Attenuation of a hydrogen–air detonation by acoustic absorbing covering

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Abstract. Using of sound-absorbing surfaces to weaken and decay of a detonation wave in hydrogen-air mixtures was investigated experimentally. Experiments were carried out in a cylindrical detonation tube open at one end. Initiation of the explosive mixture was carried out by a spark discharge, which is located at the closed end of the detonation tube. Acoustical sound absorbing foam element of a specific weight of 0.035 g/cm^3 with open pores of 0.5 mm was used. The degree of attenuation of the intensity of the detonation wave front was determined.

1. Introduction

One of the main factors that lead to technological disasters at nuclear industry is the explosion of the hydrogen-air mixtures in the containment of the reactor or in the reactor room. Hydrogen leaks appear due to hydrolysis of water in the presence of a catalyst (zirconium). In contrast to the non-nuclear facilities, an explosive mixture can not be discharged into the atmosphere due to the possible content of radionuclides in it.

Various types of flame instabilities form gasdynamic perturbations which are reflected by walls of the reactor. These instabilities interact with each other and lead to formation of the detonation wave [1–3]. Experimental study of the effect of the acoustic field on the development of instabilities in the field of ignition is given, for example, in [4–6].

In addition to chemical methods for inhibiting detonation combustion [7], there is a method of reducing the intensity and velocity of the detonation wave by acoustically absorbing elements. The impact mechanism is such that the transverse waves are weakened constituting the detonation wave front. This causes destruction of the cellular structure of the detonation front which is an important part of the of the detonation wave propagation [8–12]. For mixtures with a regular cellular structure transverse waves play a pivotal role in suppressing the detonation [13]. In mixtures diluted with argon gas detonation suppression may also occur due to the general curvature of the combustion front, caused for example by friction at the walls.

The aim of this work was to determine the degree of weakening of the detonation wave in the hydrogen-air mixture in a cylindrical channel with the sound-absorbing coatings, depending on the concentration of hydrogen.

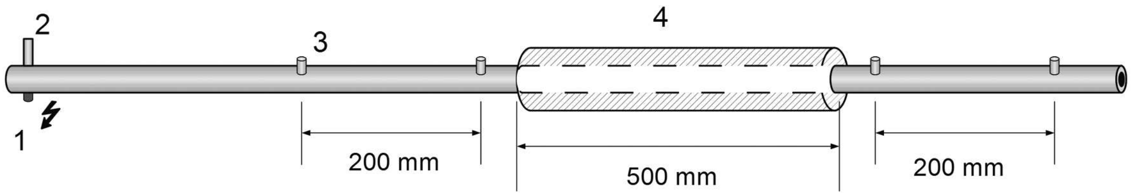

Figure 1. Experimental set-up: 1—spark gap, 2—fuel pipe, 3—pressure and light gauges, 4—acoustic absorbing section.

2. Experimental set-up

The experimental setup is shown in figure 1. The cylindrical detonation tube with an inner diameter of 20 mm and a length of 2000 mm made of steel. Absorbing surface with an inner diameter of 20 mm and a length of 400 mm was placed at a distance of 1200–1600 mm relative to the closed end of a detonation tube. In a selected range of equivalence ratio (ER) a formation of detonation took place before the sound absorbing section.

Ignition of the hydrogen-air mixture is carried out by the automotive spark at the closed end of the detonation tube. The energy of the spark discharge did not exceed 0.1 J. The sound-absorbing foam with open pores was used. The pore size was about 1 mm, specific weight equaled 0.035 g/cm^3. The initial pressure in the detonation tube was 0.1 MPa, the initial temperature was 300 K. Hydrogen–air mixture with ER = 0.8–2 was used.

3. Results and discussions

In figure 2, oscillograms of two pressure sensors and two photo diodes registering a detonation or shock wave after passing through smooth or sound-absorbing section are given. Results are shown for ER: 0.8 and 2. Speed of a detonation wave before sound-absorbing section was 2100 m/s for ER = 0.8 and 2. Pressure at the front of a detonation wave equaled 2 and 2.5 MPa respectively. The smooth behavior of the light signals on figure 2 is due to the sensors characteristics.

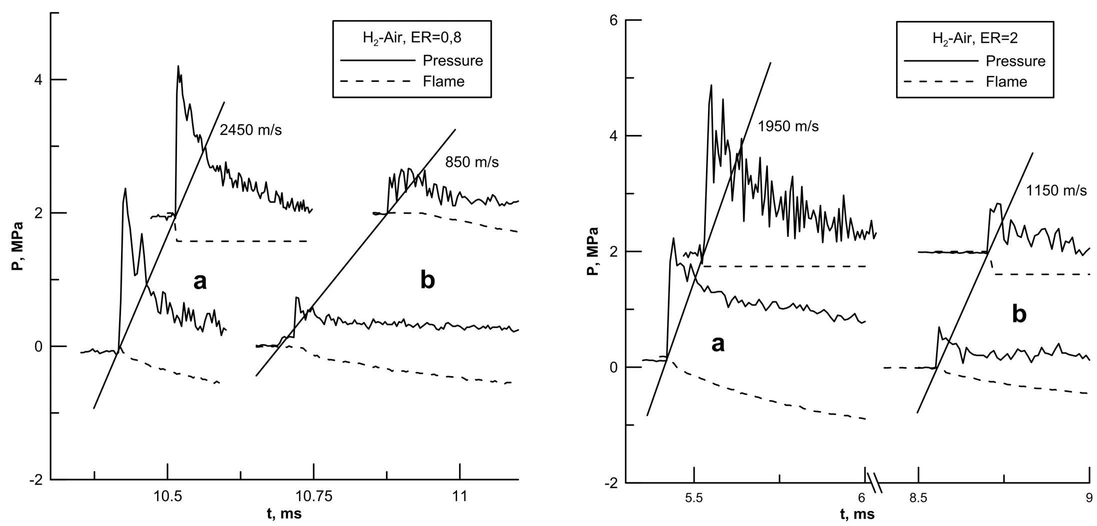

Figure 2. Pressure and light readings in smooth tube (a) and absorbing walls (b) for two ER 0.8 and 2.0.

After passing of the wave through sound-absorbing section, decay of the detonation wave on a shock wave and the front of a flame in both cases was registered. Time difference between registration of the shock front and the flame front was 100 μs for ER = 0.8 and 50 μs for ER = 1.5. Intensity of a shock wave and its speed after passing of sound-absorbing section decrease: to 0.75 MPa and 900 m/s at ER = 0.8, to 0.8 MPa and 1200 m/s at ER = 2.

Dependence of the attenuation of the velocity and pressure of the detonation waves on ER in the range of 0.8–2.0 is presented in figure 3. The minimum attenuation of the wave was registered at ER = 1.5. In this case, the velocity of the front was 0.7 from a stationary value for the detonation of Chapman–Jouguet. Pressure value was also 0.7 from a value at the initial detonation front. For ER bigger and less than 1.5 more intensive attenuation of the velocity and pressure of the detonation wave to values 0.3–0.5 from initial values was registered.

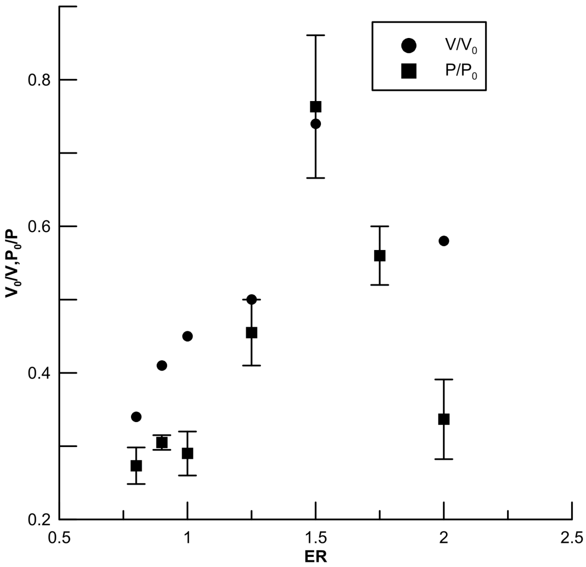

Figure 3. Coefficient of attenuation of the shock wave pressure and velocity after the acoustic absorbing section.

Attenuation of the velocity and pressure to value 0.7 at ER = 1.5 was caused by the fact, that the acoustic-absorbing cover leads to the weakening of the transversal waves on the front of the detonation wave. In spite of the minimum value of the cell size of the detonation wave is reached at ER = 1, the minimum attenuation was reached not at ER = 1, but at ER = 1.5. It was caused by the fact that at ER equal to 1.5, the sound speed of the combustion products increases. It leads to the higher velocity of the transversal waves.

4. Conclusions

It was observed that the attenuation of the detonation wave by acoustic-absorbing covering is strongly depending on the concentration of hydrogen. It was obtained that the values of the attenuation varies in the range of 0.3–0.8 with mixture ER in range 0.8–2.0.

Acknowledgments

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