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Gas explosion field test with release of hydrogen from a high pressure reservoir into a channel

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ABSTRACT

Field experiments of a high pressure release of hydrogen gas inside a 6 m long, 0.9 m wide, and 0.8 m high channel have been performed, to validate the Froude scaling and to obtain pressure and flame speed data in an inhomogeneous hydrogen–air cloud. Froude scaling with a length scale corresponding to the height of a 100% hydrogen layer in the channel was used to describe the flow of the hydrogen–air cloud in the channel. The estimated time of ignition based on the Froude scaling for release pressures of 100 bars and 150 bars agreed well with the experiments. At lower release pressures the estimated time was lower, which was most likely caused by dilution of the front of the hydrogen cloud. High speed video was used to record the flame speed. For the present experimental conditions it appeared that the deflagration taking place closer to the jet source determines the maximum explosion pressure.

1. Introduction

In the IEA Energy Technology Perspective (ETP) 2012 report hydrogen is considered to be a flexible energy carrier in the future. Hydrogen could play an important role in a low-carbon energy system with applications across all end-use sectors. Hydrogen might also play a useful role in future energy storage. However, the IEA-ETP-report also points out that safety issues are a concern with hydrogen handling [1]. The possibility of unintended leaks is always present with hydrogen handling, and these leaks may result in fires and explosions. For safety reasons, it is important to determine the nature of the gas release in the case of failure.

The consequences of a gas explosion, caused by leaking hydrogen, are strongly linked with the formation of a combustible gas cloud and the subsequent flame propagation through the cloud. The behaviour of gaseous hydrogen releases and flame propagation in hydrogen air clouds have been studied by many scientists and groups for decades, among them HySafe and IEA HIA task 19 and 31. Some examples of this work are reported by Takana et al. [2], Brennan et al. [3], Shirvill et al. [4] and Dorofeev [5].

Our group [6] have carried out dispersion experiments with leaking hydrogen, using a laboratory-scale channel with a sub-sonic hydrogen jet. The flow outside the jet zone appears to be well-described by Froude scaling, with a length scale corresponding to the height of a theoretical non air entrained layer of 100% hydrogen [6]. Computational Fluid Dynamics (CFD) codes calculating dispersion and flame propagation are necessary tools for performing safety studies. However, validation of CFD codes against field experiments is limited and

Abbreviations: BOS, background oriented schlieren; CFD, computational fluid dynamics; Fr, Froude number; QRA, quantitative risk analysis.

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Nomenclature

Fr	Froude number [–]
g	acceleration due to gravity, m/s^2
l	length scale used in Froude scaling, m
h	height of cloud, m
h_H	height of 100% hydrogen, m
L	length from end of channel to ignition point, m
Q	volume flow rate, m^3/s
u	velocity, m/s
u_F	frontal velocity, m/s
w	channel width, m
H	channel height, m
ρ_A	density of air, kg/m^3
ρ_H	density of hydrogen, kg/m^3
Δt	time of ignition, s
φ	dimensionless height, h/H, [–]
γ	ratio of specific heats, [–]
A	cross section area of nozzle, m^2
C_D	discharge coefficient, [–]
R	hydrogen gas constant, J/kgK
P_0	reservoir pressure, bar
T_0	reservoir temperature, K
y_{hy}	volume fraction of hydrogen, [–]
$\dot{m}$	mass flow rate, kg/s

there is a shortage of experimental data from field tests. The CFD tool needs to be well validated against relevant experiments [7].

This paper presents experimental results from high pressure hydrogen dispersion and explosions in a 5.8 m long and 4.1 m^3 channel. The work is a continuation of the work by Sommersel et al. [6]. The objectives of these experiments are to i) validate the Froude scaling for high pressure hydrogen dispersion in a field-scale channel, and to ii) obtain pressure and flame speed data to validate CFD codes in their modelling of an inhomogeneous hydrogen–air cloud.

2. Material and method

2.1. Experimental setup

The test channel as shown in Fig. 1 was 6 m long, 0.9 m wide and 0.8 m high. It was open at one end and closed at the other end. The inner length of the channel was 5.8 m. The channel was empty with no internal obstacles. The 2 m section adjacent to the closed end of the front wall was made of steel, and the remaining 4 m were made of transparent polycarbonate. The side view of the channel with the 2 m steel wall and the 4 mm polycarbonate wall can be seen in Fig. 1(a). Fig. 1(b) shows a front view of the inside of the channel at the closed end. The release nozzle pointing upwards against the roof can be seen in the centre of the picture.

Fig. 2shows a schematic drawing of the experimental setup, illustrating the locations ignition and the hydrogen inlet on the left hand side of the channel. The pressure transducers were located 1 m apart along the channel roof and floor.

2.2. Hydrogen gas supply

The hydrogen was supplied from a standard 200 bar gas cylinder which used a high pressure hydrogen regulator to adjust the release pressure. Opening a fast acting pneumatic ball valve allowed hydrogen gas to be injected into the channel through a 1.5 mm diameter nozzle as shown in Fig. 1(b). The nozzle was fitted at the end of a steel pipe that was connected to the pneumatic valve, and was inserted 0.5 m into the channel from the closed end at the centreline. The nozzle was positioned 0.4 m from the bottom of the channel, and the release was directed vertically upward. Hydrogen release pressures of 30 bars, 50 bars, 100 bars, and 150 bars were used.

2.3. Ignition

A Siemens ZM 20/10 high voltage spark igniter (approx. 100 W) was used to ignite the hydrogen–air mixture. The ignition was mounted on the centreline of the upper wall of the channel. The location of the ignition was central to the roof, and placed 2.5 m (Ign#1), 3.5 m (Ign#2), and 5.5 m (Ign#3) from the closed end of the channel, as shown in Fig. 2. At each ignition distance, the hydrogen was released at a pressure of 30 bars, 50 bars, 100 bars, and 150 bars. The ignition source was switched on and off in a series of short continuous pulses, fifty times per second.

2.4. Pressure recordings

Five Kistler 7001 and two Kistler 603B pressure transducers were used to measure the explosion pressures and the results were recorded digitally by an oscilloscope. As shown in Fig. 2, there were two pressure transducers on the floor, placed 0.2 m (P#1) and 3 m (P#4) from the closed wall. Also, there were five possible placements for the pressure transducers on the roof, at 1.5 m (P#2), 2.5 m (P#3), 3.5 m (P#5), 4.5 m (P#6), and 5.5 m

Fig. 1 – Experimental channel at Norward test facility a) 6 m long channel with a side wall made up of 2 m steel wall and a 4 m transparent polycarbonate wall. b) Closed end wall with nozzle in centre pointing upwards.