# On Some Conditions of Detonation Initiation behind a Multi-Orifice Plate

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## 1 Introduction

The phenomenon of gaseous detonation initiation behind a multi-orifice partition, e.g. perforated plate has attracted attention in the last years. Usually, two different methods are used for the initiation in this case. The first uses a thin membrane separating the mixture before and behind the perforated plate [1, 2]. In the second one, the membrane is absent and the mixture before and behind the perforated plate can be only the same [1, 3]. The mixture before the perforated plate detonated in both cases. The second case can be referred as detonation re-initiation, because the mixture behind the perforated plate is the same as before and detonation can be re-initiated or it cannot. The condition of the detonation failure due to the interaction with the partition is $\lambda > d$, where $\lambda$ is the detonation cell size and $d$ is the diameter of the holes of the perforated plate.

The first explanation of the phenomenon under investigation was based on the assumption that rapid turbulent mixing between reacting gas products and unburned reactants can lead to the onset of the detonation [2]. This mechanism is relevant to the DDT case when violent explosion starts between the leading shock and the flame brush. Another possible mechanism of detonation re-initiation was proposed also [3]. On the basis of 3D numerical modeling it was shown that the detonation can be re-initiated behind a perforated plate due to collisions of transverse waves. These waves are the result of the diffraction of the incident shock wave at the exit of the plate holes. The amplification of transverse waves through a set of successive collisions is possible if the mixture reactivity is sufficiently high. The calculated detonation re-initiation distances from the plate are about a few diameters of the hole and depend on mixture sensitivity. This conclusion was confirmed by the experiments of [4]. As it was shown in [4] both these mechanisms can be realized and it depends on the mixture sensitivity and the partition properties. The DDT is realized if the mixture properties are close to the limiting conditions. The collision mechanism can be valid for the initial conditions that are far from the critical conditions for re-initiation.

The multi-orifice plate can be characterized by the parameter referred to as open area ratio $OAR$ ($OAR=Nd^2/D^2$, where $N$ and $d$ are the number and diameter of the holes, and $D$ is diameter of the tube). This parameter includes both the hole diameter $d$ and the hole number density $N/D^2$.

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The present paper reports the results of experiments performed to investigate the influence of the detonation wave parameters and detonation products composition before the perforated plate on the initiation of a detonation behind it. This investigation has been conducted with hydrogen-air mixtures.

## 2 Experimental Details

The experiments were carried out in a 106 mm inner diameter tube divided into three sections as it is shown in Fig. 1.

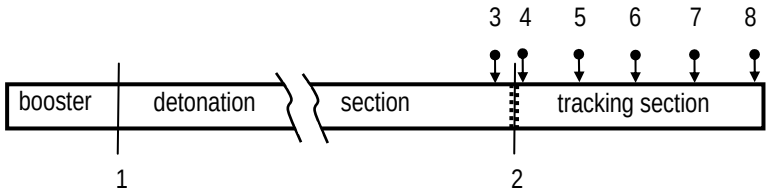


Figure 1. Scheme of the experimental set-up. 1, 2 - membranes separating different sections of the tube. Membrane 2 is located between two identical perforated plates. 3-8 – Kistler type pressure gauges.

In the 0.74-m "booster" section, separated from the "detonation" section by a plastic membrane, a stoichiometric ethylene-oxygen mixture is detonated after the ignition by a pyrotechnic igniter. After rupture of this membrane, a steady self-sustained detonation is initiated and propagates towards the end of the detonation section, where it interacts with the multi-orifice plate. The length of detonation section is 7.7 m. The pressure gauge 3 in this section (see Fig 1) is located 0.118 m upstream of the multi-orifice plate. In the performed experiments, the multi-orifice plate consists of two identical parts separated by the plastic membrane of 0.006 mm thickness. Either the detonation re-initiation, in the experiments without membrane, or the initiation, in the presence of membrane, are observed in the "tracking" section downstream the multi-orifice plate. This 1.12-m section is equipped with 5 piezo-electric pressure gauges for the recording of pressure profiles and the instant of shock arrival. A semi-cylindrical smoked plate was used for printing soot tracks of the detonation cellular structure. The length of the smoked plate is about 10 diameters of the tube. A multi-orifice plate with diameter of the holes $d$ = 6 mm and value of $OAR$ = 0.42 was used.

Different hydrogen-air mixtures were prepared by partial pressure technique in a separate vessel (mixer), where the mixing time was at least 24 h. All sections of the tube were initially evacuated to approximately 1 mbar and after that they were filled from the mixer.

Evidence of initiation/re-initiation of the detonation was derived from shock velocity measurements and observation of the detonation cellular structure: the measured shock wave velocity at the end of tracking section was compared with the calculated C-J detonation velocity ($D_{C\text{-}J}$). To analyze the cellular structure obtained behind the perforated plate, preliminary experiments without perforated plate were made for the determination of cellular structure of the self-sustained steady detonation. Comparison of the cellular structure and cell sizes appearing after the initiation with those recorded for the steady detonation without the perforated plate permits also to conclude whether the steady regime has been reached again or not.

## 3 Results and Discussion

Two sets of experiments were performed: In the "detonation" section, different mixtures at various initial pressures were used, and in the "tracking" section either a mixture of 34%$H_2$ + 66%Air at initial pressure of 0.8 bar or a mixture of 25%$H_2$ + 75%Air at initial pressure of 1.5 bar were tested. It had been shown previously [4] that the detonation could not be re-initiated in the mixtures chosen for the tracking section at the above mentioned initial pressures.

The $x$-$t$ diagrams for shocks propagating in the "tracking" section behind the perforated plate are presented in Fig. 2 for the mixture of 34%$H_2$ + 66%Air at initial pressure of 0.8 bars. The same

mixture at different initial pressures from 0.9 bars up to 1.2 bars was used in the "detonation" section. Preliminary experiments at the initial pressure of 0.8 bars in the "detonation" section with and without the membrane, showed the absence of detonation in the tracking section. Additional experiments were performed with an inert mixture in the "tracking" section; it was composed of 34%$H_2$ + 66%$N_2$ (curves 4, 5) at initial pressures of 1.2 bar and 0.8 bar correspondingly.

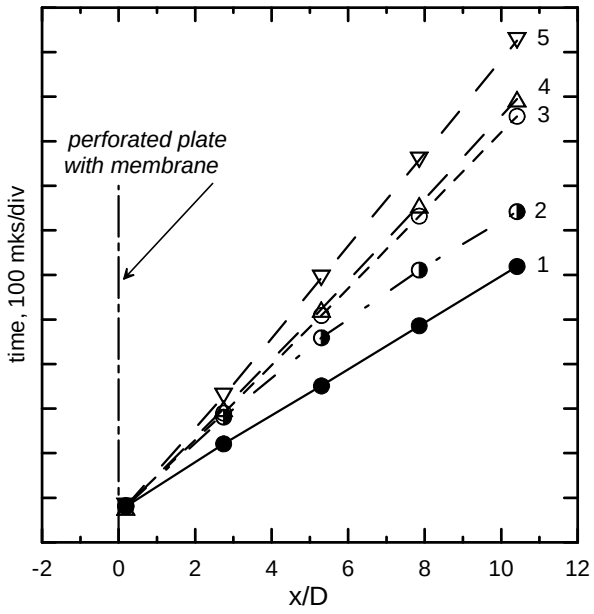


Figure 2. *X-t* diagrams of the shocks propagating behind the perforated plate in the mixtures of 34%$H_2$ + 66%Air (curves 1 – 3) and 34%$H_2$ + 66%$N_2$ (curves 4, 5) at 0.8 bar initial pressure as function of the initial pressure before the plate.

The curve 1 in Fig. 2 corresponds to the detonation initiation behind the perforated plate by the mixture at initial pressure 1.2 bars in the "detonation" section: a steady state velocity of 2020 m/s is recorded at the distance of $x/D$ = 6.5 from the perforated plate. This velocity value is slightly lower than the calculated one of 2040 m/s for this mixture. Decreasing the initial pressure in the "detonation" section to 1 bar (curve 2) leads to the increase up to $x/D$=9 of the distance where the value of the velocity becomes equal to detonation velocity. Further decrease of the initial pressure to 0.9 bar (curve 3) leads to the propagation of a complex composed of a shock wave followed by a flame front [1] with nearly constant velocity of 1220 m/s. Soot records for cases of 1.2 bars and 1 bar initial pressure are presented in Fig.3.

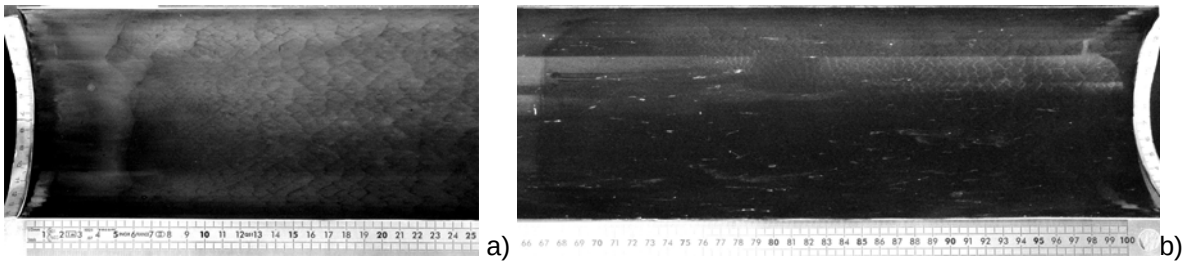


Figure 3. Case of the same mixture (34%$H_2$ + 66%Air) in the "detonation" and "tracking" sections; a) 1.2 bar initial pressure in the "detonation" section– detonation initiation; b) 1.0 bar initial pressure in the "detonation section" - DDT. Perforated plate is located at the left side of the smoked plate and detonation propagates from left to right.

As it is seen from the soot records at initial pressure of 1.2 bars in the detonation section (Fig.3a), a detonation is initiated early, at the distance of $x/D \approx 0.5$ in several discrete regions, and this detonation is overdriven. According to [5], the cell size corresponding to the steady state case for this mixture is $\lambda$ = 11.5 mm. The recorded cells which are slightly lower than this size are in agreement with this value. The shape of soot records becomes completely different when decreasing the initial pressure to 1 bar Fig.1b). A double strip perpendicular to the tube wall appears at the distance of $x/D \approx 6.4$. The thickness of this strip is about 2-3 mm in all experiments. The cell sizes start from a few millimeters and increase when progressing to the end of the tracking section. Such type of soot records takes place at distances between $x/D = 1$ and $x/D = 9$ from the perforated plate. This regime of detonation initiation can be referred as DDT according to [1, 2]. Due to the weak reproducibility and the limited number of experiments performed here and in the previous work [3] it is not yet possible to establish a correlation of this distance with the properties of the investigated mixture and the initiation conditions. For example, this distance can be two times different in two consecutive experiments with identical initial conditions.

In addition to the mixture 34%$H_2$ + 66%Air, mixtures of different hydrogen concentration (containing 25% $H_2$, 29.6% $H_2$ and 38% $H_2$ in air) were tested in the "detonation" section at different initial pressures. For these different mixtures we have calculated the theoretical values $P_D$ of the pressure at the front of the detonation wave (corresponding to the ZND pike). Thus, we have tried to estimate the influence of mixture composition and pressure at the interaction with the multi-orifice plate on the detonation initiation process in the "tracking" section filled with the mixture of 34%$H_2$ + 66%Air at the initial pressure of 0.8 bar. The results of this comparison are shown in Fig. 4.

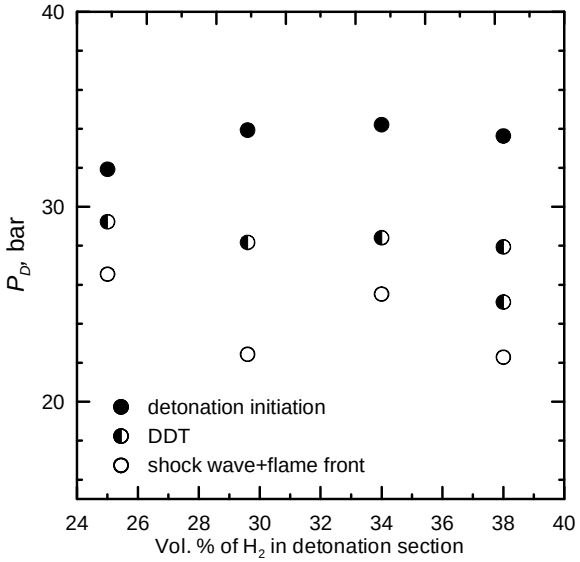


Figure 4. Influence of the mixture composition in the "detonation" section and of shock pressure at the multi-orifice plate, on the detonation initiation process of the mixture of 34%$H_2$ + 66%Air in the "tracking" section.

Based on the results presented in Fig. 4 it is impossible to conclude that the mixture composition and therefore the products of detonation can influence the process of detonation initiation under the investigated conditions. At least, if this influence exists, then it is very weak. Therefore, the conclusion about the influence of the pressure at the incident shock front emerging from the plate on the process of initiation appears to be predominant. This fact established in the present work could help to explain the broadening the limits of detonation initiation behind a perforated plate by the substitution of the hydrogen-air mixture to the hydrogen-oxygen mixture observed in [2].

Another set of experiments was performed with a lean mixture of 25%$H_2$ + 75%Air at initial pressure of 1.5 bars in the "tracking" section. According to [5], the cell size for this mixture when increasing the initial pressure up to 2 bars is minimal for 1.5 bars: $\lambda$ = 13.1 mm. Two mixtures: 29.6%$H_2$ +

70.4%Air and 38%$H_2$ + 62%Air at initial pressures of 1.75 bars and 2 bars were used for filling of the "detonation" section. As in the previous set of experiments the inert mixture of 25%$H_2$ + 75%$N_2$ was also tested in the "tracking" section.
The x-t diagrams of shock waves propagating in the "tracking" section behind the perforated plate are presented in Fig. 5 for this set of experiments.

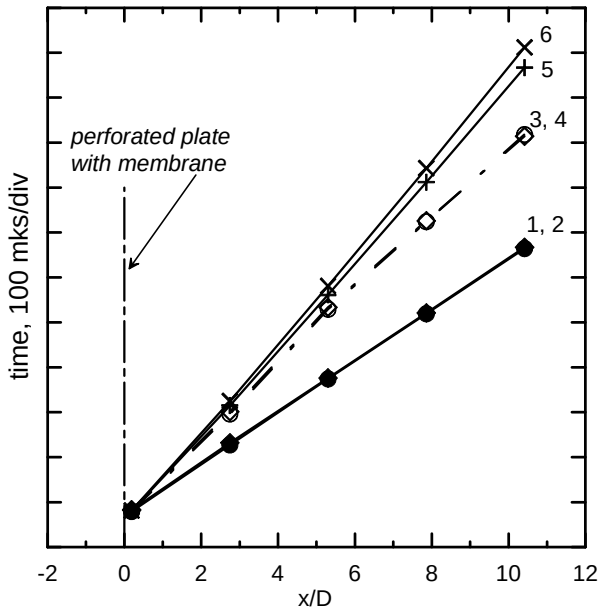


Figure 5. *X-t* diagrams of the shock waves propagating behind the perforated plate in the mixture of 25%$H_2$ + 75%Air at 1.5 bar initial pressure (curves 1-4), and the inert mixture of 25%$H_2$ + 75%$N_2$ (curves 5, 6). Initiation by the mixture 29.6%$H_2$ + 70.4%Air in the "detonation section" - curves 1, 3, and by the mixture 38%$H_2$ + 62%Air - curves 2, 4, at initial pressure 2 bars and 1.75 bars respectively. $X$ – distance from the perforated plate, $D$ – tube diameter.

It is seen from Fig. 5 that independently of the mixture composition which was used for initiation (curves 1, 2), detonation initiation takes place and the velocity of detonation becomes comparable with the calculated CJ value 1860 m/s at the distance from perforated plate of about $x/D \approx 6$.
In both cases the decrease of the initial pressure in the "detonation" section to 1.75 bar (curve 3, 4) resulted in the same consequences. The velocity of shock waves at distances more than $x/D = 6$ becomes constant with a value of about 1400 m/s. Note that this value equals about 0.75 $D_{C\text{-}J}$. It is reasonable to assume that these regimes (curves 3, 4) consist of a shock wave followed by a flame front. Previously the velocity of 0.5 $D_{C\text{-}J}$ was found for this kind of explosive process [1, 2]. Soot records of detonation initiation in these cases are shown in Fig. 6.

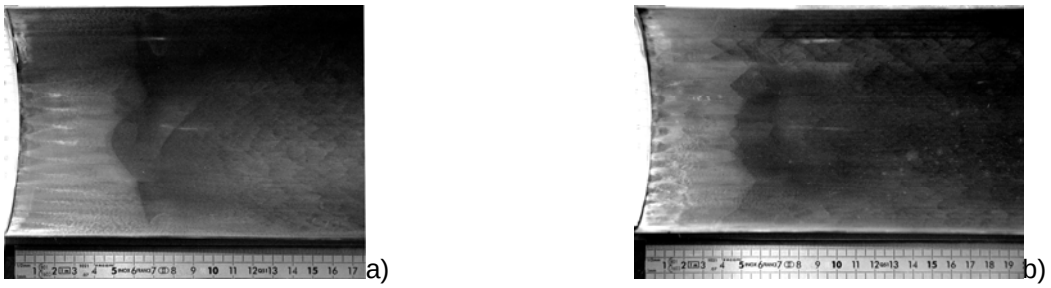


Figure 6. Detonation initiation in the mixture 25%$H_2$ + 75%Air in "tracking" section at initial pressure of 1.5 bars. "Detonation" section, at initial pressure 2 bar: a) mixture 29.6% + 70.4%Air; b) mixture 38% + 62%Air. Perforated plate is located from the left side of smoked plate and detonation propagates from left to right.

These images also demonstrate similarities in the detonation initiation dynamics. In both cases, discrete centers of initiation appear within distances from the perforated plate of about $x/D \approx 0.4\text{-}0.6$. At the larger distances, the cellular structure consists of cells the dimension of which increasing with the increase of the distance from the perforated plate. The cell sizes became about constant at the distance from perforated plate of about $x/D \approx 4\text{-}5$. As it was above mentioned the velocity of detonation becomes constant at the distance from perforated plate of about $x/D \approx 6$.
In the case of inert mixture in the "tracking" section, the analysis of the shock waves behind the perforated plate shows that there exists very weak (about 10%) attenuation along the tracking section. The velocity of these shocks is about 0.6 $D_{C\text{-}J}$ at the distance from perforated plate of $x/D = 1.4$, for initial conditions in the "detonation" section identical to that of curves 1, 2 of Fig. 5.

# 4 Conclusions

The experiment performed in the present study revealed the peculiarities of detonation initiation in hydrogen-air mixtures behind a multi-orifice plate It is shown by the examples of mixtures with 25% and 34% of hydrogen that possibility of detonation initiation depends on detonation conditions before the multi-orifice plate. The increase of the initial pressure in the mixture before the multi-orifice plate leads to detonation initiation in the vicinity of the plate exit. The influence of mixture composition on detonation initiation does not seem to play a significant role in the conditions of the performed experiments.

# 5 Acknowledgements

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