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Large scale passive ventilation trials of hydrogen

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ABSTRACT

This paper describes the investigation of a passive ventilation solution to manage the hydrogen concentration within a large ullage space (0.9–3 m deep) above a liquid (free surface area of ~40 m^2) containing a hydrogen source. The aim of the ventilation is to maintain the hydrogen concentration within the ullage space below 25% of the Lower Explosive Limit (LEL). The programme of tests involved examination of the ventilation performance in terms of sensitivity to chimney position, hydrogen release rate, hydrogen release point, ullage height and chimney diameter.

The tests carried out lasted many hours, and the hydrogen concentration was monitored at a number of points within the ullage space. Pairs of ventilation chimneys with associated instrumentation systems were used to control and monitor the hydrogen concentration within the ullage space.

This paper describes the approach to the testing, the results obtained and their analysis.

Introduction

Hydrogen is approximately fourteen times less dense than air, with a specific gravity of 0.0696 (air = 1) and a high diffusivity [1]. As a result, hydrogen leaks rapidly disperse with the surrounding air, and even low concentrations can form buoyant pockets/flows when released into the atmosphere [2]. Based on these properties, one approach to control the build-up of hydrogen within enclosures is to employ passive ventilation, which in many ways can be regarded as an "inherently safe" or a "high reliability" approach. The scope of this work is in relation to high hazard installations, where such an approach is essential to address situations where an indefinite loss of power may occur, such as after a catastrophic seismic event. Specifically, this paper describes experimental work to investigate the feasibility of using passive ventilation to control the hydrogen concentration in a large ullage space to below one quarter of the Lower Explosive Limit (LEL). The large ullage space sits above water, through which hydrogen was bubbled at a variety of rates, and from different release configurations.

The aim of this investigation was to test whether a passive ventilation solution that uses chimneys in the roof of a vessel can manage hydrogen build-up to less than 1% hydrogen by volume in air for a range of hydrogen release rates. The study was performed in a large-scale test rig at HSL (see Fig. 1), which is approximately 40 m^2 in horizontal cross section. The hydrogen was released from a grid of release points; rising through several meters of water before entering the ullage space that was varied between 0.9 and 3 m in height.

The majority of the passive ventilation trials were performed with chimney pairs with internal diameters up to 300 mm, but comparison tests with 150 mm diameter chimneys were also performed. Different chimney positions (five combinations of chimney pair locations) were investigated,

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Fig. 1 – The large-scale test rig at HSL.

varying both their physical location and separation distance. Hydrogen release rates (flow rates) covering the range 0.56–2.25 $m^3\ h^{-1}$, equivalent to 9.4–37.5 $l\ min^{-1}$ were examined. The effect of concentrating the hydrogen release into individual quadrants, as opposed to distributing it across the whole area of the base of the tank, was investigated. The bulk of the trials were carried out with an ullage height of 0.9 m, but a set of comparison tests was also done with a 3 m ullage height.

Models and curve fitting

Prior to the start of the work, the results from a computational fluid dynamics (CFD) model of the system showed that the time dependence of the hydrogen concentrations in the ullage would be consistent with a simple mass balance equation of the form:

$$\text{conc.} = c \cdot \left(1 - e^{-t/\tau}\right) \tag{1}$$

where c is the asymptotic final value of the hydrogen concentration, t is time and τ is the time constant of the system.

This mass balance equation was used in the experimental control system software to determine when to end a test. As the data were collected, the software fitted an exponentially rising curve of the form given in Equation (1). From this fit, the software calculated τ, the time constant for the test. After a period preset by the operator, the software applied a preset multiplier to τ to create a duration for the test. After each test, the data were fitted to a slightly different form of Equation (1) to produce c or the final hydrogen concentration (see Experimental method and Results).

The hydrogen release system

The hydrogen was released within the water in the vessel via a bubbler system which consisted of 100 release positions, designed in a grid pattern over the floor of the tank. Each release position consisted of a syringe barrel connected to the hydrogen supply. A frame raised the open end of the syringes above the floor of the tank. The syringes were set at an approximate angle of 10° to the vertical. This produced hydrogen bubbles of approximately 20 mm diameter, that rose unimpeded from the open end of the syringe through the water column to the ullage. These bubbles were oblate spheroids.

The steel frames were aligned in pairs a set distance apart and these were laid out as a row of ten pairs with the same set distance between the rows. Rubber tubes were connected to form four grids of 25 interconnected syringes. Each grid covered a quadrant of the floor of the tank and was connected via a non-return valve to a manually operated ball valve situated outside the tank. The inlet side of these ball valves was linked via a manifold. Hydrogen was supplied to this manifold through a mass flow controller (MFC) and ancillary valves. The bubbler could be manually set to release hydrogen from any or all of the four quadrants. The MFC set the required hydrogen flow rate and the pneumatically controlled valve was used by the control system to start and stop the hydrogen flow.

Although the large scale test rig shown in Fig. 1 is designed to withstand deflagrations, a requirement of the project was to minimise the temperature gradient between the water, the air in the ullage and the external atmosphere. The main hindrance to a successful test was the heating of the air within the ullage by solar radiation on the steel walls and roof of the tank. To avoid this, the tests were performed at night, under an automatic control system.

The safety requirements for the trials required that the risk of a hydrogen deflagration in the ullage be minimised. The first step in achieving this was to create a system that would run autonomously while monitoring the hydrogen concentration, and take action if the concentration exceeded a safe threshold. Hydrogen concentration measurement sensors were connected to a logic controller programmed to close the hydrogen supply valve if any of the hydrogen sensors indicated a concentration above the threshold. This also resulted in the termination of the test.

Software logged the hydrogen concentrations from each sensor as the test progressed and fitted the data to an exponential curve of the form given in Equation (1). A time constant could be evaluated and multiples of this value used to calculate an end time for the test if all the hydrogen concentrations were below the safe threshold. At the end of a test, the software initiated a purge procedure to remove the hydrogen within the ullage. The software would then start a further test after a delay specified by the operator; it also controlled running the fan for a given period after all the hydrogen sensor measurements had fallen below a lower threshold and doing the number of tests specified by the operator.

Hydrogen sensing

Mini-katharometer [4] hydrogen sensors were used, each fitted in a stainless steel housing with a sintered mesh opening to allow the hydrogen to diffuse to the katharometer. The hydrogen sensors were installed through ports located at