

Effects of a radial strip injection pattern on a rotating detonation engine using Navier-Stokes equations

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1 Abstract

Most of current numerical simulations on the rotating detonation engine (RDE) are based on Euler equations and a simple fuel-injection pattern is usually used. In this study, the Navier-Stokes (N-S) equations coupled with the one-step chemistry reaction model are used for RDE simulations. Besides, a radial strip injection pattern is adopted. It is found that the injection set-up affects the number of detonation waves in the RDE. The transition process from the single-wave mode to the double-wave mode is discussed.

Keywords: Rotating detonation engine; Injection pattern; Wave number

2 Introduction

There has been a renewed interest in the development of the rotating detonation engine (RDE) because it has higher efficiency, simple structure and it only needs one initiation [1-3]. The major part of the RDE is a co-axial annular combustor. So far, a series of experimental and numerical studies have been conducted. The reacting flow in the RDE has very high temperature and the detonation wave propagates rapidly, and thus the numerical method is widely used to investigate the physics of the RDE [4-7].

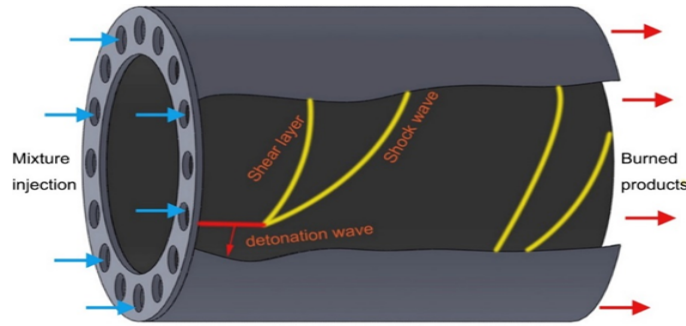


Fig. 1. Schematic of a co-axial annular combustor model of RDE

Fig.1 is a model of a rotating detonation engine (RDE). The premixed hydrogen/air gas is injected into the combustion chamber along the axial direction. The red line is the detonation wave, it is coupled of shock wave and combustion wave. The yellow line is oblique shock wave and shear layer.

3 Physical model and numerical methods

3.1. Governing equations

The N-S equations with the one-step two-species chemistry model in generalized coordinates are used as the governing equations.

3.2. Numerical methods

The advection terms are integrated by the fifth-order monotonicity preserving weighted essentially non-oscillatory (MPWENO) scheme [8-12] and the second-order central difference scheme is used for the diffusion terms. The temporal terms are discretized with the third-order TVD Runge-Kutta method [8-13]. As shown in Fig.1, the injection is assumed to be Laval nozzle inflows. The ratio of the nozzle exit area to the nozzle throat area is set to 10. The premixed stoichiometric hydrogen-air mixture is injected into the chamber along the axial direction with the stagnation pressure and temperature of 2 MPa and 600 K, respectively. An extrapolated method is used for the outflow boundary condition.

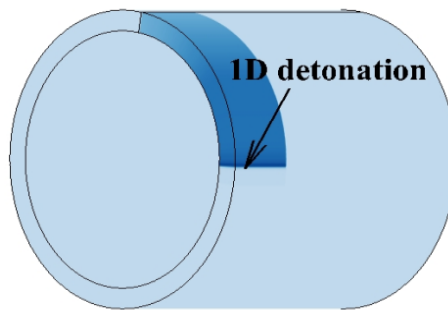


Fig. 2. Schematic of a co-axial annular combustor model of RDE

No-slip and adiabatic boundary conditions are used on the inner and outer walls. The flow-field is filled with unreacted mixture with the initial velocity, pressure, and temperature of 0 m/s, 3 atm and 300 K. The RDE is initiated by a one-dimensional Chapman-Jouguet (CJ) detonation wave.

4 Results and discussion

4.1 Convergence analysis

With reactive NS equations, The thermochemical model and computation scheme have been validated for one-dimensional and two-dimensional test cases with grid size of 0.05mm, 0.1 mm and 0.2mm by Wu Dan. It is noted that the maximum pressure changed little with different grid resolutions. As a compromise between computational costs and numerical resolutions, grid size of 0.2mm can be used. In this paper, a progressive refinement grid is used in the radius direction near the inner and outer wall. Numerical dissipation is not considered in this paper. In the present simulation, the grid size of 0.2mm is used.

4.2 Effect of injection set-up

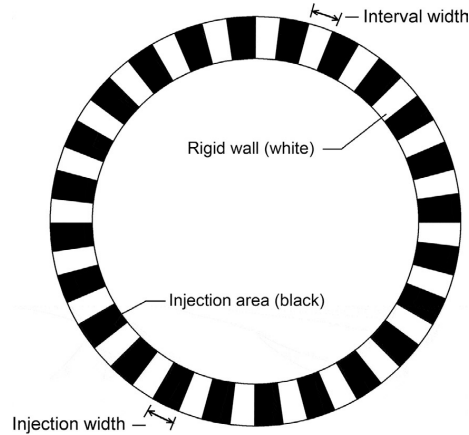


Fig.3 Schematic diagram of a radial strip injection set-up.

Table 1: Simulation cases and parameters

Case	Injection area / Total inlet area	Number of detonation fronts
CASE1	90%	1
CASE2	85%	2
CASE3	80%	5
CASE4	75%	3
CASE5	70%	1

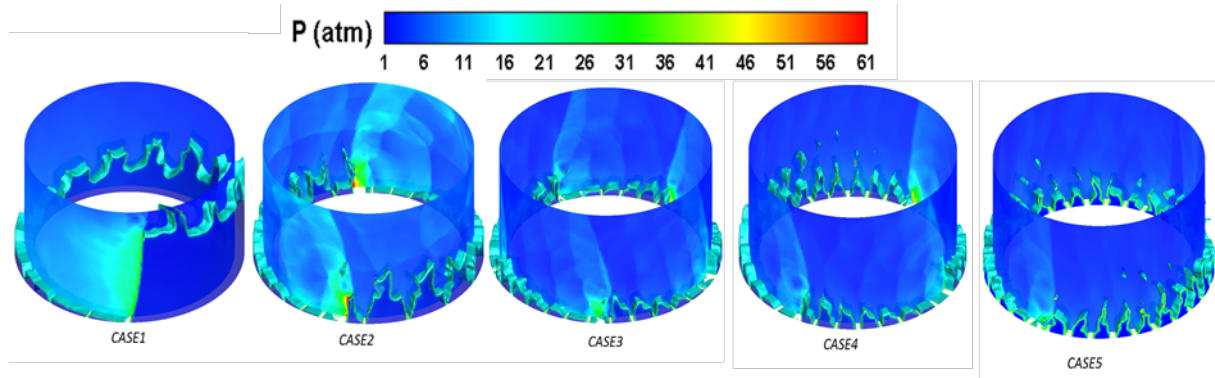


Fig.4 Pressure distribution of different simulation cases

Figure 3 is the sketch of a radial strip injection set-up [13]. As Table 1 and Fig. 4 suggest, the number of intervals is fixed but the size of the intervals is changed: the ratio of the injection area to the total inlet area is reduced from 90% to 70%. It shows that the number of the detonation fronts first increases and then decreases. When the ratio of the injection area to total inlet area is reduced from 90% to 80%, the number of the detonation fronts increase, because with the intervals enhance, the detonation wave can induce many reflected shock waves, which makes the wave system complicated after the detonation wave. What's more, with the increase of intervals, the shock waves behind the detonation waves will develop into a detonation wave easily. When the injection area ratio decreases from 80% to 70%, the number of the detonation fronts decrease. The reason of that is with the intervals further increase, the air intake decrease, as the same time, the increase of the intervals is conducive to the mixing of the combustible gas and the uncombustible gas, leading to the increase of fresh gas burned off by the deflagration wave, which makes the fuel in the combustion chamber insufficient and make the shock wave difficult to develop into the detonation wave.

4.3 Transition process

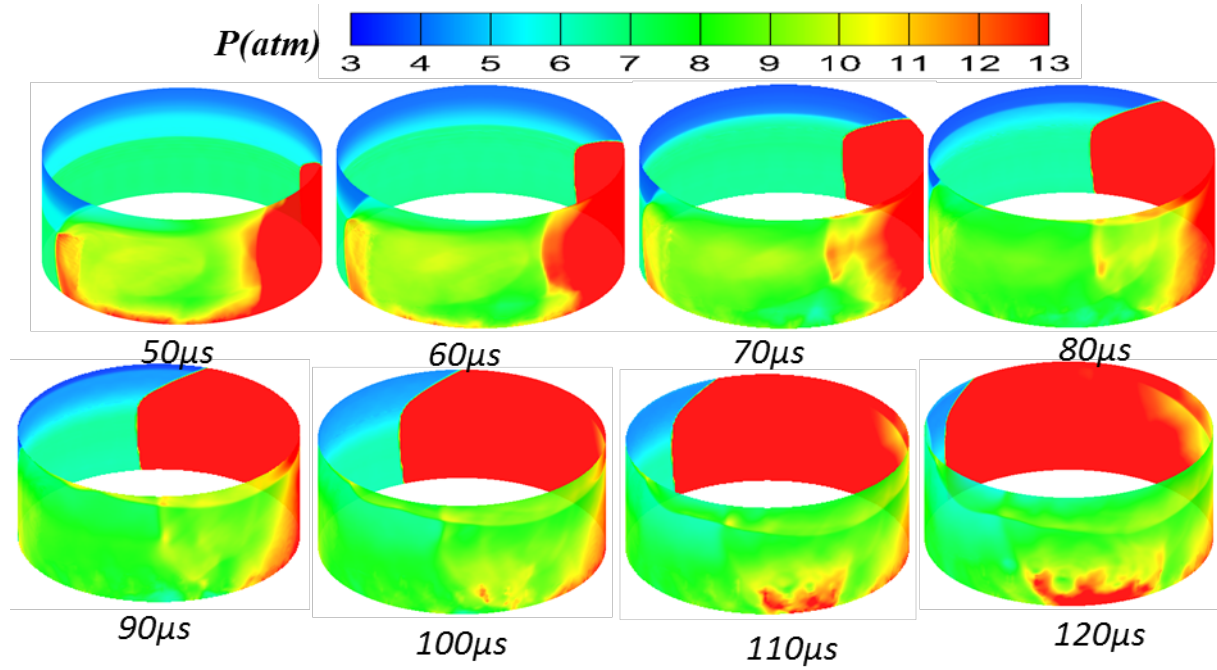


Fig.5 Pressure distributions of case 2 from 50 " μ " s to 240 " μ " s.

Figure 5 illustrates the transition process from single detonation front to double detonation fronts in case 2 (Fig.4). After ignition, a detonation wave propagates counterclockwise and a shock wave propagates clockwise (50 μ s). As the combustion products expand, there is a shock wave propagating clockwise, and gradually weakened (50-90 μ s). At 110 μ s, the shock wave collides with the injection wall and its strength rapidly enhanced, creating two strong shock waves (110-120 μ s) which propagate in the opposite direction. The shock wave propagating clockwise is gradually weakened, while the shock wave propagating counterclockwise is enhanced and a detonation wave is induced (220 μ s). Finally, two uniformly distributed detonation waves propagate stably (case 2 in Fig. 4). This can be used to explain the phenomenon of detonation wave induced by the shock wave which propagates from downstream to upstream.

5 Conclusion

- (1) The number of the detonation fronts first increases and then decreases when the ratio of the injection area to the total inlet area is reduced from 90% to 70%.
- (2) Detonation wave can be induced by the shock wave return from downstream to upstream.

Acknowledgments

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