ON THE SPECIFICS OF DETONATION TRANSFER IN AIR AND WATER IN THE CASE OF EXPLOSION OF OXYHYDROGEN CONTAINED IN AN ELASTIC SHELL

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Detonation waves in gases have been studied for a long time; however, recently this field has experienced a resurgence of interest. The main reasons behind it appear to be the desire to harness the phenomenon of gas mixture detonation to perform practical tasks in bespoke impulse plants and dedicated power installations for aircraft and rockets, including detonation impulse engine prototypes.

It is known that there exist two ways to generate a detonation wave: direct initiation and the so-called process of deflagration-to-detonation transition.

In the first case, a sufficiently powerful source generates an intense shockwave, behind the front of which there begins a chemical reaction, thus forming a detonation wave. A shockwave like this calls for a high energy density in the source.

In the second case, a relatively low-power source, such as a spark plug, is used to ignite a gas mixture in a tube. Since flow turbulence occurs in smooth tubes as well, the surface area of the flame increases. As the flame front accelerates, a compression wave is formed in front of it. This wave further increases the turbulence in the combustible gas, leading in turn to the flame front accelerating further and the pressure in front of it increasing. The perturbations at the front add up, it grows steeper and steeper, and as a result, a shockwave followed by a chemical reaction emerges, which is, by definition, detonation. This is the physics behind our experiments.

The aims of the study are as follows:

- Investigate the mechanisms underlying the deflagration-to-detonation transition for various initial conditions.
- Investigate experimentally the transfer of detonation across air and liquid (water) from an active charge consisting of gas mixture confined in an elastic shell to a passive charge also consisting of the same gas mixture confined in an elastic shell.

Experiment setup

We conducted our experiments using a laboratory installation designed at the High-Precision Airborne Devices department of Bauman Moscow State Technical University [1-4]. The installation comprises a shock tube made out of a transparent smooth-walled acrylic glass pipe that is 1000 mm long, has a40 mm outside diameter and a 30 mm inside diameter. The pipe is fixed vertically on a special mounting. Its bottom part is covered by a metal case. The function of the case is twofold: 1) it prevents the tube bursting while the explosive mixture is being pumped; 2) it provides the explosive charge with an initiation system.

The active explosive charge is an elastic shell filled with a gas mixture, placed at the bottom of the shock tube. The passive charge is also an elastic shell filled with a gas mixture, placed at the top of the shock tube at the desired distance from the active charge. The acoustic impedance of these elastic shells is low enough to be safely disregarded.

We designed our experiments so that the space between charges was filled with either air or liquid (water).

The active charge was initiated by an electric spark from a spark plug mounted in a dedicated detonator. The detonator, which is connected to the active charge by means of a transparent flexible tube, boasts a system of valves that helps to accumulate the mixture of gases in the combustion chamber, the flexible transparent tube and the active charge. It also can ignite the mixture at the desired moment and transfer the impulse to the active charge. We placed the installation in our blasting chamber and used its portholes to set up lighting and video recording using the Fantom 1610 camera. We filmed at 84000 frames per second.

In order to create a sharp boundary between charges and liquid, we developed a technique of pumping gas into the passive charge and simultaneously using a drain tube to pump out the air from the shock tube.

The explosive in our experiments was a mixture of oxygen and hydrogen in a ratio close to stoichiometric. The oxygen/hydrogen mixture was being pumped through the system for at least 5 minutes to ensure that the mixture composition should become stable.

Experiment results

Experiment 1

Active charge: L=350 mm; passive charge: L=415 mm; air gap: L=230 mm. According to fig. 1, the video registration shows the following: 1) up the tube, along the active charge, a deflagation front is moving at 850 m/s, then, as it reaches the interface, a reflected shockwave is generated, which then travels down the tube at 1470 m/s and eventually fades. After the shell of the active charge is destroyed, a shock wave is travelling up the air in the tube at 1340 m/s, followed by the products of detonation of the active charge. The wave travels through the passive charge at 2846 m/s. A detonation mode is initiated in the passive charge.

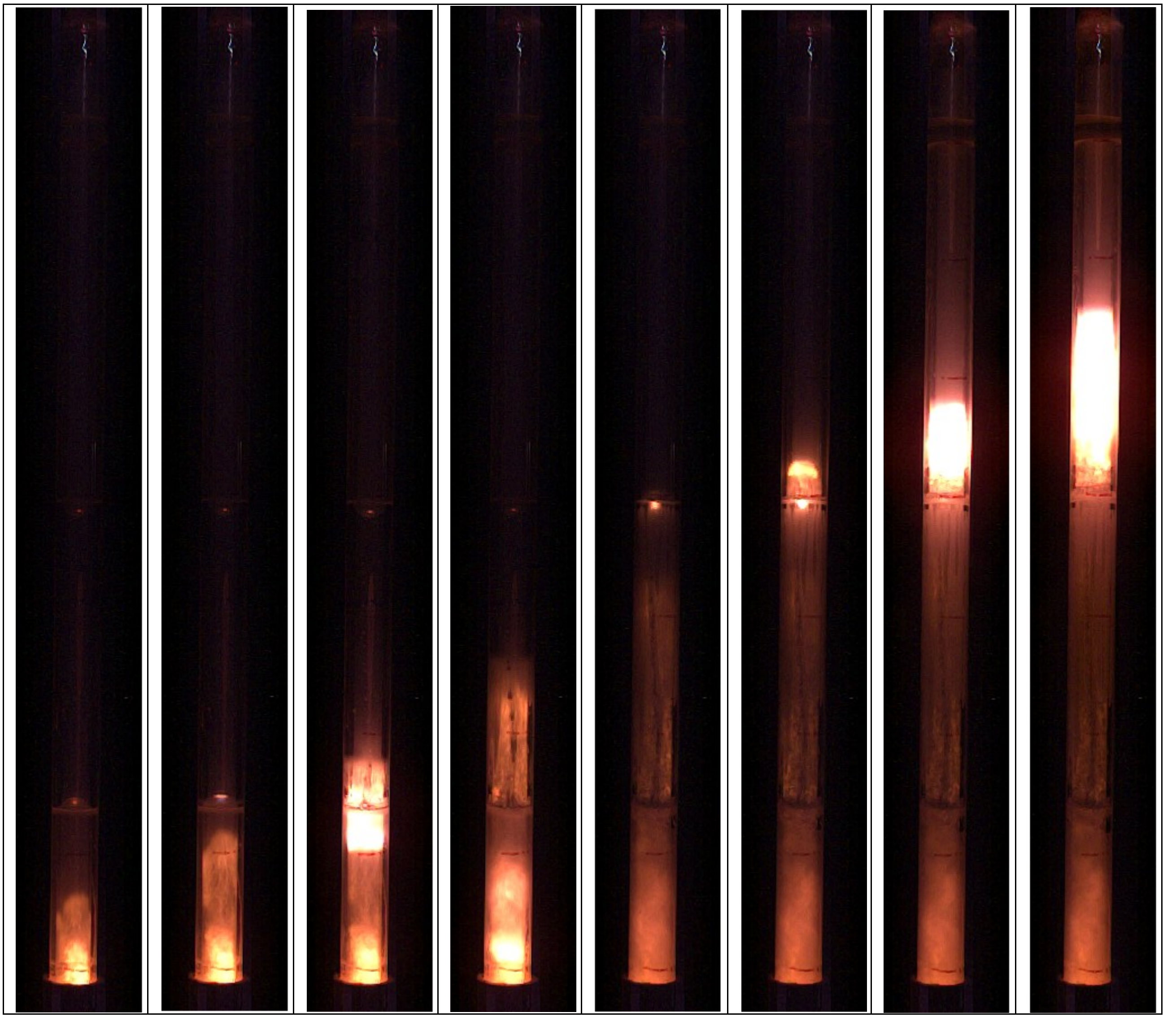

Figure 1. Video recording of the experiment no. 1

Experiment 2

Active charge: *L*=400 mm; passive charge: *L*=320 mm; air gap: *L*=237 mm. Video registration frames in fig. 2 demonstrate the following: since there is a wave travelling up the active charge at 2753 m/s, we assume that a detonation mode has been initiated in it. Reaching the interface, the wave refracts at the discontinuity, sending a shock wave up the tube along with detonation products (wave propagation rate is 1270 m/s), and a reflected shockwave downwards. Then detonation is initiated in the passive charge and propagates along it at 2925 m/s.

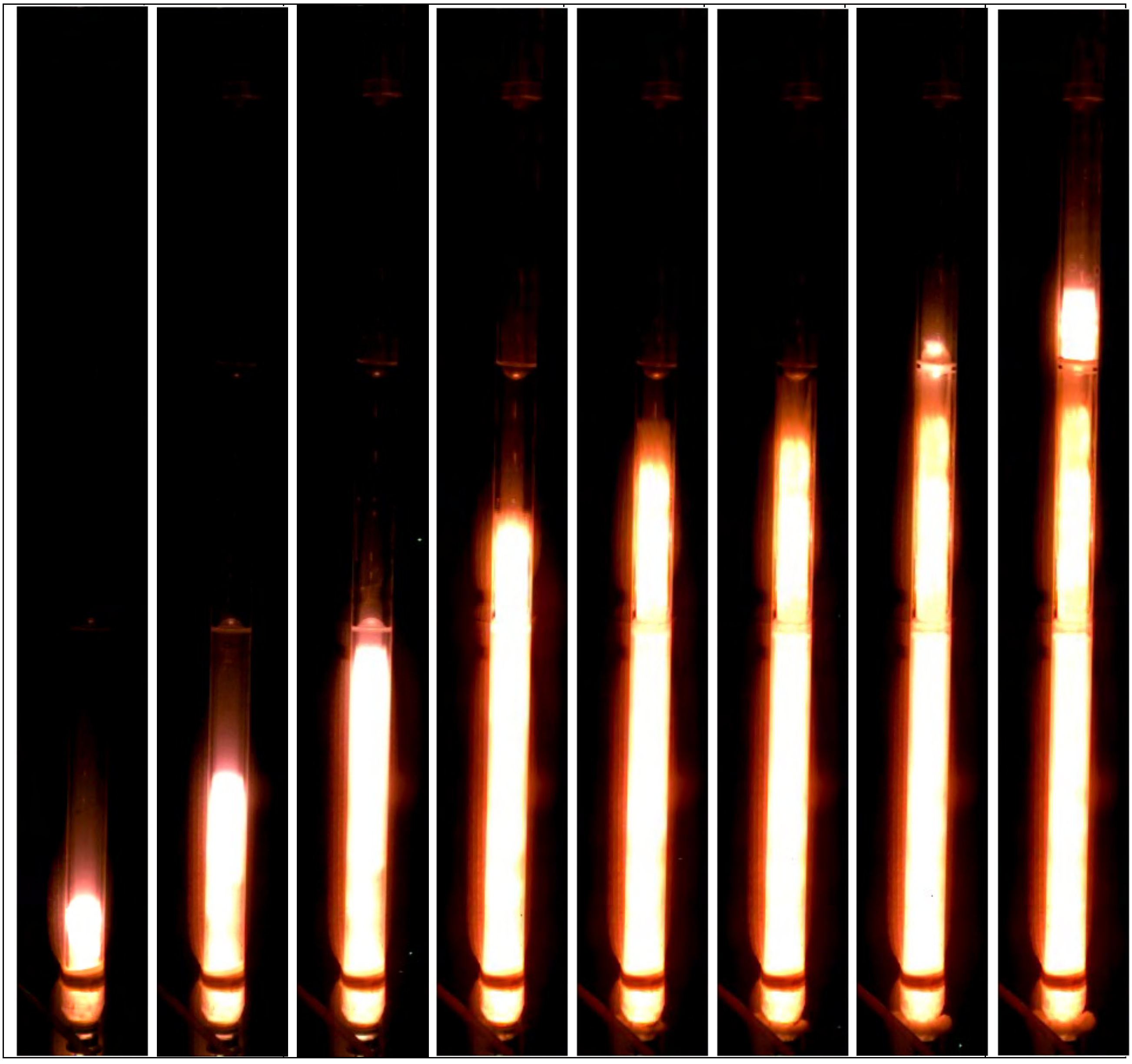

Figure 2. Video recording of the experiment no. 2

It means that in the experiment 2 we also observe detonation transfer from the active charge to the passive charge across an air gap.

Experiment 3

Active charge: *L*=400 mm; passive charge: *L*=500 mm; gap filled with liquid (water): L=10 mm. The video recording shows the following (see fig. 3): the active charge deflagrates (the wave travels up the tube at 708 m/s); since a reflected wave additionally compresses the gas, there develops a detonation zone close to the top boundary of the active charge. Then the detonation wave travels down the tube along the whole length of the active charge at 2216 m/s. At the same time, the detonation products drag the elastic shell along and impart an impulse to the water, which, in turn, impacts the shell of the passive charge as a piston. When the detonation wave in the active charge reaches the bottom end, it reflects, and a reflected shockwave begins to travel upwards at approximately 1500 m/s. Next, a detonation mode is initiated in the passive charge, and a detonation wave travels upwards along it.

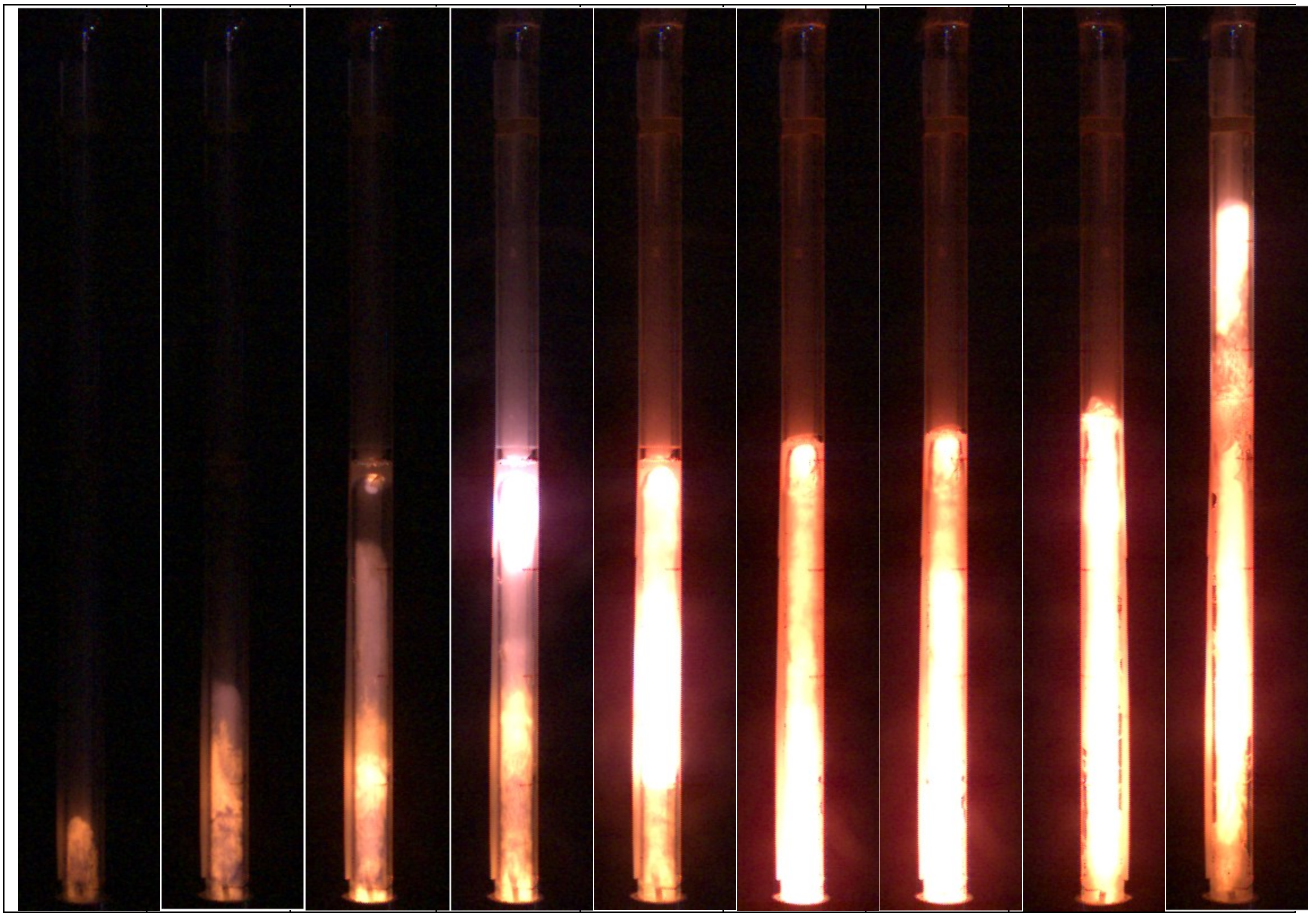

Figure 3. Video recording of the experiment no. 3

It means that in the experiment 3 we observe detonation transfer from the active charge to the passive charge across a 10 mm gap filled with liquid (water).

Conclusion

- The investigations conducted showed that it is possible to use high-speed optical recording methods to study the mechanisms underlying the transition from combustion to detonation;
- We proved that detonation transfer happens across gaps of certain sizes filled with various media (such as air or water).

Our investigation results may be used to validate existing numerical models of the processes studied.

In our investigation we used equipment designated as GA 3.6196.2017/7.8 and GA 3.6257.2017/7.8.

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EXPERIMENTAL STUDY ON THE REACTION EVOLUTION OF PRESSED EXPLOSIVES IN LONG THICK WALL CYLINDER CONFINEMENT

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Abstract: The non-shock initiation reaction behavior of pressed HMX-based PBXs inside long thick wall steel tube is studied with detailed diagnostics of tube movement on different sampling sites along the tube and its two ends. The multi-stage reaction processes are revealed with transportation of reaction products, e.g. the convective flow of high temperature gaseous products driven by high pressure along the seam between the HE pellets and the inner wall of the confinement tube, the early stage burning of HE pellets on their surface with an induction time delay and uneven pressure growth alone the tube, the late stage violent reaction with rapid expansion and rupture of the tube wall. These processes last nearly 10ms which is much longer than the corresponding detonation duration. The pressure measured by tube wall velocities is much less or about 1GPa for two tested HMX-based PBXs correspondently while the tube wall is accelerated to almost 200m/s during the last 200μs -300μs before the confinement rupture. The observed reaction evolution could not be explained by classic DDT mechanism without consideration of convective flow of reaction products along the seam between tube wall and HE pellets when there is no reaction activated in HE bulk by the ramp wave caused by upper stream non shock initiation reaction.

Introduction

The possibility of deflagration to detonation transition in dense PBXs or solid propellants is under question for long time [1, 2] though there were many reports of experimental observation of DDT behavior in recent years [3, 4]. In the classic 1-dimensional DDT concept of Macek [5], the mass transportation of reaction products from the initial end is not considered (typical 2-D phenomenon), consequently the convective mechanism of combustion front propagation through structure seam or HE cracks might be thoroughly ignored. The high pressure gaseous products convection might be the dominant factor in the reaction propagation and reaction violence evolution beside the stress wave mechanism for reaction initiation of HE in long tubular confinement, and also in any explosive charges under various confinement. In this study, a group of experiments were conducted with heavy steel DDT tube confinement in comparing with the experiments of the same HMX-based PBX in thin wall light confinements [6].