On the Effect of Argon Dilution on Detonation Diffraction in C_2H_2/O_2 Mixture through Cones

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1 Introduction

Critical diameter of detonation transition from a tube to the open space d_{cr} in most hydrocarbon-air and hydrocarbon-oxygen mixtures scales with detonation cell thickness λ, namely, the detonation diffracts to a space if $d_{cr}/\lambda>13$, else detonation failure takes place [1]. Later it was found that the critical number of cells depends on initial pressure and can vary from 11 to 15 [2]. Moreover, strong dilution by monoatomic gas, i.e. argon, strongly increases the critical number of cells to 26-30 and more [3,4]. Up to now this effect has no reliable explanation.

In this work we present results of experimental study of detonation diffraction in $C_2H_2+2.5O_2+15Ar$ mixtures through cones of different divergence angle. The experimental study is complemented by a numerical modelling, which was performed under the assumption that the heat release in the considered mixtures is not monotonous but proceeds in two consecutive steps: $A \rightarrow B$ and $B \rightarrow C$. The reaction rate constants of both stages were found by reducing the detailed kinetic scheme.

In general, results of two-dimensional modelling of detonation diffraction performed for axisymmetric case reasonably agree with experimental data.

2 Experimental Study

The experiments were performed in a 7-m long shock tube with inner diameter of 52 mm (details are described in [5]). The conical expanding section was connected at the end of the tube and the history of detonation transition or failure was recorded using the smoked foil technique. We have varied the initial pressure and the cone expansion angle α. Figure 1 shows summary of the experimental results (upper curve) for the $C_2H_2+2.5O_2+15Ar$ mixture. These results were plotted taking into account that the cell size λ of self-sustained detonation in this mixture drops with an increase of ambient pressure P_o as $\lambda=3586P_o^{-1.19}$, where λ is expressed in mm and P_o in mbar. Particularly, this plot shows that in the case of diffraction to the open space (α=90°) about 32 cells across the tube diameter are necessary for the detonation transition to occur.

3 The Model

The principle feature of the proposed model is that it takes into account the two-stage character of heat release in the considered strongly diluted mixtures. Nonmonotonous character of heat release is demonstrated in Fig.2, which shows profiles of temperature in the steady ZND detonation reaction zone calculated at constant value of

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preexponential factor of the leading reaction and different values of the preexponential factor Z_2 of the second reaction. Both reactions were described using Arrhenius laws. The reduced two-step kinetics at Z_2=5E6 reasonably reproduces the temperature profile corresponding to the detailed kinetic mechanism.

Numerical simulation of detonation diffraction was made assuming that the flow is axisymmetric. The two-dimensional Euler conservation equations were solved using the FCT scheme [6].

3 Results

Figure 3 shows calculated traces of maximum pressure when there are 18 cells across the tube diameter (d/λ=18) and the half-angle α of the cone expansion equals 50°. This case corresponds to detonation extinction. It is worth to note that the length of extinction cone is markedly longer than the tube diameter. This effect is due to the contribution of heat release of the first reaction only. Slight reduction of the cone expansion angle to 47.5° at the same ambient pressure as above (188 mbar) favours detonation transition as one can see in Fig.4. Comparison of Fig.3 and Fig.4 gives one more example of a competition between energy losses caused by volumetric expansion and the heat release rate, which is now markedly nonmonotonous.

Figure 1 shows, along with experimental results, a summary of calculation results. One can see that the proposed work for the first time gives a consistent and nearly quantitative explanation to the increase of critical cell number necessary for detonation transition in strongly diluted argon mixtures. However, our model does not reproduce the strong change of critical cell number in the narrow range of cone expansion angle 25°<α<35°.

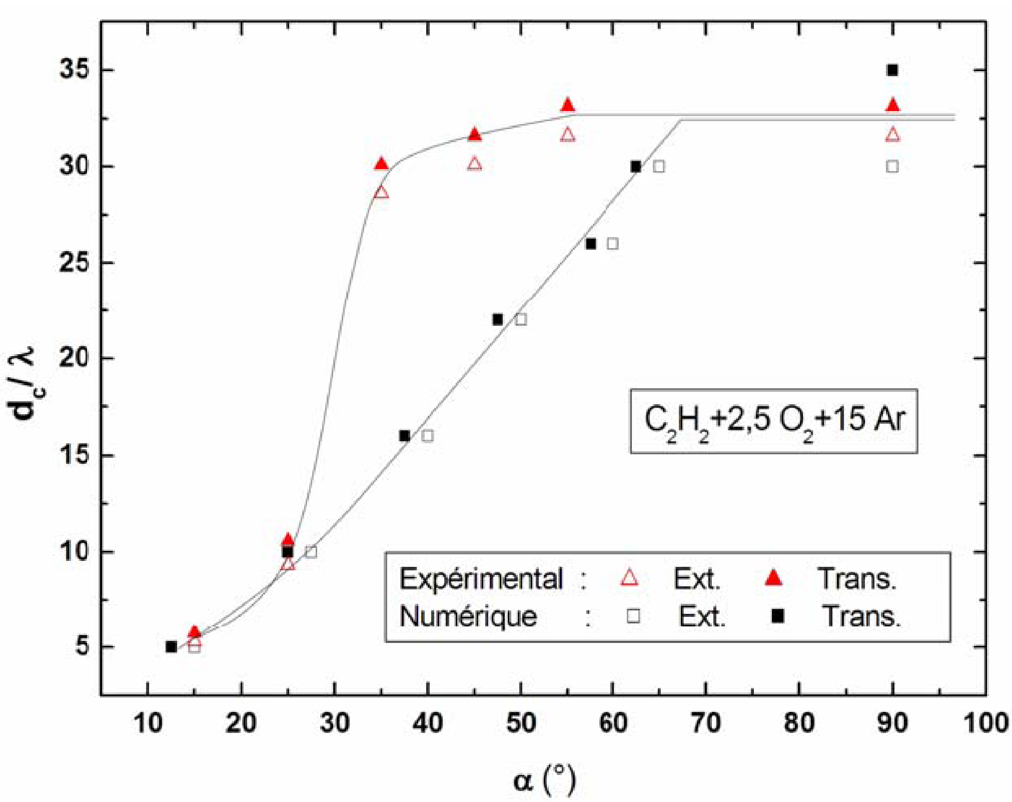

Figure 1. Experimental and numerical evolution of critical number of cells necessary for detonation transition in function of half-angle of cone expansion

3 Conclusions

Detonation diffraction through cones in stoichiometric acetylene-oxygen mixture highly diluted by argon is studied experimentally and dependence of critical number of cells on cone expansion angle is established. A numerical model is proposed, which explicitly takes into account the non-monotonous two-step character of heat release in the considered mixtures. For the first time a self-consistent explanation is proposed for the effect of nearly 2-fold increase of critical number of cells with 80% argon dilution in stoichiometric C_2H_2/O_2 mixtures.

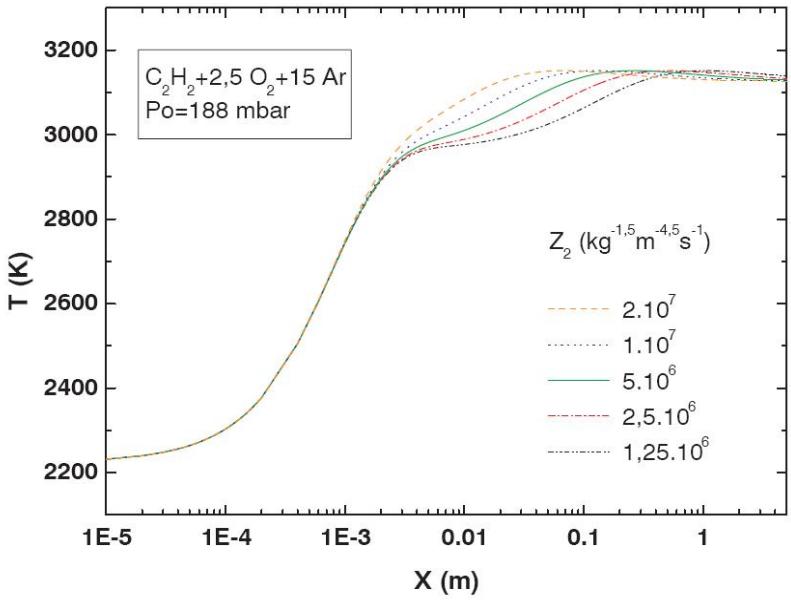

Figure 2. Temperature profiles behind the shock front of a steady detonation at P_o=188 mbar

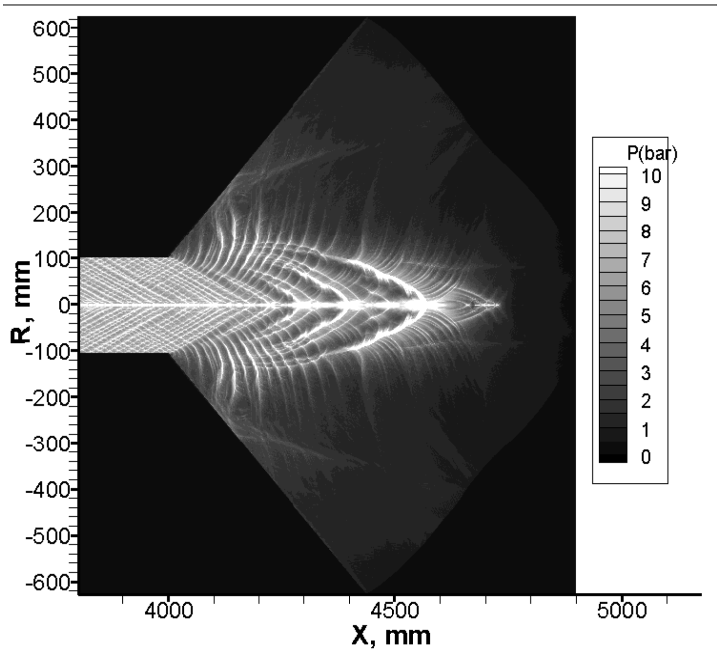

Figure 3. Detonation extinction at d/λ=18 and α=50°

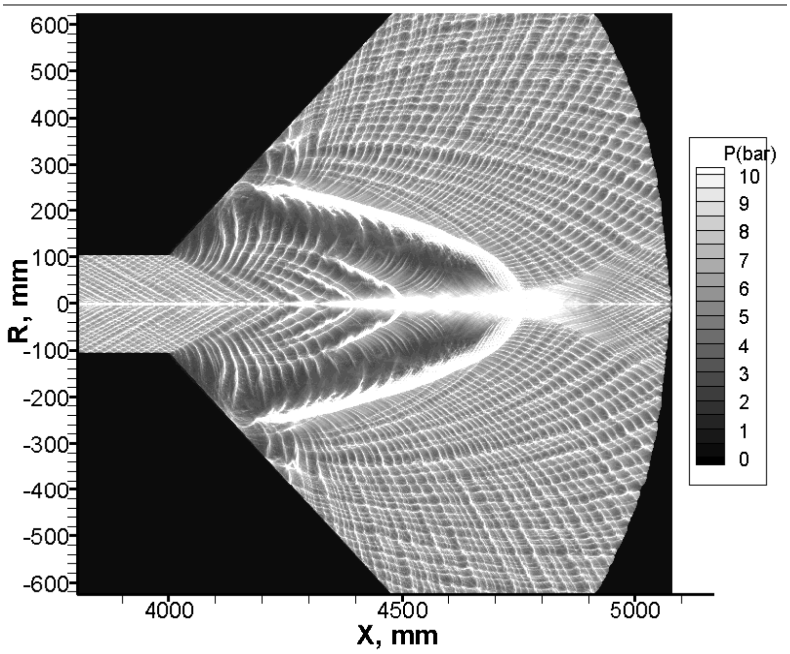

Figure 4. Detonation transition at d/λ=18 and α=47.5°

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