Combustible Mixture Injection and Ignition in Downstream of 2-D Detonation

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1. Introduction

Since several years ago, there have occurred the trends to control the detonation propagation, and utilize its high-power and high density energy in positive directions like pulsed detonation engines(PDE) [1]. It was Eidelman who reignited the study of PDE. The study of pulsed detonation engine has widely spread out recently, because it is considered as a candidate for space propulsion application of next generation[2]. In the application of PDE, the key issue is how to generate CJ detonation with a short distance. Therefore, recently, an investigation of injection and ignition becomes important.

In this paper, a 2-dimensional analysis of PDE cycles containing Ar-diluted stoichiometric oxyhydrogen mixture is performed. For the purpose of achieving "high-cycle" engines, we specially pay attention to its injection and ignition in the 2nd cycle, where the burnt gas generated in the 1st cycle remains. In this analysis, a 2nd accurate MacCormac-TVD scheme is used for Navier-Stokes equations and a two-step chemical reaction model[3] is introduced.

2. Numerical Analysis of 1st cycle

The fundamental equations are Navier-Stokes ones containing the mass conservation equations for the two progress variables α(induction reaction) and β(exothermic reaction) [4]. Figure 1 shows a process of the two-step chemical reaction model. For a unburnt mixture, both reaction progress parameters, α and β are set to zero. The parameters, α and β are $1>\alpha$

>0 and β =1 in the induction period, α =0 and 1> β >β_{eq} in the exothermic period. In this analysis, we introduce the parameter, χ:

$$\chi=(\beta-\beta_{eq}) / (1-\beta_{eq}).$$

Using χ, the mixture gases are shown in Table 1.

Working principle of this calculation model PDE can be explained in the following: a simple type PDE of straight shape is considered, which has the closed upstream end having Ar-diluted stoichiometric oxyhydrogen mixture ($2H_2 + O_2 + 7Ar$) injection port and igniter while the downstream end is open for the exhaust of burnt gas. In this analysis, a calculation of 1st cycle starts after an Ar-diluted stoichiometric oxyhydrogen mixture is filled up in the channel of 3cm width and 38cm length at the initial pressure 5atm and temperature 298.15K (Fig.2(a)). The ignition is artificially performed by assuming the CJ detonation obtained from 1-dimensional analysis (Fig2(b)). In order to generate a 2-dimensional detonation, the initial CJ detonation is disturbed by placing the properties of unburnt mixture at intervals of 0,2mm in the 1mm x 1mm region near the channel wall immediately behind the shock wave front. The combustion wave is accelerated to a detonation in a short DDT distance and propagates to the downstream end (Fig2(c)). Thereafter, the detonation leaves the chamber, followed by the burnt gas being exhausted from the chamber (Fig2(d)), in synchronization with the fresh mixture injection in the next cycle.

The grid points are 3800x300($\Delta x=\Delta y=$ 0.1mm). The present grid number is found to be sufficient through a grid study. Figure 3 shows the soot pattern in the 1st cycle. The triple point appears at the 6cm location and the cell pattern exists from the 6cm location to the downstream end. The propagation velocities of the detonation wave front is shown in Fig.4. The calculated velocity is in good agreement with the CJ velocity. Thus, we can conclude that the CJ detonation propagation is achieved in the 1st cycle.

3. Numerical Analysis of 2nd cycle

Immediately after the shock wave front reaches the downstream end, a fresh combustible mixture is injected from the injection port, as shown in Fig.5. In this analysis, the combustible mixture is an Ar-diluted stoichiometric oxyhydrogen mixture ($2H_2 + O_2 + 7Ar$) of 3.0atm initial pressure and 298.15K temperature. Calculated contour of parameter, β at the 2.82×10^{-3} sec after injection start is shown in Fig.6. Figure 6 explains that the injected fresh combustible mixture is expanded in the channel and diffuses into the burnt gas.

4. Conclusions

In this paper, a 2-dimensional analysis of PDE cycles containing Ar-diluted stoichiometric oxyhydrogen mixture is performed. As a result, the detonation propagation is achieved in the 1st cycle. By injecting the combustible mixture into the channel, the expansion and diffusion of the mixture is observed.

References

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3) Korobeinikov, V.P., Levin, V.A., Markov, V.V. and Chrnyi, G.G.: Propagation of Blast Waves in a Combustible Gas, Astronautica Acta, Vol.17, pp.529-537. 1972.

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Table 1　Relation between β and Mixture of Gases

β	1	0	β_{eq}
Mixture of gases	$2H_2+O_2+7Ar$	$\chi(2H_2+O2)+(1-\chi)H_2O+7Ar$	$2H_2O+7Ar$

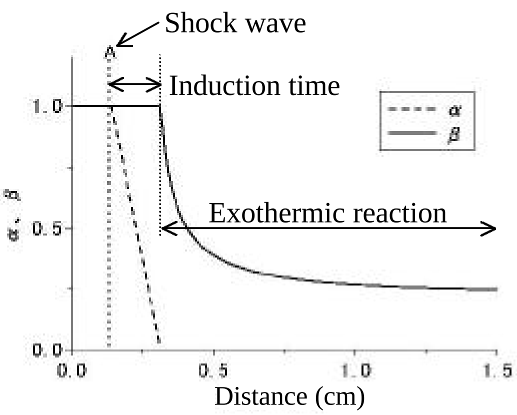

Fig.1 Behavior of the Reaction Progress Parameters α and β

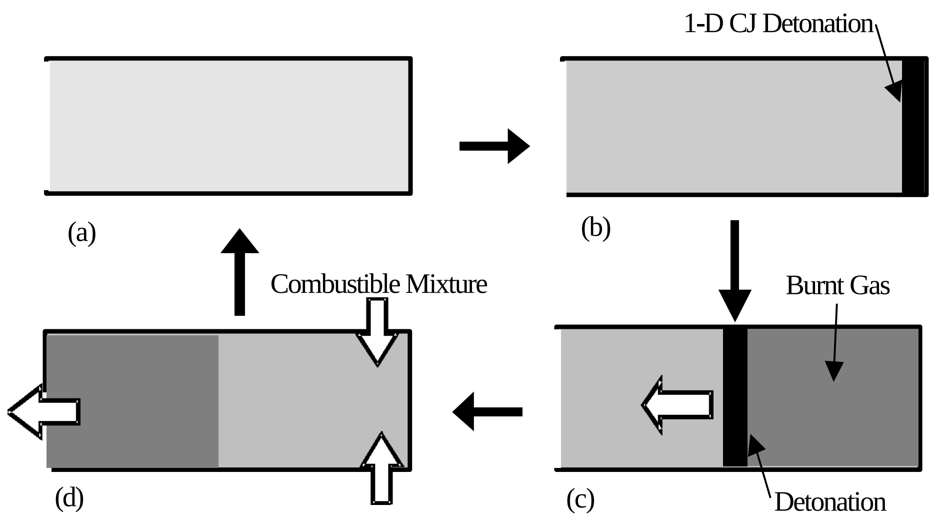

Fig.2 PDE Thermodynamic Processes

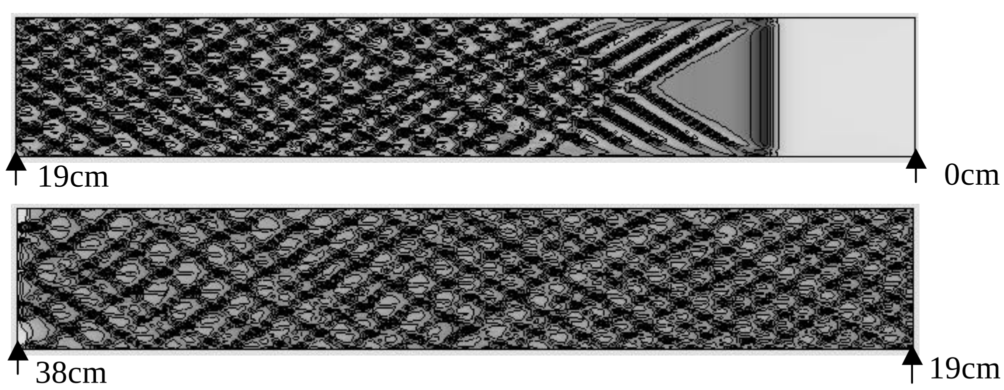

Fig.3 Soot Pattern in the 1st Cycle

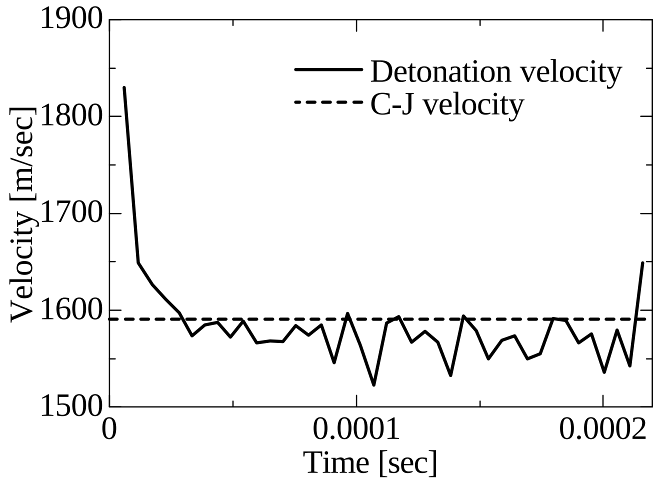

Fig.4 Temporal Variation of Detonation Propagation Velocity

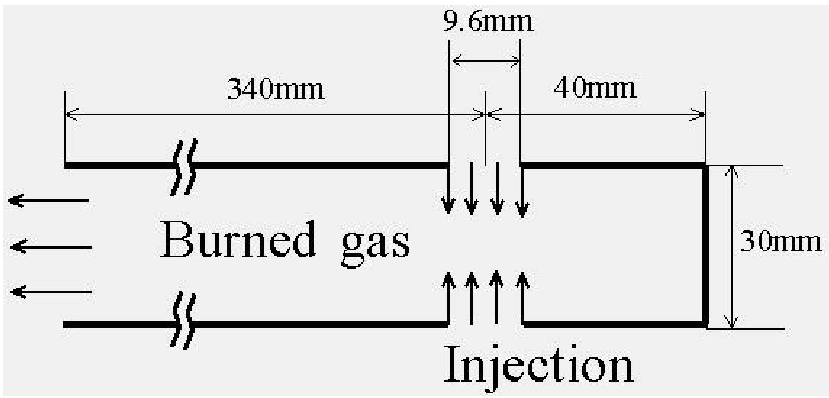

Fig.5 Geometry of the present Injection Model

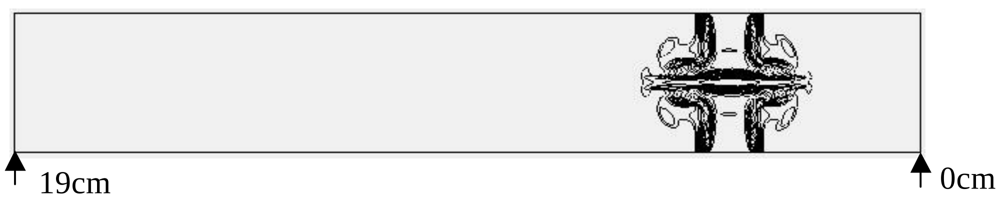

Fig6 Parameter, β Contour at the $2.82x10^{-3}$ sec after Injection Start