Effects of isothermal wall boundary conditions on continuous detonation chamber

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1 Introduction

Continuous detonation chamber (CDC) has drawn wide attention over the past decades as it needs only one initiation and has higher thermodynamic efficiency. However, due to high temperature, high pressure and high heat flux characteristics of the CDC, the cooling of CDC is a great challenge. So far, most of the researches focus on measuring heat flux by experiments, while there are few studies on heat flux by numerical simulations. It is mainly because of the fact that most numerical simulations on CDC are based on the Euler equations ignoring the effects of heat flux. For this reason, the present study focuses on the effects of isothermal walls on a CDC.

2 Governing Equations and Numerical Model

2.1. Governing equations

The *Navier-Stokes* equations with the one-step reactive chemical model in generalized coordinates are used as the governing equations.

2.2. Numerical methods

The advection terms are discretized with the fifth-order monotonicity preserving weighted essentially non-oscillatory (MPWENO) scheme and the second-order central difference scheme is used for the diffusion terms [1]. The temporal terms are integrated by the third-order TVD Runge-Kutta scheme. The pre-mixed stoichiometric hydrogen/air mixture is injected into the chamber along the axial direction with the stagnation pressure and temperature of 30 atm and 600 K, respectively. The injection is assumed to be Laval nozzle inflows, and the area ratio of the nozzle exit to the throat is set to 10. An extrapolated outflow boundary condition is used for the outflow [2]. The inner and outer walls are non-slip walls. Besides, adiabatic and isothermal walls are used for the inner and outer walls of different cases.

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3 Results and Discussion

2.1. Governing equations

As shown in Fig. 1, with adiabatic walls, a dynamically stable detonation wave is rapidly formed after initiation. The detonation velocity is about 1827.3 m/s.

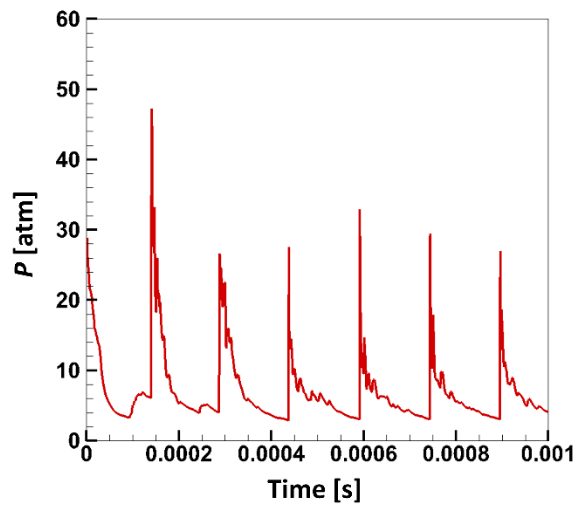

Figure 1. Pressure-time profile at the point (r= 4.3 cm, θ= π/2, Z= 0.3 cm) for adiabatic walls.

3.2. Isothermal walls of 300 K

A detonation wave propagating in the axial direction is found in Fig. 2. It can be observed that there are two detonation waves, named as 1 and 2, propagating in the axial direction and the route of the axial detonation waves are along the downstream shock wave. This is because of the pressure and temperature of the reactant gas increases after swept by the downstream shock wave, thus it is easier to be initiated. The speeds of the axial detonation waves 1 and 2 are about 980 m/s and 1300 m/s, respectively. Bykovskii et al. [3] and Wang et al. [4] also found the axial detonation waves in their experiments and the average propagation velocity of the axial detonation wave is about 1000 m/s. The present numrical results are in good agreement with experimental results.

3.3. Isothermal walls of 600 K

As shown in Fig. 3, the whole process of initiation and stable propagation of the detonation wave with the wall temperature of 600 K is similar to that with adiabatic walls. The reason is that temperature of the reactant gas newly injected is about 590 K, which is close to the wall temperature of 600 K. Thus the isothermal walls has little effect on the newly injected gas. The velocity of the detonation wave is 1728.7 m/s, which is smaller than 1827.3 m/s with adiabatic walls. The decrease of the velocity is because isothermal walls trigger heat loss compared with adiabatic walls.

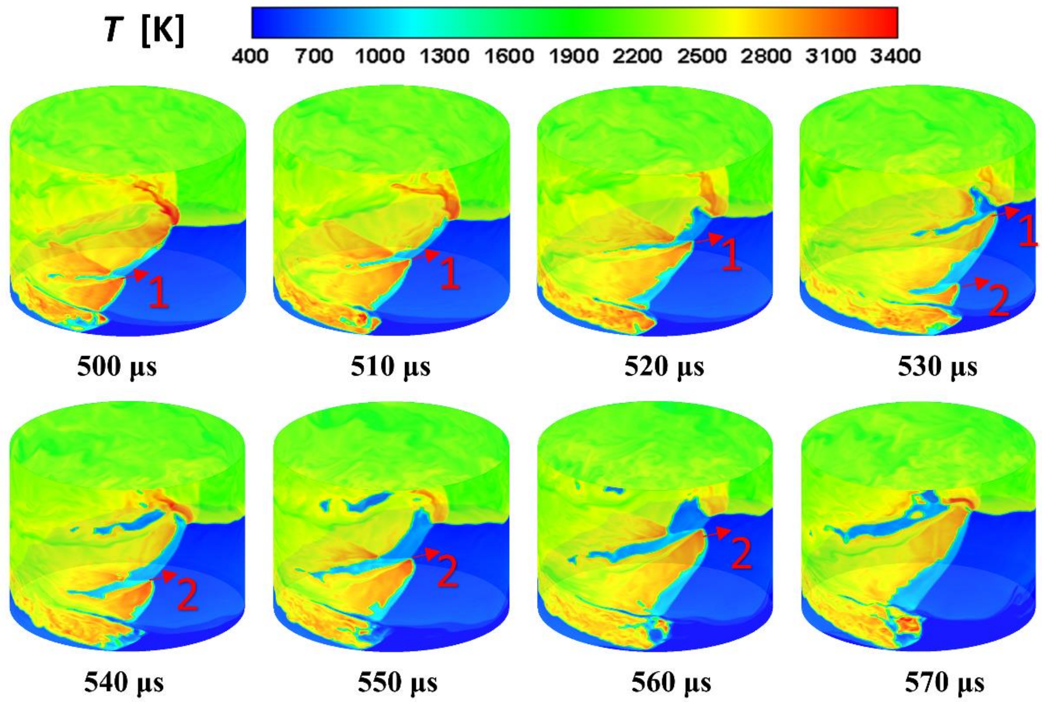

Figure 2. Propagation process of the axial detonation wave for isothermal walls of 300 K on r = 4.3 cm.

3.4. Isothermal walls of 900 K

As shown in Fig. 4, the detonation wave with the isothermal walls of 900 K undergoes a process of quenching, reinitiation, and stable propagation. From 0 to 500 µs, there is no detonation wave in the flow field. This phenomenon is also found in the experiments of Kindracki et al. [5] and the numerical simulation of Yao et al. [6].

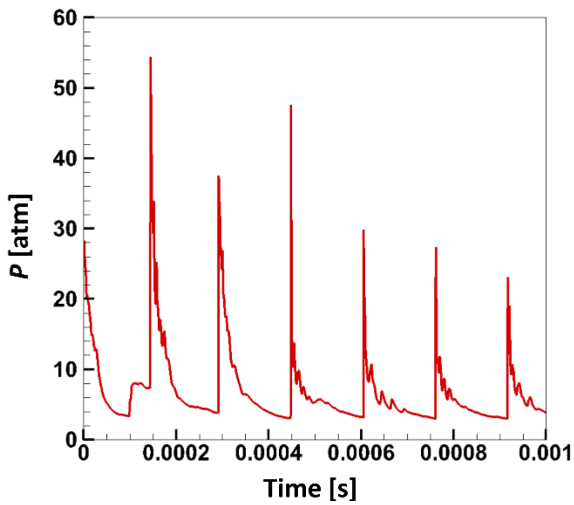

Figure 3. Pressure-time profile at the point (r= 4.3 cm, θ= π/2, Z= 0.3 cm) for isothermal walls of 600 K.

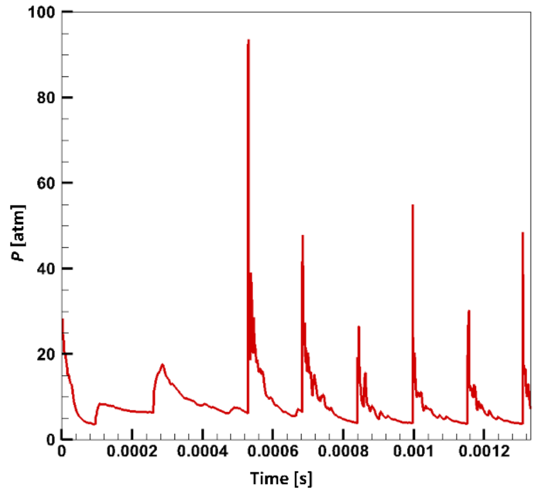

Figure 4. Pressure-time profile at the point (r= 4.3 cm, θ= π/2, Z= 0.3 cm) for isothermal walls of 900 K.

3.5. Heat flux

Figure 5 is the heat flux distribution of the outer wall for the isothermal walls of 600 K and 900 K. Heat flux peaks at the detonation wavefront, which is consistent with the experimental results of Bykovskii et al. [7] and Randall et al. [8].

Table 1 shows the average heat flux for the whole combustor and average peak heat flux with isothermal walls of 600 K and 900 K. As the wall temperature increases from 600 K to 900 K, the average wall heat flux and the average peak heat flux decrease. The reason is the temperature gap of inside and outside of the combustor narrows as the temperature of the wall increases from 600 K to 900 K. It can also be seen from Table 1 that the average peak heat flux is about 2.8 and 2.7 times of the average heat flux for these two cases. This is in consistence with experiment study of Bykovskii et al. [7] where the peak heat flux is 2-3 times of the average heat flux.

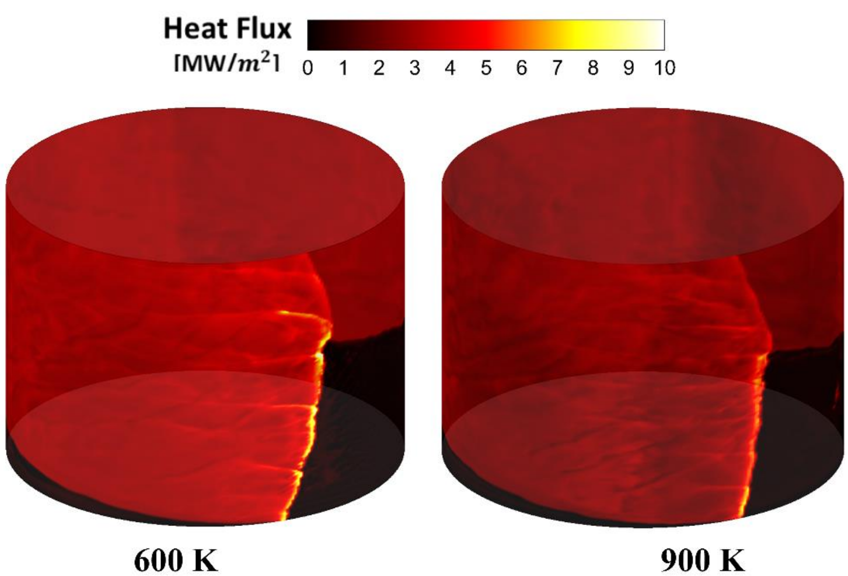

Figure 5. Heat flux distribution of the outer wall with isothermal walls of 600 K and 900 K.

Table 1. Comparison of the heat flux with isothermal walls of 600 K and 900 K.

Wall temperature (K)	Average heat flux(MW/m^2)	Average peak heat flux(MW/m^2)
600	2.6	7.4
900	2.2	6.0

4 Conclusions

1. With 300 K isothermal wall, axial detonation waves are observed.

2. With the wall temperature of 600 K, the process of initiation and stable propagation of the detonation wave is similar to that with adiabatic wall. Whereas propagation speed of detonation wave is smaller than that with adiabatic wall.

3.The detonation wave undergoes a process of quenching, reinitiation, and stable propagation in the CDC with the isothermal walls of 900 K.

4. In the cases of isothermal walls of 600 K and 900 K, the heat flux peaks at the detonation wavefront and is about 6.0 MW/m^2 and 7.4 MW/m^2. The average peak heat flux is about 2.8 times of the average heat flux.

Acknowledgments

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