INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 43 (2018) 19293–19304

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Non-homogeneous hydrogen deflagrations in small scale enclosure. Experimental results

M. Carcassi, M. Schiavetti*, T. Pini

University of Pisa, Department of Civil and Industrial Engineering (DICI), Largo Lucio Lazzarino, 2, 56122, Pisa, Italy

ARTICLE INFO

Article history:
Received 10 May 2018
Received in revised form
23 August 2018
Accepted 26 August 2018
Available online 19 September 2018

Keywords:
Hydrogen deflagration
Pressurized release
Hydrogen stratification

ABSTRACT

University of Pisa performed hydrogen releases and deflagrations in a 1.14 m^3 test facility, which shape and dimensions resemble a gas cabinet. Tests were performed for the HySEA project, founded by the Fuel Cells and Hydrogen 2 Joint Undertaking with the aim to conduct pre-normative research on vented deflagrations in enclosures and containers used for hydrogen energy applications. The test facility, named Small Scale Enclosure (SSE), has a vent area of 0,42 m^2 which can host different types of vent; plastic sheet and commercial vent were tested. Realistic levels of congestion are obtained placing a number of gas bottles inside the enclosure. Releases are performed from a buffer tank of a known volume filled with hydrogen at a pressure ranging between 15 and 60 bar. Two nozzles of different diameter and three different release directions were tested, being the nozzle placed at a height where in a real application a leak has the highest probability to occur. Three different ignition locations were investigated as well. This paper is aimed to summarize the main features of the experimental campaign as well as to present its results.

Introduction

Due to the high buoyancy of hydrogen, most of the real accidents that can happen in closed environments foresee an accumulation of the released gas under the canopy of the enclosure and a stratification in layers at different concentrations, instead of homogeneous mixtures.

Nevertheless, most of the experimental tests performed in the past were performed at highly idealized conditions. Particularly, apart from a few experimental campaigns [1–3], most tests were performed in empty enclosures. Furthermore only few experimental campaigns were conducted investigating non-homogeneous mixtures [4–6].

HySEA project [7] conducted pre-normative research to inform the European and International Standards organizations on "hydrogen explosion venting mitigation systems" and to update and harmonize the international standards for sizing and optimizing the design of venting devices for fast-deploying containerized hydrogen-energy products. Experimental tests were performed in 12 foot ISO-containers by GexCon [8,9] and in a small scale enclosure by University of Pisa (UNIPI), investigating both homogeneous and stratified mixtures in real volume applications with and without the presence of obstacles.

The small scale enclosure (SSE) is designed to reproduce volumes and arrangements of a gas cabinet. In a first experimental campaign tests were performed in homogeneous conditions (tests label TP) [10–12]. In the second part of the

* *Corresponding author.*
E-mail address: martino.schiavetti@gmail.com (M. Schiavetti).
https://doi.org/10.1016/j.ijhydene.2018.08.172

experimental campaign (tests label NHTP), described in this paper, the release is carried out using a buffer tank filled at the desired pressure, from a nozzle of a known diameter. The nozzle is placed at a height where the leak has the higher probability to occur in a real application, namely the area above the bottles where connections with the gas manifold are located. During the release the inner atmosphere is sampled at 5 different heights both when the release stratifies for some minutes before ignition, then when it is ignited at the end of the release. Furthermore the small scale enclosure was used to collect data on the variability of the opening pressure of commercial vent as a function of the rate of pressure rise during the deflagration. The effect of the time of ignition was investigated as well as the one of the ignition location on the maximum achieved overpressure.

A total number of 82 releases and deflagration tests, named NHTP, were performed during the experimental campaign. This paper summarizes the aforementioned aspects of the data analysis, while other collected data will be published in the future.

Experimental setup

UNIPI, with technical support from HySEA partners, has designed a generic experimental enclosure suitable for investigating vented hydrogen explosions in installations such as gas cabinets, cylinder enclosures, dispensers and backup power systems. The dimensions of the enclosure, 0.92 m width, 0.66 m depth, 2 m height, had been chosen taking into account the dimensions of gas cabinets and dispensers commercially available on the market, while the dimensions of the vent were chosen to accommodate commercial vent panels provided by FIKE (see Fig. 1). FIKE is a globally recognized supplier of vent panels that protect vessels and buildings from explosions and a partner of the project HySEA. Two different obstacle configurations were tested: the empty enclosure and 3 bottles inside the enclosure (see Fig. 3). The free volume of the empty facility is 1.14 m^3, while the 3 bottles occupy 14.6% of the internal volume.

The enclosure consists of a solid steel frame, built using L-Shaped Cross-section steel bars (50 × 50 × 4 mm), bolted to the basement beams of a 25 m^3 experimental facility. The frame external faces are covered with various combinations of walls, doors, and vent panels bolted to the structure.

The back wall, closed by a 5 mm thick steel plate bolted to the frame, is strengthened around the position of a pressure transducer (P_{side}) which is located at a height of 1690 mm from the floor. The back wall is also fitted with holes and connections for the measurement system and hosts the release nozzle which axis is placed at 1520 mm height from the floor (see Figs. 1 and 2(b)).

The top face of the facility is designed to host different types of vent: commercial FIKE panel (dimension 500 mm × 800 mm) or plastic sheet. The tested FIKE vent, single element, integrated frame, was selected during the first experimental campaign involving homogeneous mixtures for its lower dependency of the opening pressure with the pressure rise rate with respect to composite layers stainless steel and fluoropolymer vents.

The front face is divided into two parts: the upper part, which height is 0.62 m, is closed with a bolted steel plate of which the displacement is measured during the deflagration; the lower part, height 1.38 m, was closed by a 5 mm thick steel plate. The location of the displacement measurement, that is the external bowing of the bolted plate provoked by the internal pressure rise inside the enclosure during the deflagration, is opposite to the pressure transducer placed on the back-wall. Two thicknesses of the plate have been tested, namely 2 and 5 mm. Results from the displacement measurement are listed in the HySEA deliverable [12], while the discussion on the capabilities of FE and CFD codes in reproducing the phenomena has been discussed in another paper [13,14].

The two lateral faces host frames with transparent polycarbonate panels (LEXAN) in order to have the possibility to video record the flame from outside.

Salty water aerosol was injected inside the enclosure before starting the release in tests were the flame front was filmed. Comparison of similar tests performed at the same H_2 concentration with and without salty water aerosol injection allowed to verify that effect of the aerosol on the resulting pressure time history was negligible.

Two small commercial cameras (Go-Pro Hero 5) are used to record the deflagrations with a recording frequency of 240 frames per second: the internal camera is placed on the bottom of the facility facing the top vent, the external camera was used to record the vent opening features in some tests and to video record the flame inside the facility when salty aerosol was injected to visualize the flame.

Hydrogen is contained in a buffer tank of a 3.785 L volume, see Fig. 2(a), that is filled to the desired pressure, the release is initiated opening a valve. Nozzle diameters are 0.5 mm, (area 0.196 mm^2), and 0.95 mm, (area 0.709 mm^2), respectively. The release has been performed in different direction: horizontally, upward or downward direction have been tested in the experimental campaign. Downward release impinges in a hydrogen sampling steel tube and in the L-shape frame of the structure, see Fig. 2(b).

Concentration sampling tubes suck the inner atmosphere from a location on the centreline of the facility at 5 different heights, 0.2 m; 0.6 m; 1.0 m; 1.4 m and 1.8 m from the floor. During the release and consequent stratification the concentration measurements were recorded at a frequency of 1 Hz.

In some of the tests the volume above the bottles was occupied by the sampling lines of the oxygen sensors. Oxygen sensors were used to measure the concentration close to the roof of the enclosure where the concentrations could exceed the reading limit of the hydrogen sensors. The presence of the sampling lines affects the distribution of hydrogen as discussed in the following paragraphs. Nevertheless the results of the oxygen sensor measurements were not considered satisfactory and their results are not included in this report. More information please refer to the HySEA report [15].

The flammable mixture has been ignited in three different positions, all the igniters are located on the centreline of the facility, bottom ignition at 0.5 m above the floor, centre ignition 1 m above the floor, and top ignition 1.5 m above the floor (see Fig. 1).