Investigation of hydrogen ignition during outflow into atmosphere from high pressure system

Pawel Oleszczak, Piotr Wolanski

Warsaw University of Technology, Warsaw, Poland

1. Introduction

The first investigations concerned with a problem of ignition of hydrogen during outflow from the high pressure installation were carried out nearly 40 years ago by Wolanski and Wojcicki [1-3]. The research was concerned with a dramatic accident in Chorzow Chemical Plant „Azoty", where explosion of synthesis gas (hydrogen-nitrogen mixture, $3H_2 - N_2$, 300 °C, 30 MPa) had killed four people. After initial investigation, potential external sources of the ignition had been exluded and the main aim of the research was to determine the real source of the ignition. More recently there have been submitted several other publications on ignition resulted from a high pressure hydrogen leaks without an external ignition source [4-7]. Hydrogen is regarded as a perspective fuel for various kinds of vehicles: fuel cell cars, trucks, buses etc. The crucial safety problems are concerned with storage of hydrogen at a very high pressure. High pressure of hydrogen storage causes potential risk of a sudden rapture of tank or of a high pressure installations which can lead to ignition and potential explosion. Mixing of the hydrogen and air heated up by the shock wave generated by expanding hydrogen can cause an ignition of produced combustible mixture. Many papers dealing with numerical and experimental investigation concerned with hydrogem safety and the high pressure hydrogen outflow ignition have recently been published [8-10]

The aim of this research is the investiagtion of hydrogen ignition as a result of compression and heating of the air by shock wave generated by the discharge of hydrogen and also determination of critical pressure which can lead to ignition. The critical pressure for ignition depends mainly on geometrical configuration of an outflowing system (tube diameter) and presence of obstacles. The paper presents results of experimental and numerical investigations of the high pressure hydrogen outflow ignition.

2 Experimental facility

The experimental tests have been conducted on a facility constructed in the Combustion Laboratory of the Institute of Heat Engineering, Warsaw University of Technology. The view and the scheme of the facility are presented in Figure 1 and Figure 2. The main element is a high pressure hydrogen container. The flow of the hydrogen after the discharge is registered with the use of Schlieren system and high speed digital camera.

Test with various configurations have been performed to determine critical conditions for high pressure hydrogen ignition to occure. Pictures taken during the test without obstacle and with hydrogen pressure equal to 13.9 MPa are presented in Figure 3. The illumination of hydrogen flame is very low (emission basically in the ultraviolet), so, for the purpose of comparison, tests with the outflow of hydrogen into nitrogen in the same configurations have been conducted. It has helped to determine the condition of ignition. Also measurements of emitted radiation by photodiode have been conducted.

Correspondence to: polesz@itc.pw.edu.pl

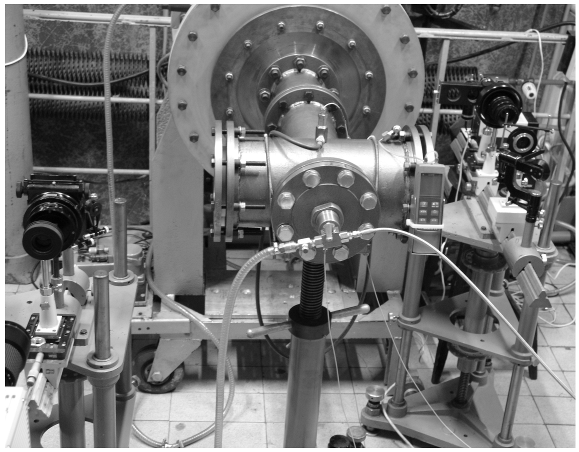


Figure 1. The general view of the experimental facility.

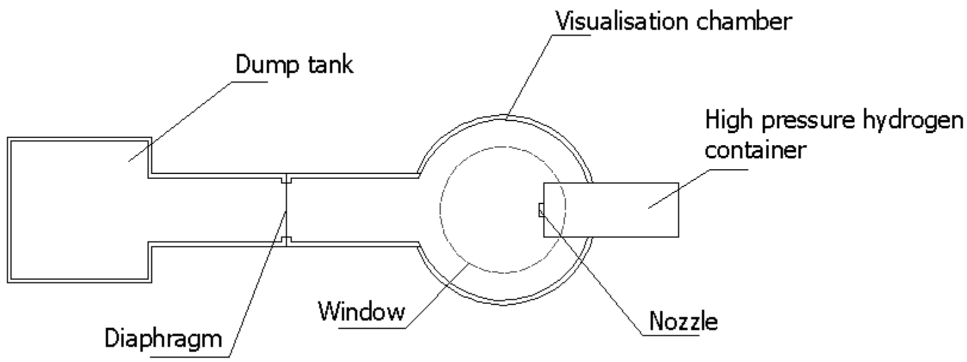


Figure 2. The scheme of the experimental facility.

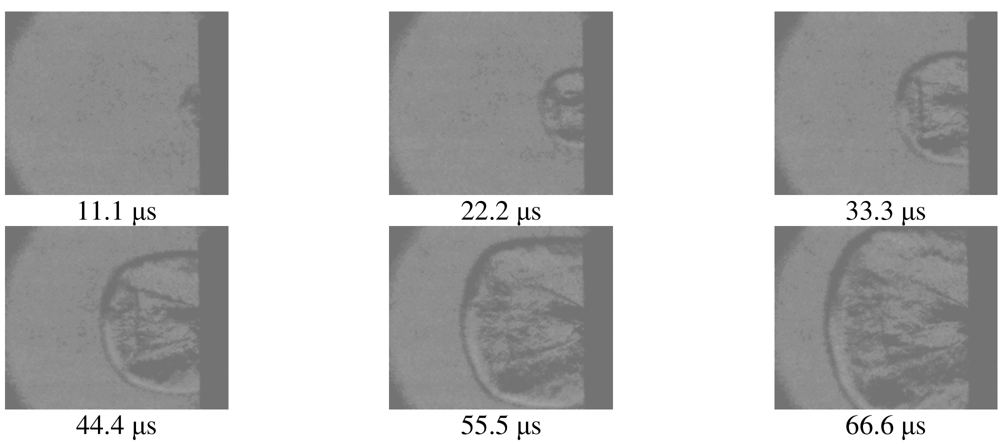


Fig 3. High speed Schlieren picture of hydrogen ignition during outflow into air. Frequency: 80000 f/s, exposition time 1/298000 s, p_{H2} = 13.9 MPa, nozzle diameter 10 mm, nozzle length 10 mm.

The scheme of the facility configuration with an obstacle is presented in Figure 4. Pictures taken during the test with obstacle and with hydrogen pressure equal to 9.1 MPa are presented in Figure 5. As it can be seen on the pictures, there appeared the ignition in center of the obstacle but a flame was present for only for a short duration.

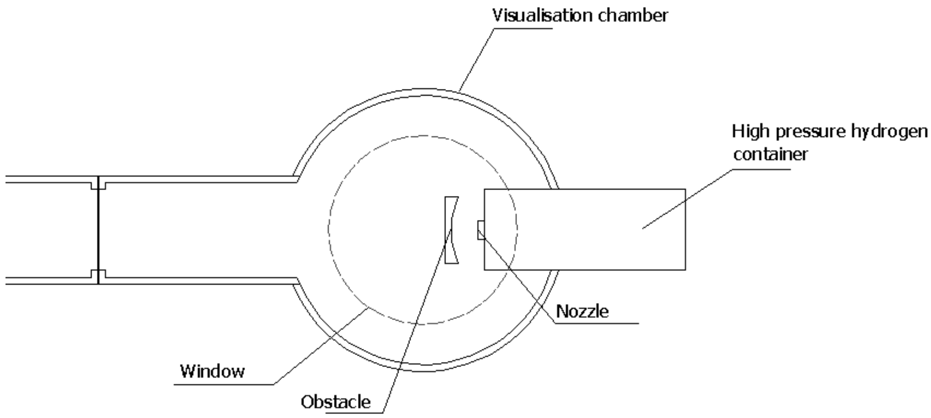
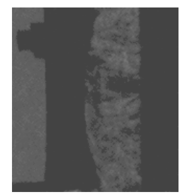


Figure 4 The scheme of the facililty with obstacle.





44.44 μs 88.88 μs 133.33 μs

Figure 5. High speed Schlieren picture of hydrogen ignition during interaction with obstacle. Frequency: 90000 f/s, exposition time 1/288000 s, p_{H2} = 9.1 MPa, distance between nozzle and obstacle 20mm.

3 Numerical simulations

To compare the experimental results with the theoretical analysis series of numerical calculations using Gambit 2.3.16 and Fluent 6.3.26 software were performed. The main aim of the calculations was to find a difference between experiments and numerical analyses to correct reaction mechanism used in the calculations. It was found that the use of simplified, one reaction mechanism gives unrealistic results and underestimates critical hydrogen pressure required for the ignition. It was an initial stage of numerical investigation.

Numerical calculations were also used to study influence of the geometry of high pressure hydrogen outflow system and of obstacles on the minimal pressure of hydrogen required to cause the ignition. It was found on the basis of the research that the presence of obstacles has a strong influence on the feasibilty of the ignition caused by the high pressure hydrogen outflow. The initial numerical investigations suggest that the obstacles placed in a proximity of the discharge (nozzle) has stronger influence on the critical value of hydrogen pressure which leads to the ignition. Results of the numerical tests with 10 mm of diameter and 10 mm of length nozzle are presented on the pictures in Figure 6. There is an ignition in the center of the outflow 14 μs after hydrogen discharge, what is indicated by high temperature and chemcal reaction rate rise .

4 Summary

The obtained result of the numerical and experimental research show that the geometrical configuration has a strong influence on the ignition of hydrogen flowing out from the high pressure system. The experimental facility enables detailed studies of the ignition of the high pressure hydrogen outflow in different configurations. The tests suggest strong influence of obstacles on the critical ignition pressure. Results from the numerical simulations with use of Fluent code provide only qualitative information about the studied phenomena. A more advanced software is required to obtain more detailed and precise data concerned with structure of the outflow of high pressure hydrogen and critical value of hydrogen pressure which leads to ignition of outflowing high pressure gas.

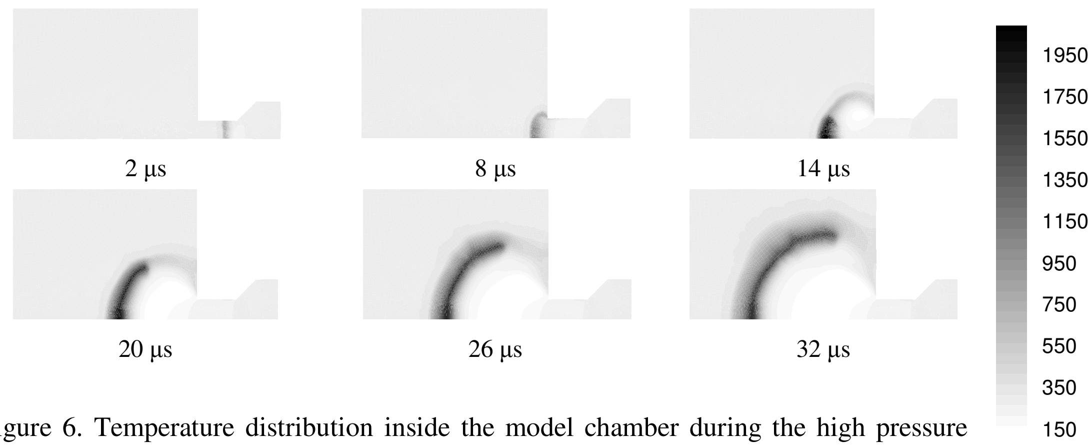


Figure 6. Temperature distribution inside the model chamber during the high pressure hydrogen outflow. Hydrogen pressure 11 MPa, diameter of the nozzle 10 mm, length of the nozzle 10 mm.

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