Diaphragm Effect on Detonation Wave Transmission from Propane/Oxygen to Propane/Air

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1 Introduction

Transmission of detonation waves from one mixture to another of different sensitivity is of interest in fundamental detonation physics and its practical application. For transmission experiments performed within a straight tube of constant bore, some investigations used a detonation wave from a donor propagating into a buffer section with a nonreactive mixture to generate a shock wave, which is to observe a shock-induced ignition process in the acceptor mixture [1]. Other investigations used a detonation wave rather than a shock wave propagating into the acceptor mixture [2].

Among these transmission experiments, a diaphragm or a slide valve was employed to separate the two mixtures. One may note that slide valves were used to obtain a concentration gradient at the separation interface [1,3]. Diaphgrams, when used, are kept thin to minimize their effect on the experment. It was found that diaphragms cause a time delay due to the time required for the detonation wave to break the diaphragm or reinitiating the damped detonation wave [4–6]. Here the damped detonation wave, in fact, is a transmitted shock wave formed due to the diaphragm destroying the cellular structures in the acceptor mixture. Our previous work using the smoked foil technique showed that a thin diaphragm (e.g. 38 μm) did not completely destroy the cellular structures. To understand the diaphragm effect on the detonation wave transmission in detail, the present study examined the effect of diaphragms of different thicknesses and with a slide valve on the detonation wave propagation from a propane/oxygen mixture to a propane/air mixture.

2 Experimental setup

Single-shot experiments were conducted in a smooth aluminum tube with a 50.8 mm internal diameter. The length of the donor tube in front of the diaphragm was 167.6–304.8 mm long while the acceptor tube after the diaphragm was 922 mm long, see Fig. 1. A stoichiometric propane/oxygen mixture filled the donor tube while a stoichiometric propane/air mixture filled the acceptor tube. In the donor tube, an incident detonation wave was achieved via the deflagration-to-detonation transition (DDT) process which was ignited by an electric spark located at the closed end. The degree of the overdrive, the ratio of detonation wave velocity to Chapman–Jouguet velocity, of the incident detonation wave D^*

impacting the diaphragm was varied by changing the donor length L_d, axial distance of the diaphragm from the closed end.

Propane/oxygen and propane/air mixtures were separated by 9 μm thick SHINPEX polyester diaphragms and 25, 38, 100 μm thick LUMIRROR polyester diaphragms. A slide gate valve (ITT Engineered Valves, XS150) was also used to examine the wave transmission process without a diaphragm. It must be noted that opening the slide valve prior to the initiation will cause the abrupt gradient interface to diffuse into a concentration gradient interface [1–3]. Due to the horizontal test tube, gravity will cause this diffuse interface to distort. To minimize these effects, the spark was ignited at 30 ms after the complete withdrawal of the slide valve. The time for the incident detonation wave to reach the interface location after ignition was 7.5–9.5 ms, related to the donor tube length. In addition, the slide valve required 0.274 s to be completely opened.

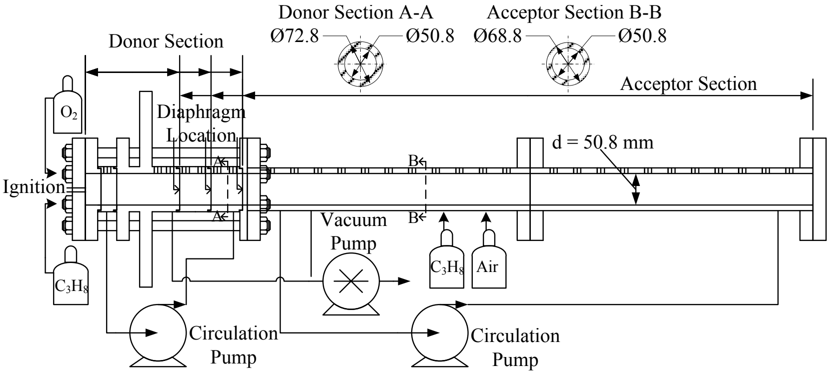
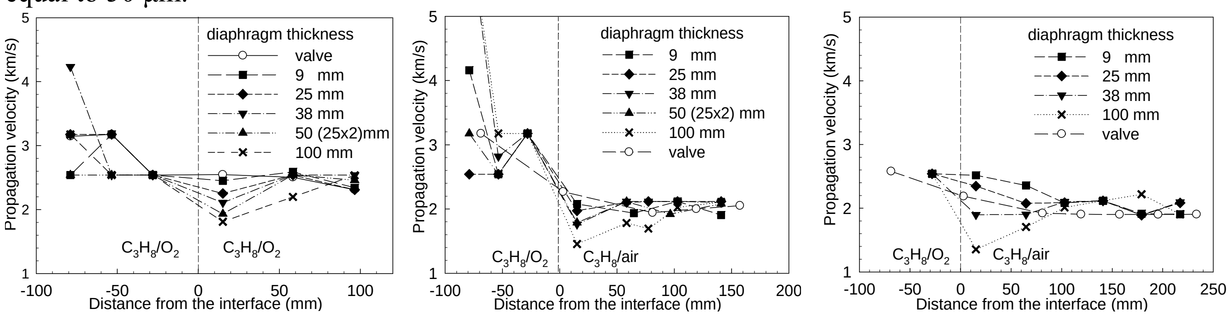


Fig. 1. Experimental facility

Pressure transducers (PCB 113A22) were mounted along the streamwise direction to estimate the wave propagation velocity. In addition, 130 × 900 or 120 × 900 mm^2 smoked foils were rolled into the acceptor tube to record cellular structure development due to either diaphragm rupture or slide valve withdrawal. The distances of the smoked foil from the diaphragm and from the slide valve were ≈ 0 and 3 mm, respectively.

3 Results and discussion

The results of the propagation velocity in the transmission of detonation waves are shown in Fig. 2. Figure 2(a) shows results for the entire tube filled with a stoichiometric propane/oxygen mixture, where the trend of a larger velocity decrease with a thicker diaphragm is observed. The figure shows that the 100 μm thick diaphragm has a more deleterious effect compared to the thinner diaphragms. Next, as is evident in Fig. 2(b), thinner diaphragms gave almost identical post-transmission results in experiments with a mixture change. These results indicate that the wave transmission phenomenon from propane/oxygen to propane/air is independent of the diaphragm thickness when it is less than or equal to 50 μm.



(a) L_d = 254 mm (b) L_d = 254 mm (c) L_d = 304.8 mm

Fig. 2. Diaphragm effect on the propagation velocity

Figure 2(c) shows results for L_d = 304.8 mm where the lower value of D^*=1.08 was obtained because of the attenuation of the overdriven detonation wave [7]. A decrease in velocity with a thicker diaphragm was observed and similar post-transmission results for different diaphragm thicknesses were presented behind the diaphragm 100 mm. It indicates that the diaphragm effect on the wave transmission is relevant to D^*. In addtion, the cases using the diaphragms has a slightly higher propagation velocity both at the incident and post-transmission states than those using the slide valve whether L_d = 254 or 304.8 mm. The higher post-transmission propagation velocity is considered to be due to a higher D^* when a diaphragm is used. In a DDT process, the existence of a diaphragm downstream will reflect compression waves accompanying the DDT process and thus leads to a higher D^* [7].

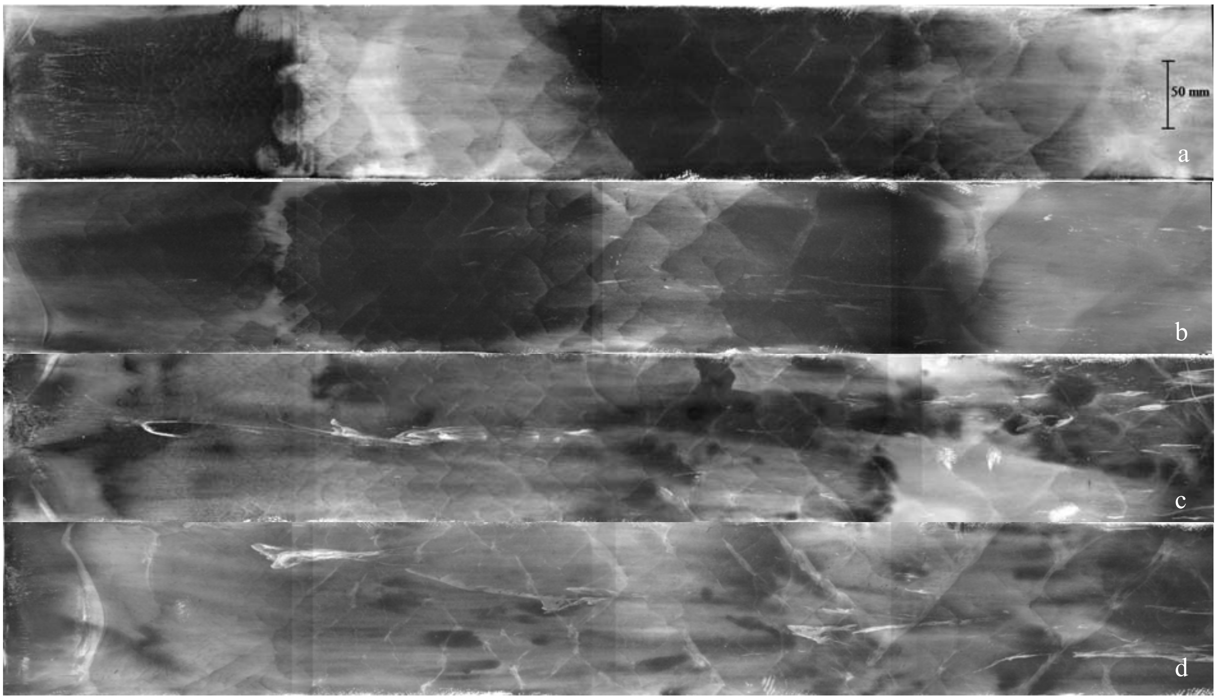


Fig. 3. Smoked foil record after diaphragm rupture, L_d =254 mm, (a) 9 (b) 25 (c) 38 (d) 100 μm thick diaphragm

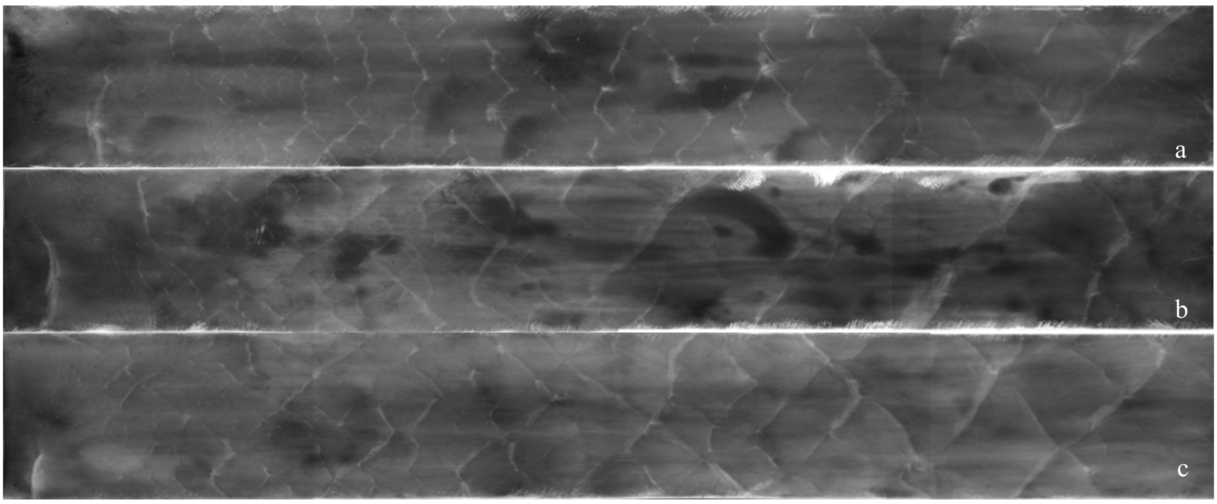


Fig. 4. Smoked foil record after slide valve withdrawal, L_d = (a) 193 (b) 243.8 (c) 294.6 mm

The post-transmission smoked foil records for different diaphragm thicknesses are shown in Fig. 3. From these figures, the cellular structures (cell widths ≤ 1.0 mm) appear immediately after diaphragm rupture and then abruptly disappear after several mm. The figures reveal that a damped detonation wave is first obtained and then fails to a transmitted wave without cells formed. This transmitted wave may be a shock wave or a shock wave followed by a combustion wave. A detailed analysis will be included in the full paper. Further downstream, this transmitted wave is reinitiated to to an overdriven detonation wave, as evident from the very fine cells found after the reinitiation. The attenuation of the overdriven detonation wave as it propagates downstream also yielded progressively larger cells [7]. One can see that the 100 μm thick diaphragm required a longer distance to reinitiate than the thinner diaphragms, Fig. 3(d). This behavior is attributed to the lower strength of the transmitted wave obtained with a thicker diaphragm. While a thin diaphragm is used, a strong wave is transmitted and leads to a nearly direct transmission without complete quenching of detonation cellular structures (e.g. 9 μm thick diaphragm shown in Fig. 3(a)).

Figure 4 shows smoked foil records after slide valve withdrawal. Failure, reinitiation, and attenuation of the transmitted detonation wave are also observed. The failed detonation wave is attributed to the concentration discontinuity. Based on our previous study, the detonation wave that was attained via a DDT process for these three L_d has a similar overdrive [7]. Thus, the post-transmission phenomena of these three waves are comparable. The post-transmission cell sizes obtained using diaphragms (except for the 100 μm thick one) were smaller and showed a gentler rate of increase compared with those obtained with the slide valve. These results may be attributed to a stronger incident detonation wave obtained due to the use of the diaphragm.

4 Conclusions

The present study describes the effect of a diaphragm on the transmission of a detonation wave from propane/oxygen to propane/air. It is found that the concentration discontinuity causes the detonation wave to fail to transmit whether a diaphragm is used or not. In general, a diaphragm is expected to damp the detonation wave and to destroy its cellular structure. However, at the same time, the diaphragm induces a stronger incident detonation wave obtained ahead of a concentration discontinuity. When the diaphragm is too thin enough (≤ 38 μm), the induced stronger incident detonation leads to a stronger transmitted wave, hence reinitiating to a stronger transmitted detonation wave than when no diaphragm is present.

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