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A Study of Propagating Detonation Waves in Narrow Channels

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Abstract : Detonation cell width and velocity deficit, both implicitly include the wall effects, are investigated to obtain insight on propagating detonation waves in narrow channels. The total length of the 50.5 mm i.d. detonation tube is 5350 mm, which comprises of several sections including a 850 mm long driver section and a 1500 mm long test section. The detonation in the test section is initiated via a detonating driver gas, which bursts a thin diaphragm separating these two sections. The velocity deficits predicted by the boundary layer displacement theory developed by Murray were compared to those obtained experimentally. Good agreements are found between the theoretical predictions and the experimentally obtained velocity deficits for all the channel dimensions studied for the present gaseous systems. However, the experimentally measured cell widths are found to be larger than those evaluated from the induction zone length calculated by the ZND model. This gives a basis to conclude that the extinction of some of the triple points, which leads to form larger cellular structures inside the channel as compared to the original one measured before the channel entrance, may be made by the boundary layer developed at the wall surfaces. To approximate the experimental cell width (λ_m) in the channel through the predicted cell width (λ_P), a relation $\lambda_m = B\lambda_P$ was found in this study where the value of *B* is slightly dependent on the reaction model. *B* was evaluated to be 1.2 using Lutz et al.'s reaction model and 1.3 using GRI Mech 3.0.

Key Words : Detonation, Velocity deficit, Cell width, Boundary layer

1. Introduction

The detonation cell width, which has been proposed as a characteristic detonation length scale, is commonly employed to measure the detonation sensitivity or detonability [1]. In fact, several criteria based on the cell width for combustible mixtures have been arisen which draw the possibility of detonation initiation and propagation in a given geometry [2-5]. Ishii et al. [6, 7] have shown that generally a detonation is capable of propagating inside a narrow channel with a velocity deficit, even when the channel height is smaller than the cell width measured in circular tube. The detonation cellular structure has been found to vary in size depending on sensitivity of mixture compositions and channel configurations [8].

The propagation of a detonation in any practical situation depends strongly on confinement in which detonation passes [9-12]. To capture detonation propagation in view of avoiding the hazardous phenomena of a detonative system in complicated structure such as chemical industry where detonable gaseous mixtures are handled in pipes, it is necessary to investigate the change in detonation velocity and change of detonation cell width through such flow restrictions in confinement. The present study is motivated by the need to acquire knowledge on the velocity deficits and the change in detonation cell widths induced by the boundary layer growth in narrow channels. The knowledge on this feature is important in assessing the likelihood of a detonation and its consequences in the narrow channel.

This paper is aimed to assess the role of boundary layer effect on modifying the detonation cell width of the test gas mixture in the narrow channel. A good number of tests were performed using stoichiometric hydrogen-oxygen mixtures diluted with various amount of inert argon or nitrogen. To clarify the propagation behavior of detonation waves in the current work, attempts have been undertaken to focus on the velocity deficits and cell widths for the narrow channel experiments.

2. Experimental Arrangement

2.1. Detonation Tube and Test Section

The detailed configuration of the experimental facility used for detonation propagation in a narrow channel of rectangular cross-section can be found in the schematic illustrated in Fig. 1. The transmission and subsequent propagation of detonation waves were investigated in the narrow channel installed into a stainless

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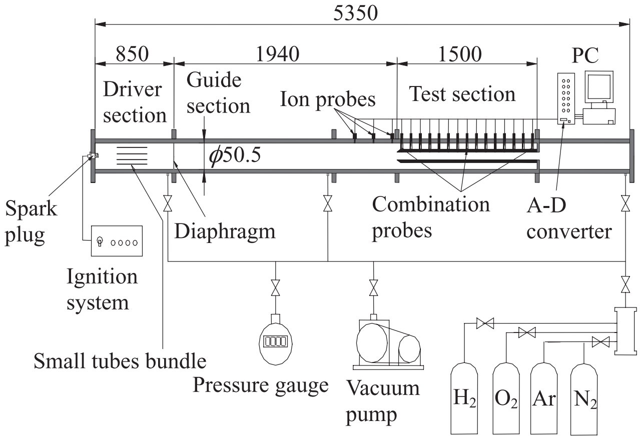

Fig.1 Sketch of experimental configuration used in narrow channel detonation tests. Dimensions are in millimeters.

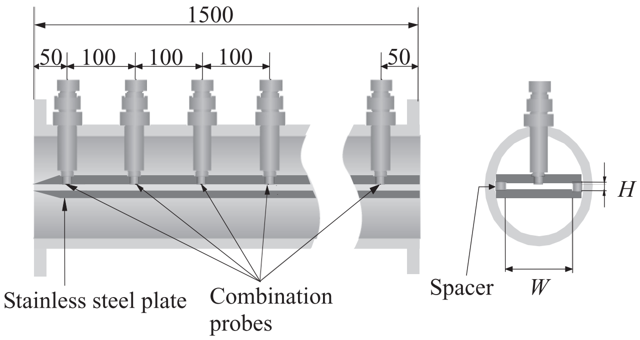

Fig.2 Detailed construction of the test section for forming a narrow channel in the detonation tube and arrangement of combination probes where its actual location does not correspond to this figure. Dimensions are in millimeters.

steel detonation tube of total length 5350 mm and 50.5 mm inner diameter.

The tube is composed of a driver section (850 mm in length), a guide section (1940 mm in length), a test section (1500 mm in length) and a rest part (1060 mm in length) to keep away the effect of wave reflection at the tube end. The driver section, which was separated by a 50 μm thick polytetrafluoroethylene diaphragm from the guide section, was charged at 65.0 kPa with a stoichiometric hydrogen-oxygen mixture. This mixture was ignited with a conventional spark plug for automobile-use mounted at the end flange of the driver section. After deflagration-to-detonation transition process, a steady detonation after bursting the diaphragm advanced towards the guide section to ignite the test gas mixture kept at 39.0 kPa and allowing the detonation to propagate into the channel. To promote rapid initiation of detonation in the driver section, dense bundle tubes of small diameter [13] were placed at 50 mm from an ignition point in the driver section. Lastly, a steady detonation, which was confirmed from the record of cellular structure obtained on smoked aluminium foils and propagation velocity measured by ion probes, was achieved before the test section. In the test section, a narrow channel 1500 mm in length was constructed by three pairs of stainless steel plates of equal length 500 mm, each has width 46 mm and thickness 8 mm. Two metal spacers of various thicknesses and widths were interposed at both side edges of the plate of each individual pair to construct the different channel heights *H* and widths *W*. The detailed construction of the narrow channel installed into the test section is exposed in Fig. 2.

2.2. Instrumentation

At the time of filling detonation tube with the gas mixture, the desired mixture pressure for the driver section and test section was monitored by a pressure gauge mounted on the tube. The channel was brought in contact with fifteen combination probes [14], each of which comprised of an ion probe and a pressure probe. The ion probe was composed of two coaxial electrodes so that the combination probe was fixed to the stainless steel plate with flush mound for avoiding generation of flow disturbances in the narrow channel. Every successive two combination probes were separated by a distance 100 mm. The combination probe can sense the arrival of shock and reaction front at one measurement location inside the channel. From the arrival time of the shock and reaction front, an average shock front and reaction front velocity can be obtained inside the channel. Moreover, three ion probes were installed on the detonation tube before the channel entrance. The velocity at the channel entrance, which was found to be approximately equal to the CJ value, was calculated from the time-of-arrival at these ion probes positioned 200 mm apart from each other.

2.3. Experimental Procedure

The best and easiest way of obtaining cell imprints is to use the smoked-foil technique. A thin and flexible aluminium foil (0.3 mm in thickness and 150 mm in length) was uniformly coated with a thin film of soot by holding it over the flame of wax candle. To record the original cellular structure in the circular tube before the channel entrance, this soot-covered foil was inserted fitting tightly on tube's inner surface in the circumferential direction. This foil was then taken out of the tube after each experiment and sprayed with a lacquer to preserve the cell imprints. In the same way, soot was also covered on both surfaces of the stainless steel plates forming the narrow channel. Thus the variation of cellular structure produced by tracks of the triple points inside the channel was recorded. All the joints and flanges were sealed to block leakage into surroundings. The tube was then made clean and evacuated by a vacuum pump to introduce the desired gas mixtures into both the driver and test section via coflowing streams of pressurized commercial hydrogen, oxygen and argon or nitrogen in calibrated proportions using sonic nozzles. For all experiments reported in the present paper, stoichiometric amount of hydrogen-oxygen mixture diluted with several amounts of argon or nitrogen in volumetric percentages were introduced into the test section. The driver section was always loaded with a stoichiometric hydrogen-oxygen mixture through all the experiments. The amount of argon dilution was varied from 50 % to 80 % in volume to study the effects of cell width on detonation propagation in the narrow channel, while the nitrogen dilution was varied from 15 % to 45 % in volume. Several tests were repeated under the same experimental condition. A numerous combinations with different channel widths ranging from 10 mm to 40 mm and different channel heights ranging from 1.2 mm to 2.0 mm are employed to vary the channel sizes. Immediately after every test, the product of combustion including water vapor were redirected to outflow through the vacuum pump so that erasing of the cellular structure formed by trajectory of the triple points contained in detonation front could be avoided. In most cases this produced good quality picture of the cellular structures.

3. Results

Experimental results of the present work demonstrate the propagation of detonation in the narrow channel with various configurations and mixture compositions. As the cellular structure is affected by the channel configurations and argon or nitrogen dilutions, survival of the triple points entering into the channel would be an important tool to measure the cell width of propagating detonation in the narrow channel. The experimental cell width (λ_m) was measured through the simple relation $\lambda_m = 2W/N_{TP}$, where N_{TP} is the average total number of triple points in the region 1100 mm ~ 1450 mm of the channel. The counting procedure of the triple point contained in smoked plate is shown by sketching an arbitrary plate surface in Fig. 3. Figures 4 to 7 show the original cell width (λ_0) obtained before the channel entrance and the dependence of measured cell width (λ_m) on the channel dimensions for several experimental conditions. It is to be noted that the stable detonations obtained in the channel for argon and nitrogen diluted hydrogen-oxygen mixtures are described in these Figures. Figures 4 and 5 show the effects of the channel heights on the cell width with the channel width fixed at 40 mm. The cell width in the channel increases with decrease in the channel height for all the mixtures investigated. Also it is seen in these Figures, for larger channel height, the cell width is found to decrease, although this is above the original cell width obtained before the channel entrance. Figures 6 and 7 show the effects of the channel widths on the cell width for various argon and nitrogen dilutions, respectively with the channel height fixed at 2.0 mm. It is observed that the cell widths in the channel are gradually decreasing for relatively larger channel widths, although this width is still larger than λ_0. Therefore, the cell width for both systems in the channel becomes larger than λ_0 even in the wide channel dimension, while this width was found to be enlarged more for minimal channel size and maximal dilution.

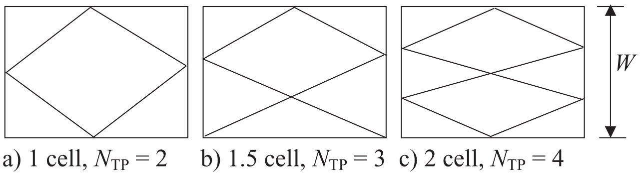

Fig.3 Sketch of arbitrary smoked plate records showing the triple point count. W denotes the width of the channel.

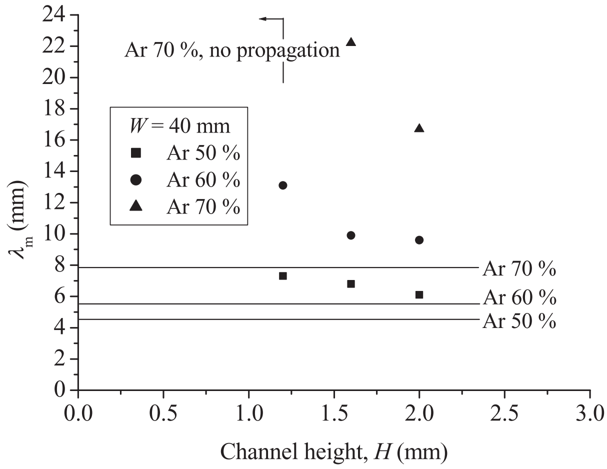

Fig.4 Effects of channel heights on cell width in the test mixtures diluted by various amount of argon with the channel width W = 40 mm. Solid line denotes the original cell width λ_0 measured in the circular tube before the channel entrance.

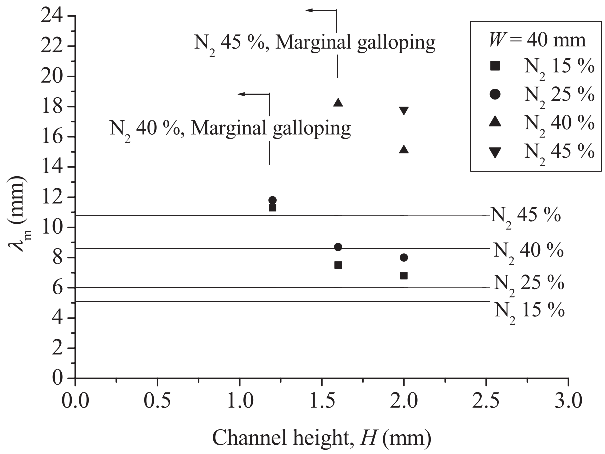

Fig.5 Effects of channel heights on cell width in the test mixtures diluted by various amount of nitrogen with the channel width W = 40 mm. Solid line denotes the original cell width λ_0 measured in the circular tube before the channel entrance.

Unstable behavior of hydrogen-oxygen-nitrogen detonation, particularly the galloping mode was obtained in the channel experiments. It was extremely complicated to measure the width of locally obtained fine cellular structure associated with the galloping mode. This behavior is described in another look, apart from the above discussion. Under near-limit conditions, neither galloping detonation nor reinitiation [15] was found

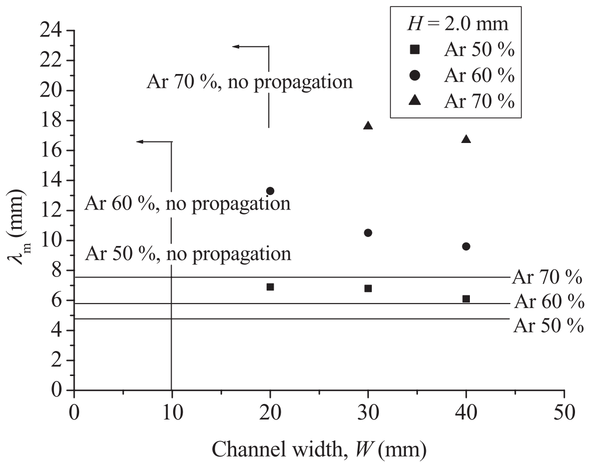

Fig.6 Effects of different channel widths on cell width for the channel height $H = 2.0$ mm in the test mixture diluted with 50 % to 70 % argon. Solid line denotes the original cell width λ_0 measured in the circular tube before the channel entrance.

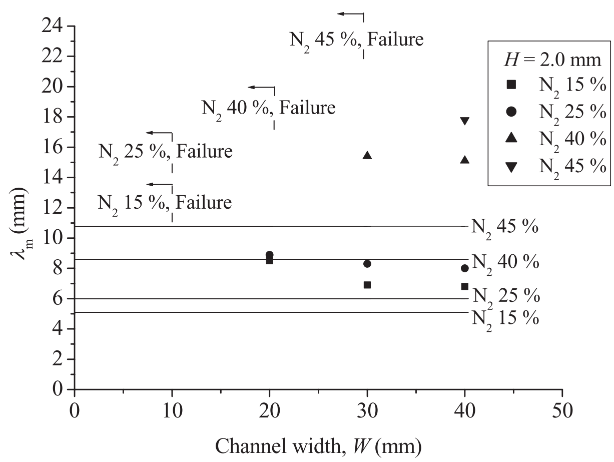

Fig.8 Cell width versus channel width for stoichiometric hydrogen-oxygen mixture diluted with various amount of nitrogen in volume. Channel height is 2.0 mm and solid line denotes the original cell width λ_0 measured in the circular tube before the channel entrance.

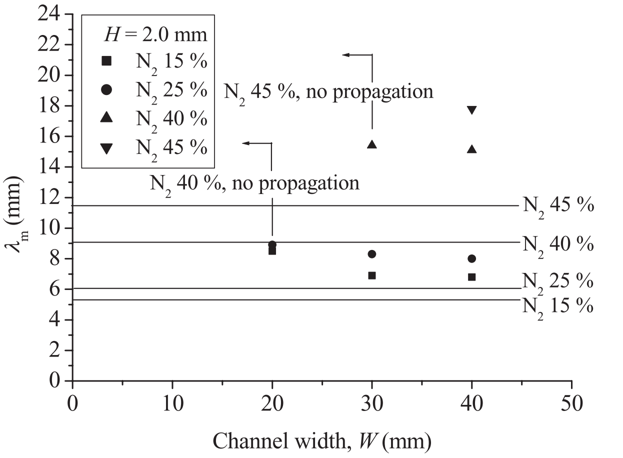

Fig.7 Effects of different channel widths on cell width for the channel height $H = 2.0$ mm in the test mixture diluted with 15 % to 45 % nitrogen. Solid line denotes the original cell width λ_0 measured in the circular tube before the channel entrance.

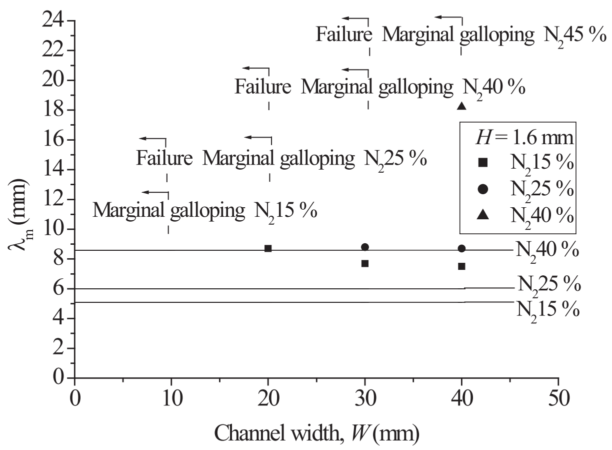

Fig.9 Cell width versus channel width for stoichiometric hydrogen-oxygen mixture diluted with various amount of nitrogen in volume. Channel height is 1.6 mm and solid line denotes the original cell width λ_0 measured in the circular tube before the channel entrance.

in stoichiometric hydrogen-oxygen mixtures diluted by argon [8]. However, in the present experiments conducted with nitrogen diluted hydrogen-oxygen system, unstable near-limit phenomenon such as galloping detonation is found to occur in the narrow channel. Takai et al. [16] disclosed by numerical simulation that polyatomic diluents such as nitrogen provide longer ignition delay followed by a sudden heat release and that disturbs the pressure profile, while monoatomic diluent, namely argon makes the pressure profile smoother. This characteristic of the polyatomic gas may be accounted for the fact that mixtures diluted with nitrogen have slight tendency to show the galloping mode or velocity fluctuation of detonation. It should be noted that there are a growing number of evidences that the regularity of cellular structure with nitrogen is much poorer than with argon dilution [17].

By varying the channel height, unstable galloping propagation mode can be produced for nitrogen diluted hydrogen-oxygen mixtures in the channel. Figs. 8 and 9 show effects of the channel width on the cell width for stoichiometric hydrogen-oxygen mixture diluted by nitrogen in volumetric percentages ranging from 15 % to 45 %. Additionally, comparison between these two Figures reveals the effect of the channel height on propagation modes of detonations. No galloping phenomenon occurs in the channel of the height 2.0 mm, as shown in Fig. 8. While the channel height is reduced from 2.0 mm to 1.6 mm then for the same range of channel width and gas system as of Fig. 8, the detonation propagation changes drastically. This severe change in detonation propagation is presented in Fig. 9. In the case of

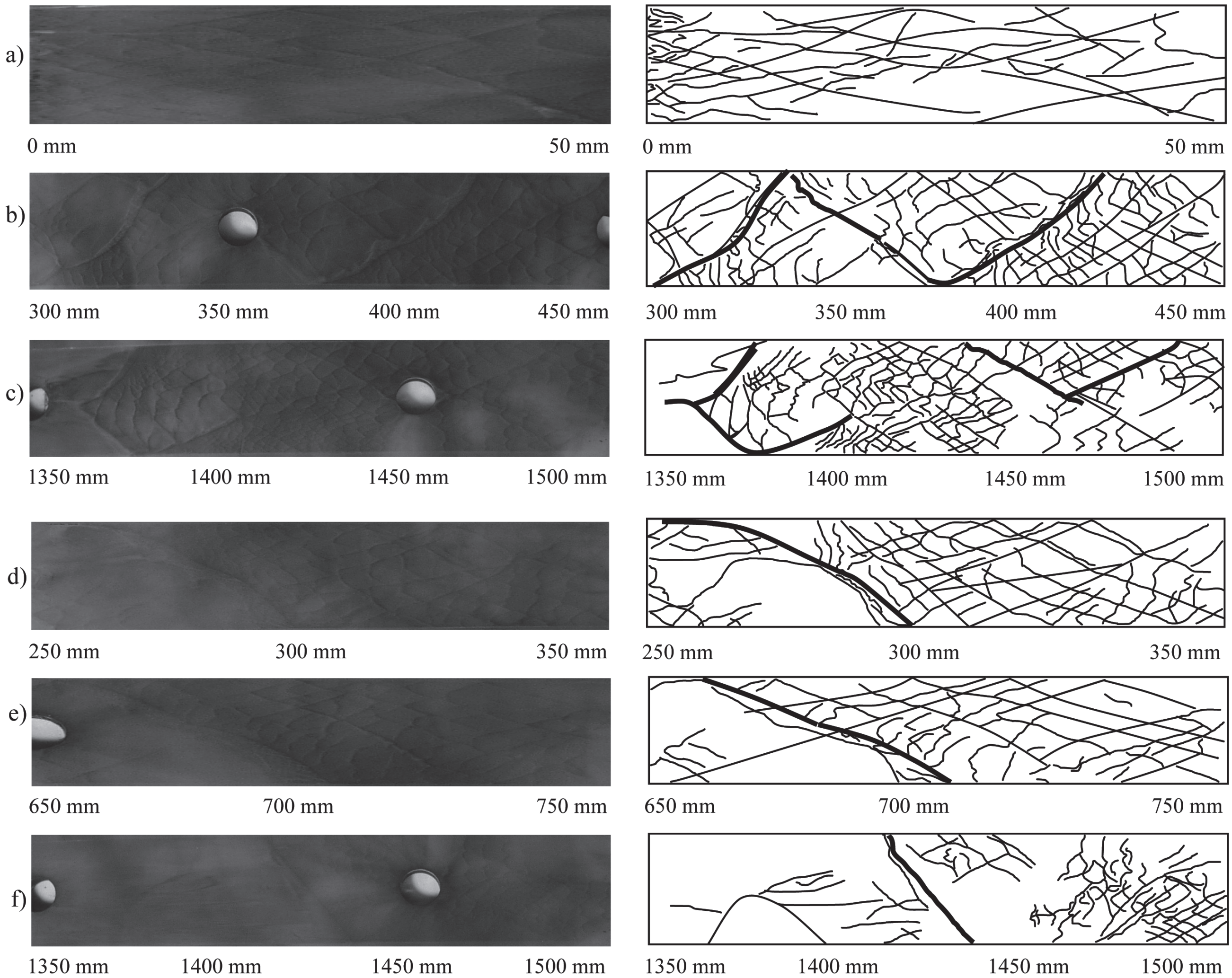

Fig.10 Smoked plate records showing the galloping phenomenon obtained in 25% nitrogen diluted stoichiometric hydrogen-oxygen mixture in the channel with H = 1.2 mm, W = 30 mm. a-c) corresponds to one test, while d-f) corresponds to another test for the identical condition. Each sketch of traces of the triple points on right side corresponds to the plate records on the left side. The distance from the channel entrance is given below the each record. Bold lines in the sketches indicate the traces of a strong triple point.

low detonable mixture e.g. the mixture diluted by 40 % or 45 % nitrogen, the galloping mode of detonation occurs for the channel width of 30 mm or 40 mm, respectively. Owing to this change in height, the galloping phenomena occur in the low sensitive mixture even for relatively larger channel width. Stable to failure via unstable galloping detonations occur on reducing the channel height in the present study is consistent with the results of Haloua et al. [18] that stable to fast flame through unstable stuttering and galloping modes of detonation could be produced on reducing the initial test pressure in stoichiometric propane-oxygen mixture.

Shown in Fig. 10 is the smoked plate exhibiting the trajectories of the triple points contained in the galloping detonation front, which interact with the wall edge in this case. Growing of fine cellular structure locally caused by this interaction leads to galloping phenomenon which is obtained in stoichiometric hydrogen-oxygen mixture diluted by 25 % nitrogen in the channel with H = 1.2 mm and W = 30 mm. The smoked foil imprint in this case is exemplified in Fig. 10, where the detonation wave is moving from left to right. The smoked plate records described on the left side in Fig. 10 are illustrated for clear visualization on the right side in the same Figure by drawing the tracks of the triple points. In the vicinity near the channel entrance, many triple points exist in Fig. 10 (a) and according as the detonation advanced in the channel, some part of the triple points are quenched and then rest part constitutes large cells. From the practical standpoint, Ishii et al. [6] showed the increase in the cell width essentially corresponds to the velocity deceleration. Nevertheless, one strong triple point, whose traces are shown in Fig. 10 as bold lines, travels frontward reflecting at the side edge of the channel wall as in a spinning detonation. A lot of fine complex cellular structures are observed locally, which is a result of local explosion induced by the reflection of the triple

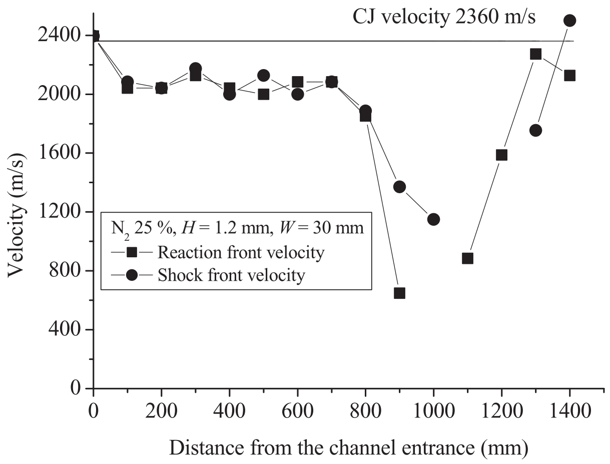

Fig.11 Velocity profile of an unstable galloping detonation obtained for 25 % nitrogen diluted hydrogen-oxygen mixture in the narrow channel with dimensions H = 1.2 mm and W = 30 mm.

points with sidewall of the channel. Figs. 10 (d) to (f) show the similar phenomenon with identical condition in another test. However, the location of fine cells evolution varies in this test. One surface of the smoked plate forming the channel is shown in Fig. 10, and it was confirmed that the other surface shows symmetric traces of the triple points. Furthermore, the velocity profile for the galloping detonation corresponding to Fig. 10 is shown in Fig. 11. It is seen that the decoupling of the shock and reaction front occurs at a distance of about 800 mm from the entrance of the channel. Although the shock and reaction fronts decelerate, the velocity of the later becomes lower than that of the former. Afterwards, the reaction and shock front accelerate at about 1100 mm and then the detonation is re-initiated. It might be emphasized that the variations of cellular structure can occur not only from one test to another but also from one cycle to the next within an experiment.

However, Fig. 10 embodies the most important structural changes in galloping detonations that are obtained in the present experiment. At this juncture, a query, which may be raised by the present observation, is that an uncertainty in the recognition of the galloping and failure detonation in nitrogen-diluted system might exist due to the limited length of the test section. There is a chance that propagation length of the period of a galloping detonation might exceed the length of the present channel. Therefore, one full sequence of generation of the fine cellular structures cannot be observed in the present experimental facilities. Thus, actually a galloping detonation can mistakenly be interpreted as a failure because of the insufficient channel length to observe the birth of the fine cellular structure. To confirm the limiting detonation more precisely, it would be required to use even a longer channel. Experimental study in the proposed channel may help to establish beyond question that the observed detonations were galloping or failure.

The results displayed for stable detonations attained in the channel for both systems allow to realize that some portion of the triple points (the locus of which constitutes the cellular structure) must be extinguished in the channel during the propagation of detonation. Then the triple points, which still continue to subsist inside the channel, compose the larger cellular structure in repercussion. Generally in circular tubes, a detonation propagates in single spin mode under marginal conditions in which one triple point travels frontward over the wall surface with spiral motion. Ishii et al. [19] have found that detonation propagating in a narrow channel shows single head mode for less detonable mixture, in which one triple point moves onward reflecting at the channel edge. No single head mode detonation in the present channel has been observed under the present range of experimental conditions.

4. Discussion

The velocity deficit, ΔV_m was measured through the experimental data by the following relation:

$$\Delta V_m = \frac{V_0 - V}{V_0} \times 100, \quad (1)$$

where V_0 and V are the average velocity measured with the three ion probes located before the channel entrance and the average velocity obtained inside the channel, respectively. It is to be noted that V_0, which was considered as velocity at the channel entrance, is approximately the same as the CJ velocity. The velocity change of a detonation wave propagating in the narrow channel is shown in Fig. 12 for 70 % argon diluted hydrogen-oxygen mixture with the channel dimensions H = 2.0 mm and W = 40 mm. Velocity deficit, ΔV_p was predicted in the narrow channel according to the Fay's boundary layer displacement theory [20] modified by Murray [21]. Murray has calculated the reduction in detonation

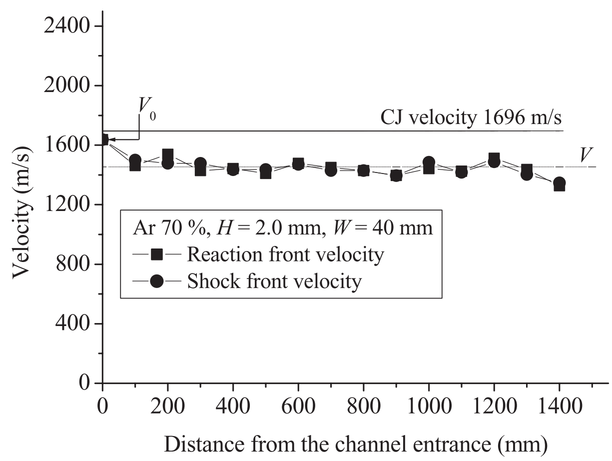

Fig.12 Velocity change obtained for 70 % argon diluted stoichiometric hydeogen-oxygen mixture in the narrow channel with dimensions H = 2.0 mm and W = 40 mm.

velocity (V_{CJ}-V) in his work by using the following relation:

$$\Delta V_P = \frac{V_{CJ}-V}{V_{CJ}} = 1 - \sqrt{\frac{\left\{1-\left(\frac{\varepsilon}{1+\gamma}\right)\left(\frac{\xi}{1+\xi}\right)\right\}^2}{\left\{1-\left(\frac{\varepsilon}{1+\gamma}\right)\left(\frac{\xi}{1+\xi}\right)\right\}^2+\gamma^2\left\{2\left(\frac{\varepsilon}{1+\gamma}\right)\left(\frac{\xi}{1+\xi}\right)-\left(\frac{\varepsilon}{1+\gamma}\right)^2\left(\frac{\xi}{1+\xi}\right)^2\right\}}} \tag{2}$$

where, ξ is the fractional area increase of the tube due to the development of boundary layer, ε is defined by

$$P_2\xi\varepsilon = \int_0^{\xi} Pd\xi \tag{3}$$

in which P_2 refers to CJ pressure, and γ is the ratio of specific heats of the detonation product. This expression predicts the velocity deficit of a detonation wave dependence on ξ, ε and γ. Application of the solution involves choosing the appropriate values of these parameters. Assuming the displacement thickness as δ^*, the fractional area increase of the present channel can be correlated incorporating the channel height (H) and width (W) as follows:

$$\xi = \frac{2(W\times\delta^*)+2(H\times\delta^*)+4\delta^{*2}}{W\times H} \tag{4}$$

For the various channel configurations and argon or nitrogen dilutions, the boundary layer displacement thickness δ^* was estimated by the equation used by Fay based on measurements of Gooderum [22] of turbulent boundary layers in shock tubes

$$\delta^* = 0.2x^{0.8}\left(\frac{\mu_e}{\rho_1 V_{CJ}}\right)^{0.2} \tag{5}$$

where ρ_1 and V_{CJ} are the initial density and the CJ velocity of the gas system, μ_e is the viscosity of the gas system in the combustion zone at the outer edge of the boundary layer at a distance x behind the shock front. The above expression has reported initially by Gooderum for the growth of the turbulent boundary layer behind a shock in a shock tube. Fay argued systematically that this expression might also be employed for the displacement thickness δ^* behind the strong shock present in a detonation wave. In applying this model to current data, it is important to set the value of x over which the area increases and hence the velocity deficits are to be evaluated. Fay had used reaction zone length in his model [20] over which the area increase due to divergence of the wall was calculated and the velocity deficits deduced from this area divergence were found under predicted. On the other hand, selecting hydrodynamic thickness (i.e. ~ 2-4 cell lengths according to Edwards et al. [23]) over which the area increase was calculated and hence velocity deficits data were found over estimated [21]. Murray [21] found that selecting one detonation cell length over which the calculated velocity deficits resulted in well accord to the experimental data. In the current work, x was set equal to one detonation cell length, L_c to evaluate the velocity deficits in the channel. This detonation cell length (L_c) was calculated by the simple invariant correlation between the cell width and cell length, λ_0=0.6L_c used by Edwards et al. [24]. The numerical value of ε was presumed to be one as undertaken earlier by Fay and Murray. To calculate the velocity deficit inside the narrow channel, the value of γ was taken as 1.2 that was also considered by Dupré et al. [25] based on Dabora's choice for the hydrogen-oxygen mixtures. Murray's theory, after introducing ξ, ε and γ for the narrow channel experiments, was employed suitably to calculate the velocity deficit inside the channel. Theoretically predicted and experimentally measured velocity deficits for all mixture compositions and channel dimensions are summarized in Figs. 13 and 14 as a function of the fractional area increase over one detonation cell length. From these Figures, it is

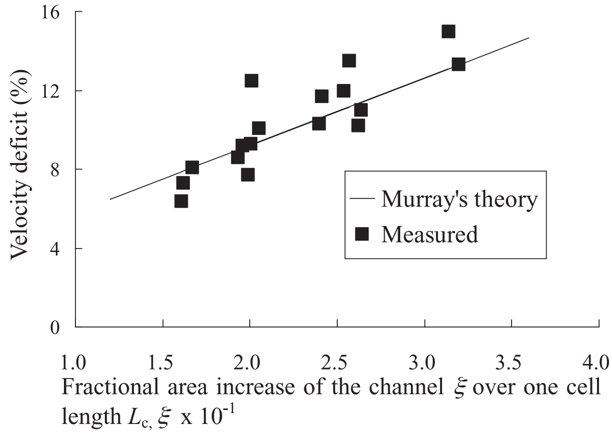

Fig.13 Experimentally measured and theoretically predicted velocity deficits versus the fractional area increase in the channel ξ over one cell length L_c for the entire argon diluted test mixtures and channel dimensions.

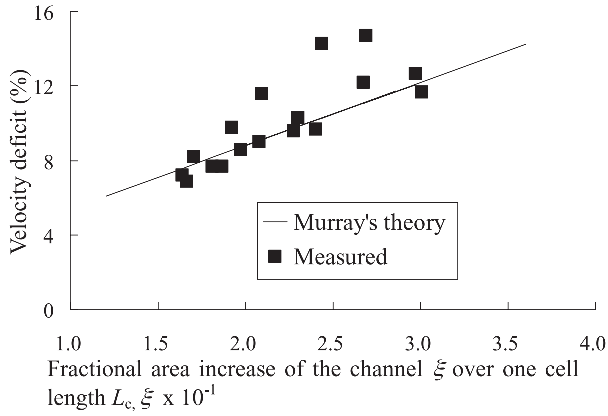

Fig.14 Experimentally measured and theoretically predicted velocity deficits versus the fractional area increase in the channel ξ over one cell length L_c for the entire nitrogen diluted test mixtures and channel dimensions.

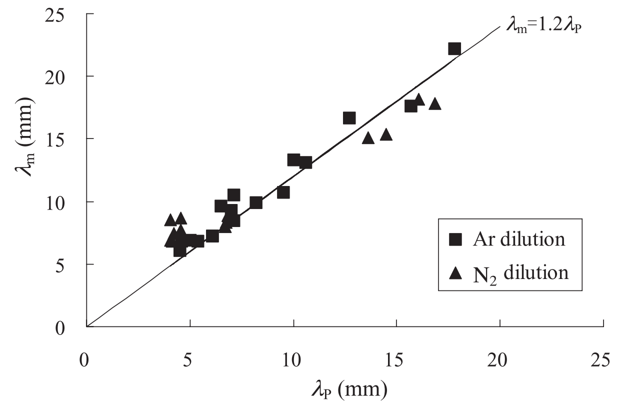

Fig.15 Measured cell width versus cell width predicted based on Lutz et al.'s reaction model for all channel dimensions and both the mixture systems. Solid line shows the approximation of cell width in the channel by means of λ_P.

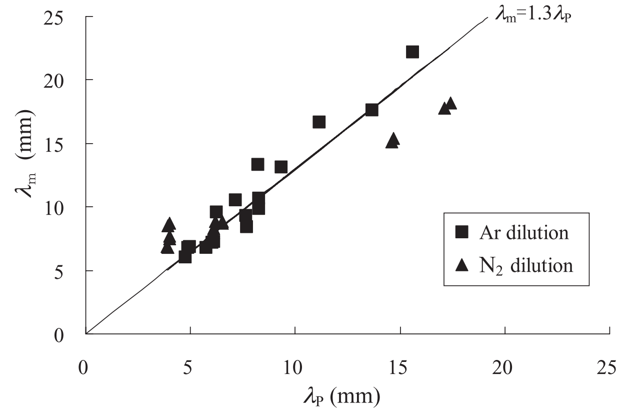

Fig.16 Measured cell width versus cell width predicted based on GRI Mech 3.0 for all channel dimensions and both the mixture systems. Solid line shows the approximation of cell width in the channel by means of λ_P.

observed that the predicted and measured velocity deficits are in good agreement for the present experimental range with a slight scatter of data.

It would be noteworthy to mention that the predicted cell width inside the channel was calculated by the simple linear relation, $\lambda_P=AL$, which involves the original suggestion that the cell width is proportional to the induction zone length by Shchelkin and Troshin [26]. It is to be noted that the induction zone length L inside the channel is determined using the ZND code developed together with the chemical kinetics mechanism of Lutz et al. [27] and CHEMKIN-II subroutine [28] by Shepherd [29], where L is defined as the distance between the leading shock and the location of the maximum rate of OH concentration rise [30]. The propagation velocity in the channel, which was given as an input in the ZND code to ascertain L, was predicted through Murray's theory as previously described. The value of A is determined with the original cell width, λ_0 divided by the induction zone length computed by the ZND code before the channel entrance.

The measured cell widths in argon-diluted and nitrogen-diluted systems are found to collapse on a line in a plot against the predicted value. Experimentally measured cell widths versus theoretically predicted cell widths using Lutz et al.'s reaction model is exemplified in Fig. 15 for both the systems and channel dimensions. As seen in Fig. 15, the predicted and measured cell widths are clearly different in size. In particular, the predicted cell width is smaller than the cell width obtained from the smoked plate inside the channel for a given condition. The change in detonation velocity and measured cell width in the channel can be credited as a result of momentum losses to the wall mainly induced by the viscous property of the gas system. Thus the results depicted in the Figs. 13 and 14 for stable detonations obtained in various mixtures and channel dimensions reveal that $\Delta V_P \approx \Delta V_m$. However, Fig. 15 shows $\lambda_P<\lambda_m$, which indicates that the cell width can not be determined only from the detonation velocity, namely average velocity of the leading shock wave. Since viscous effect near the wall causes both the shock and transverse wave to decelerate, this feature may be related to the cell width enlargement in the channel. In the process of the theoretical cell width evaluation using induction zone length, only decelerated shock speed was used and then predicted value might be found smaller than that was obtained in the experiment.

This motivated to approximate the cell width in the channel by means of predicted value, λ_P. As Fig. 15 shows that λ_P and λ_m are correlated ($\lambda_P<\lambda_m$), it may be possible to find a certain constant, say B for both the mixture systems and channel geometry to give the cell width in the channel through the relation, $\lambda_m=B\lambda_P$. It was found that B tends to nearly 1.2 for the whole range of experimental conditions.

The induction zone length calculated from the ZND model may depend on the reaction model to be used so that the value of B may be dependent on the reaction model. Considering the reaction model effect on B, the value of B using GRI Mech 3.0 was evaluated to be 1.3. Although the difference of 0.1 between these two values is relatively small, the value of B is slightly dependent on the reaction model. Experimentally measured cell widths versus the cell widths predicted through the reaction model GRI Mech 3.0 is exemplified in Fig. 16.

5. Summary

Stable detonations attained in the channel for both mixture systems allow to realize that some portion of the triple points must be extinguished in the channel during the propagation of detonation. As a result, the remaining part of the triple points inside the channel composes the larger cellular structure. Particularly in nitrogen-diluted mixture, stable to failure via unstable galloping detonations occur on reducing the channel height in the present study.

Comparison with the experimental data, Murray's theory has provided a good prediction of values of the velocity deficits over the range of the present experimental conditions. Agreement between the velocity deficits calculated by Murray's theory incorporating the fractional area increase for the narrow channel and experimentally measured velocity deficits suggests that the boundary layers evolved on the channel wall surfaces have influence on the propagation of detonation. The measured cell widths are found larger than what is predicted from the induction zone length calculated by the ZND model. The boundary layer behind the leading shock front of a detonation wave might be responsible for extinction of some part of the triple point in the narrow channel. To approximate the experimental cell width (λ_m) in the channel through the predicted cell width (λ_P), a relation $\lambda_m = B\lambda_P$ was found in this study where the value of B is slightly dependent on the reaction model. B was evaluated to be 1.2 using Lutz et al.'s reaction model and 1.3 using GRI Mech 3.0.

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