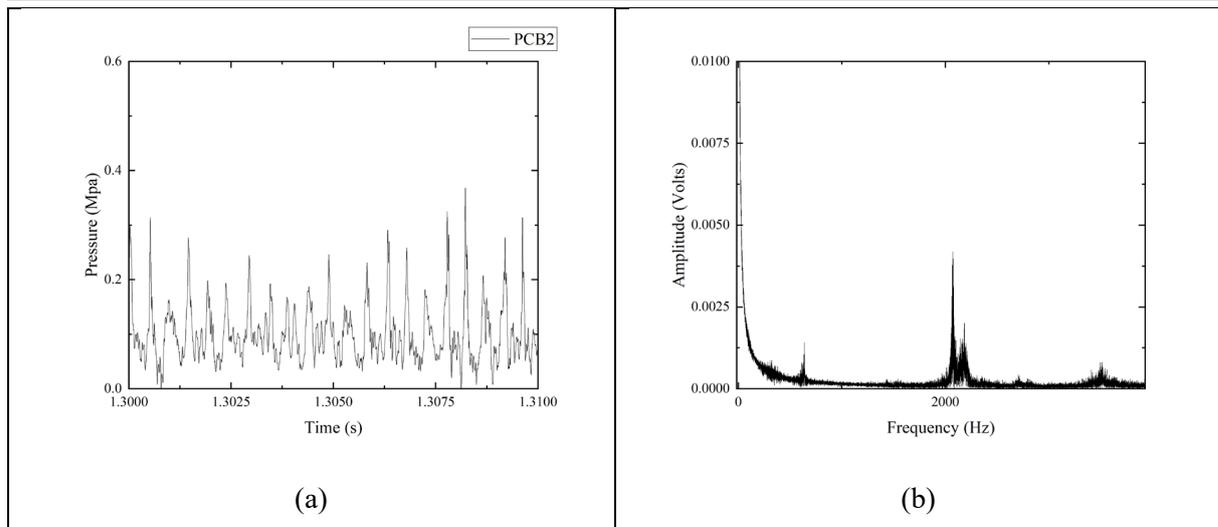Figure 5:ER=0.405, Radial injector : (a) High-frequency pressure history, (b) FFT result.

Figure 5:ER=0.305, Axial injector : (a) High-frequency pressure history, (b) FFT result.

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