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Experimental study of ignited unsteady hydrogen releases from a high pressure reservoir

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ABSTRACT

In order to simulate an accidental hydrogen release from the high pressure pipe system of a hydrogen facility a systematic study on the nature of transient hydrogen jets into air and their combustion behavior was performed at the KIT hydrogen test site HYKA. Horizontal unsteady hydrogen jets from a reservoir of 0.37 dm^3 with initial pressures of up to 200 bar have been investigated. The hydrogen jets released via round nozzles 3, 4, and 10 mm were ignited with different ignition times and positions. The experiments provide new experimental data on pressure loads and heat releases resulting from the deflagration of hydrogen–air clouds formed by unsteady turbulent hydrogen jets released into a free environment. It is shown that the maximum pressure loads occur for ignition in a narrow position and time window. The possible hazard potential arising from an ignited free transient hydrogen jet is described.

1. Introduction

Hydrogen is successfully used in industry in many different applications. Accidental hydrogen release from pipe systems are one of the main hazards that occur in the handling of pressurized hydrogen. The accidental H_2 release from the system should be detected fast and as safety consequence the main supply tank should be closed. So the released amount of hydrogen is limited and the release conditions are unsteady. But the generated hydrogen cloud can be ignited subsequently by an external ignition source. For low initial storage pressure, up to 16 bar, it has been shown experimentally [1] that for a given amount of hydrogen a distinct ignition time and ignition position exists for the generation of a maximum pressure wave due to a "local explosion" in the free jet. In case of a sudden hydrogen release from a high pressure initial state the possibility of a self ignited jet fire is present [2,3,4]. Currently no systematic studies are available on the hazard potential of transient releases of hydrogen from high pressures with a spontaneous or forced subsequent ignition. In this study, the free hydrogen jet release from pipes with residual overpressure is experimentally simulated by using two different start-up release conditions. The first procedure is a fast valve opening to produce the free gas jet. These releases were ignited with a forced spark ignition technique. The parameters in these experiments are: circular release opening with inner diameters of 3 mm, 4 mm and 10 mm, initial reservoir pressures of up to 200 bar, and a reservoir volume of 0.37 dm^3. In the second release configuration an additional rupture disc is installed in the exhaust pipe, which leads to a sudden hydrogen release in combination with shock wave generation from the ruptured disc [5]. The parameters of these experiments without external forced ignition are: circular release opening with an inner diameter of 4 mm with different extension pipe lengths after

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the rupture disc, different break points of the disc, initial reservoir pressures of up to 200 bar, and a reservoir volume of 0.37 dm^3. The ignited hydrogen jets were recorded with a high speed camera, and the resulting pressure and thermal loads to the environment were investigated under variation of ignition position, ignition point in time and initial vessel pressure. The goal of this work is to quantify the possible hazards arising from externally or spontaneously ignited free transient hydrogen jets.

2. Experimental set-up

The facility for the generation of a defined and transient horizontal hydrogen jet from a high pressure reservoir is shown in Fig. 1. Via a feed line valve (a) the cylindrical storage vessel (b) with a volume of 0.37 dm^3 is filled with highly pressurized H_2. A helium driven needle valve DN 4 mm (c) with a valve opening time <2 ms works as leak opening tool in all experiments. The initiation time of this valve is 16 $\pm$ 0.3 ms. Cylindrical tubes connected to the valve were used as release nozzle (d). Optionally cylindrical tubes with a rupture disc (aluminum foil) inside were installed in the experiments with self-ignition initiation, see inserted picture of the rupture disc holder in Fig. 1 right. The H_2-jets released into the free environment were ignited after a distinct time in different positions along the jet axis via a high frequency electric arc (20 kHz, ~60 kV, ~10 W) (f). The dynamic overpressure resulting from the combustion of the released hydrogen was detected by five dynamic pressure sensors (PCB Type 113A31) in special adapters that were positioned in a line with a distance of 40 cm to each other. The pressure sensor line (e) is placed parallel at a distance of 50 cm to the jet axis (h). Two heat flux sensors (g) were positioned via lances along the jet axis (h). The hydrogen flow and combustion were observed by high speed shadow-methods in different scales and techniques. The experiments were performed in a specific test chamber with a volume of approx. 160 m^3. The experimental facility was mounted on a rack in a way that the axis of the H_2-jet (h) had an unobstructed length in space of 4 m and a minimum distance to the floor and the nearest wall of 1.6 m.

In Table 1 the main experimental variables are listed, experiments with forced ignition via spark (no rupture disc in the nozzle pipe) were performed with 3 and 4 mm nozzles and initial overpressures of 100 and 200 bar. Additionally a 10 mm end nozzle was installed (this nozzle area is larger than the area in the leak valve DN 4 mm) to study the influence of an increasing release area. Experiments with rupture discs in the 4 mm nozzle pipe were performed with different initial overpressures of up to 225 bar and different extension pipe lengths between the disc and the nozzle exit. In these experiments the break pressure of the aluminum rupture disc was clearly lower than the overpressures in the vessel and the small volume between the rupture disc and the leak valve was filled with H_2 as recipient at atmospheric pressure. The extension pipe (nozzle) downstream of the rupture disc is open to the atmosphere. The nozzle exit was scanned with a photodiode to identify the luminescence of reacting hydrogen. A more detailed description to the rupture disc behavior and the experimental set up is given in [5], where the spontaneous ignition processes due to high-pressure hydrogen releases in air were studied.

3. Release conditions

To compare the hazard potential of ignited and self-ignited free transient hydrogen jets in air the release conditions in both cases are important. The effluent formula of SAINT-VENANT and WANTZELL in combination with a linear nozzle form factor [1] can describe the pressure decay in the vessel during the H_2 release. In Fig. 2 the comparison of measured and calculated pressure decay for the 4 mm nozzle and initial pressure of 200 bar in the vessel is shown for the start up of the H_2 release. In the pressure history of the vessel for a rupture disc experiment the stagnation point before the failure of the disc (burst pressure ~160 bar) is not detected, only a refraction shock wave that propagates against the flow in the vessel and is reflected there from wall

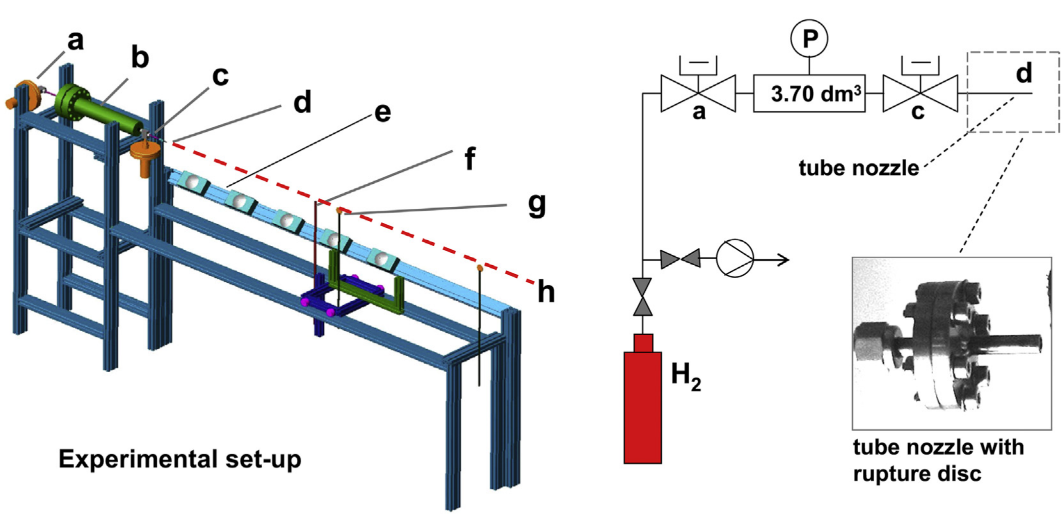

Fig. 1 – CAD-drawing of the experimental set-up and schematic of the experimental set-up.