Experimental and Numerical Study of Spontaneous Ignition of Hydrogen-Methane Jets in Air

Wojciech Rudy, Andrzej Dabkowski, Rafal Porowski, Andrzej Teodorczyk
Warsaw University of Technology, Institute of Heat Engineering
Warsaw, Poland

1 Introduction

Recently, the spontaneous ignition of hydrogen has been investigated experimentally [1-12] and numerically [13-16]. The experimental studies were mainly aimed at understanding the ignition process of depressurized hydrogen released through the extension tube with different length [3,9,13-14], diameter [7-8] and channel cross-section [2]. Generally, it occurred that ignition probability increase as the initial pressure and tube length increase and tube diameter decrease. However, none of the referred papers tried to investigate the influence of different gas addition to the hydrogen on the ignition occurrence. This paper is aimed at investigation of the spontaneous ignition process of high-pressure hydrogen-methane jets in the air.

2 Experimental facility

The experiments were conducted in a closed rectangular channel (0.1 x 0.1 x 1 m) filled with ambient air where the hydrogen-methane mixture (at 2-16 MPa and 300 K) depressurized through different tubes: diameter d = 6, 10 and 14 mm, extension tube length: L = 10, 50, 75 and 100 mm. The methane addition to the mixture was 0%, 5% and 10% [v/v]. Figure 1 presents the experimental facility scheme. The equipment used included: pressure sensors (PCB), photodiodes, ion probes, schlieren system, fast camera (75 kfps) and data acquisition system (DAS). The mixture was prepared by means of partial pressure method and compressed with an air driven gas booster (Haskel AG-75C) to a defined pressure and stored in a high pressure cylinder. Activation of the measurement system (with use of time unit) was coupled with electromagnetic valve activation and triggered by the staff. The mixture depressurized to the volume ($V = 32\ cm^3$) separated to the air-section with a diaphragm. The diaphragm ruptured when the pressure reached the burst pressure (different for different diaphragm materials and thicknesses). The diaphragm was metal sheet of copper, brass or aluminum. The first step of experimental work was to find the ignition range of pure hydrogen flow as a function of burst pressure and tube length and diameter. The results obtained were then used as a reference for the experiments with 5% and 10% of methane addition to hydrogen.

3 Numerical simulations

The numerical simulations were performed with use of KIVA-3V code [17]. The geometry used represented part of the experimental stand geometry for d = 6, 10, 14 mm and L = 10, 50, 100 mm. Only the pure hydrogen jet cases were investigated numerically. The hydrogen-air chemical reaction mechanism included 23 reactions [18]. The example temperature and OH mass fraction contours are presented in fig. 2. The comparison between obtained experimental and numerical ignition limits is presented in fig. 5.

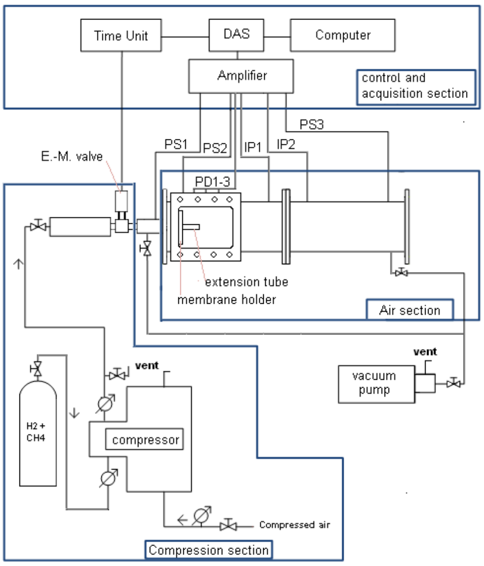

Figure 1. The experimental facility. PS – pressure sensor, IP – ion probe, PD – photodiodes, DAS – data acquisition system.

4 Results and discussion

The experiments were conducted in a closed channel filled with ambient air where the hydrogen-methane mixture (at 2-16 MPa and 300 K) depressurised through different geometries (various diameter and extension tube length). The methane addition to the mixture was 0%, 5% and 10% [v/v]. Figure 3 presents example sensors indications for pure hydrogen jet with (left) and without ignition (right). Pressure sensors PS2 and PS3 placed near the ends of the tube indicated oscillations for both cases with and without ignition. Oscillations correspond to successive shock wave reflections from the tube ends. Figure 4 shows cumulative diagram for all the experiments conducted for conditions d = 14 mm and 0% CH_4. Figure 5 shows the relationship between burst pressure, tube length and ignition occurrence for different diameters and methane addition. In all the experiments with jet ignition, the photodiodes indicated clear signal just after the jet left the extension tube which suggests that the ignition took place in the tube. In figs. 4 and 5 it is clearly visible that the extension tube length has significant influence on the ignition occurrence. This relation seems to be nonlinear as for L = 10 mm there were no ignition in any experimental case with burst pressure up to 16 MPa. The experimental results showed that only 5% methane addition may increase 2.6 times the pressure at which the mixture may ignite in comparison to the pressure of the pure hydrogen injection (case d = 6 mm, L = 75 mm). For burst pressures up to 16 MPa the 10% methane in the mixture did not cause an ignition in any case. The simulations confirm the nonlinear relationship between tube length and ignition occurrence (fig. 5). Numerical results for d = 14 and L = 10 mm indicated ignition for burst pressure equal 17.5 MPa. In this case ignition took place in the centre of the channel just after the generated shock wave left the channel. In the other numerical cases with extension tube the ignition took place in the vicinity of the tube walls and the reaction propagated along the whole contact surface which is in agreement with the work of Kim et al. [12] who visualised the hydrogen ignition process in the channel.

In spite of the research done the successive investigation should be done both experimental and numerical. The field of that research should include: wider range of the extension tube length, wider range of the burst pressures and numerical simulations of hydrogen-methane mixtures flow.

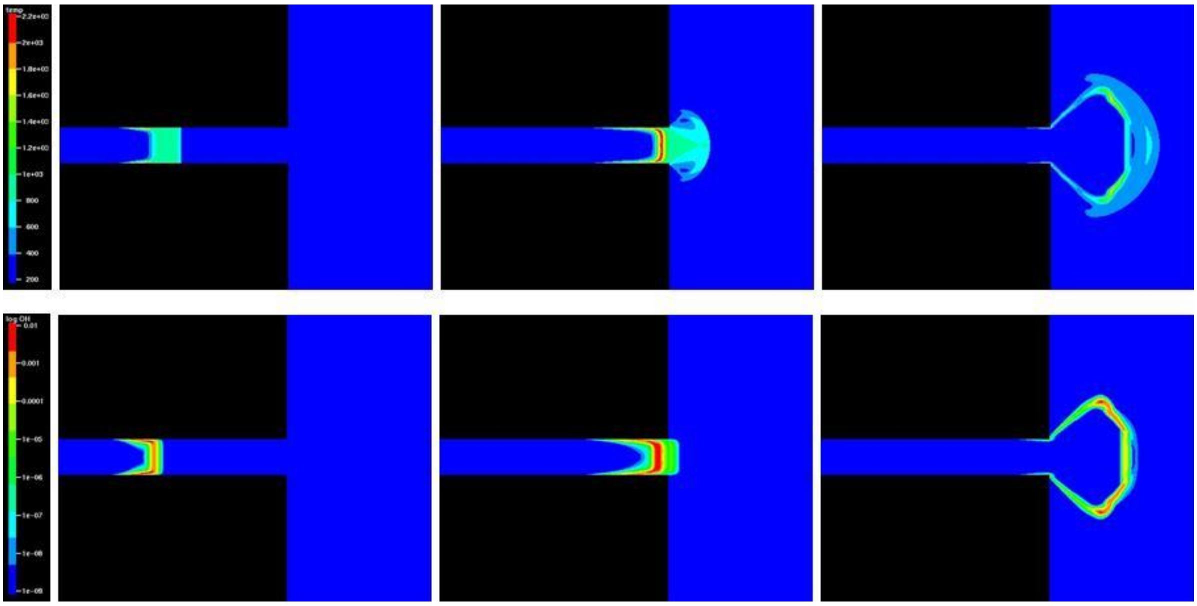

Fig. 2. Numerical results – temperature and OH mass fraction contours for case d = 10 mm, L = 100 mm, P_{burst} = 7 MPa. Times for frames are 50, 80 and 100 μs.

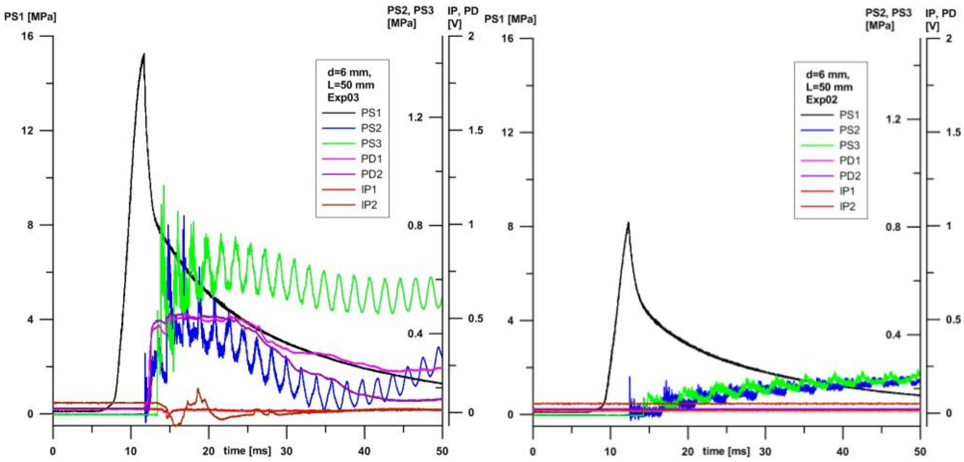

Fig. 3. Sensors indications with (left) and without ignition (right). Methane addition 0%.

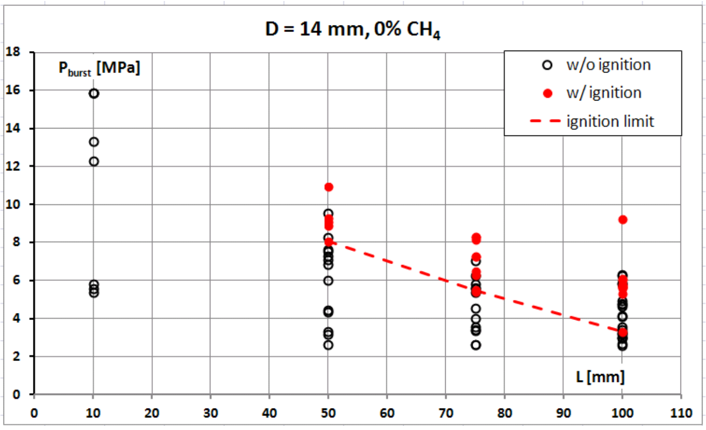

Fig. 4. Cumulative diagram for experiments with d = 14 mm and 0% CH_4 addition.

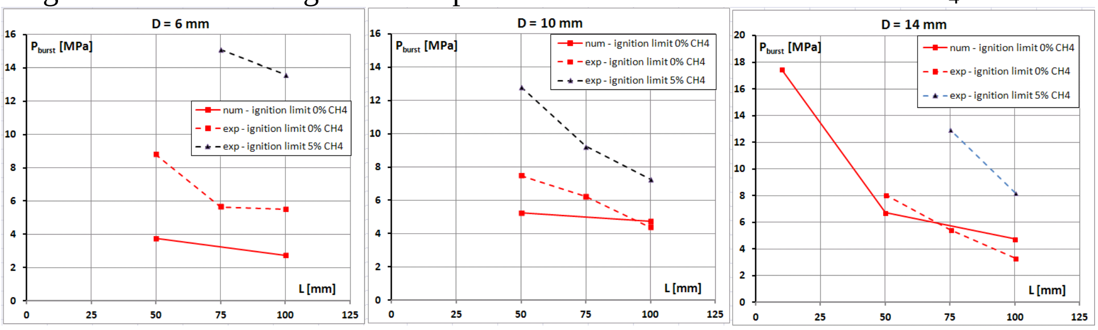

Fig. 5. Ignition limits for different jet diameter, extension tube length and methane addition. Experimental and numerical results.

Acknowledgments

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