

# **Self Ignition of Hydrogen by Various Mechanisms**

M. Royle, J. Gummer, P. Hooker, D. Willoughby, J. Udensi

This document appeared in

Detlef Stolten, Thomas Grube (Eds.):

18th World Hydrogen Energy Conference 2010 - WHEC 2010

Parallel Sessions Book 5: Strategic Analyses / Safety Issues / Existing and Emerging Markets

Proceedings of the WHEC, May 16.-21. 2010, Essen

Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-5

Institute of Energy Research - Fuel Cells (IEF-3)

Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010

ISBN: 978-3-89336-655-2

# Self Ignition of Hydrogen by Various Mechanisms

**M. Royle, J. Gummer, P. Hooker, D. Willoughby, J. Udensi**, Health and Safety Laboratory, Buxton, Derbyshire, SK17 9JN, UK

## 1 Introduction

With the inevitable transition to some form of hydrogen based economy, spontaneous or self ignition of hydrogen is clearly important<sup>(1)</sup>. A number of mechanisms have been suggested which may account for this phenomenon. This paper reports the results of studies to investigate four possible suggested reasons for this behaviour:

Sudden adiabatic compression in shock wave formation.

Charging of a hydrogen jet leading to electrostatic ignition

Charging of particles within the hydrogen stream leading to electrostatic ignition

Ignition of a premixed volume of hydrogen/air by corona discharge

Health and Safety Laboratory have performed experiments in order to attempt to define conditions under which hydrogen can apparently self ignite and to confirm which mechanisms may account for this behaviour.

Experiments were performed to investigate:

- Ignition by adiabatic compression due to boundary layer failure.
- The current and polarity necessary to ignite pre-mixed clouds of hydrogen/air by corona discharge.
- The charge produced by a hydrogen jet emerging into free air both with and without entrained particles within the jet.

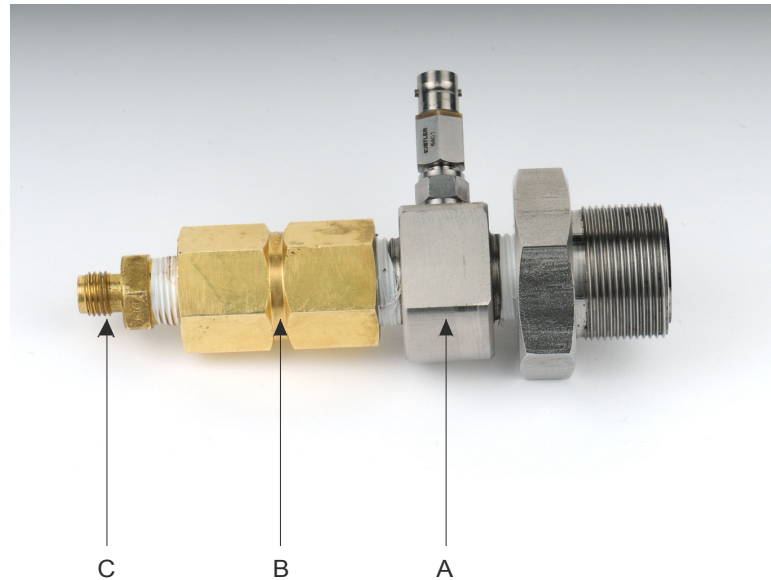
## 2 Literature Review

The first part of this project was a literature review, published separately (Gummer and Hawksworth 2007). The design of these experiments was based on Astbury and Hawksworth 2005, Golub et al 2006 and Dryer et al 2007. In particular the work of Dryer gave a starting point for the experiments to investigate the ignition of sudden releases of compressed hydrogen to atmosphere. In addition to being significant as probably the first piece of experimental work to demonstrate ignition of releases into 'normal' everyday type environments, it was important as it also identified the influence of downstream obstructions on the propensity to ignite.

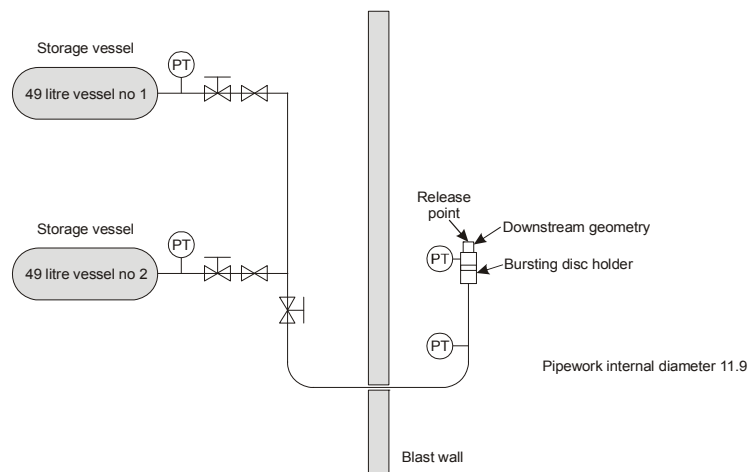
## 3 Experimental Programme Phase 1 – Diffusion Ignition Tests

The work in part of the programme involved tests using a bursting disk assembly and downstream geometry similar to that used by Dryer; a photograph of the assembly is shown at figure 1. The fitting marked A in the photograph was specially manufactured to take a Kistler pressure transducer so that the pressure profile in the cavity immediately downstream of the bursting disk could be recorded as the disk burst. The fitting to the right of A is the top of the bursting disk assembly, B is a ½ inch NPT socket and C is a restricted pipe fitting. The

hydrogen flow is from right to left. All the experiments were performed outside with the hydrogen released to open atmosphere. The hydrogen for the tests was supplied from HSL's 1000 bar experimental hydrogen facility; a schematic of the set up is shown at figure 2.



**Figure 1: Geometry downstream of bursting disk.**



**Figure 2: Simplified schematic of the spontaneous ignition high-pressure H<sub>2</sub> test facility.**

A total of 85 tests were carried out using variations on downstream geometries and pressures. The lowest disk burst pressure at which an ignition was obtained was 35.5 bar; this corresponded to a transient cavity pressure (downstream of the bursting disk) of 28.6 bar. A plot of cavity pressure against burst pressure for ignitions and non-ignitions is shown at figure 3.

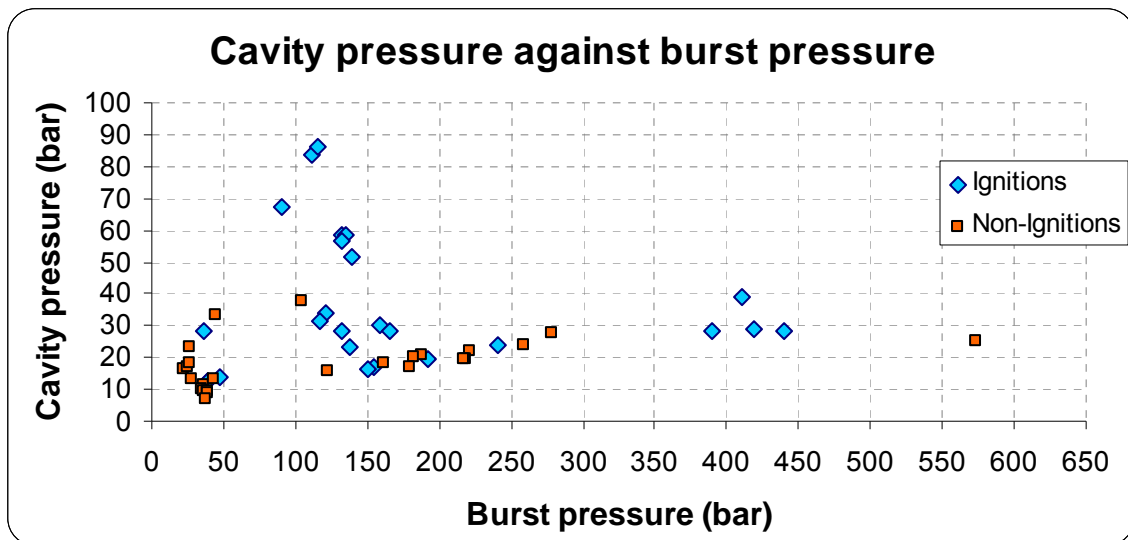


Figure 3: Plot of cavity pressure against burst pressure for cases of ignition and non-ignition.

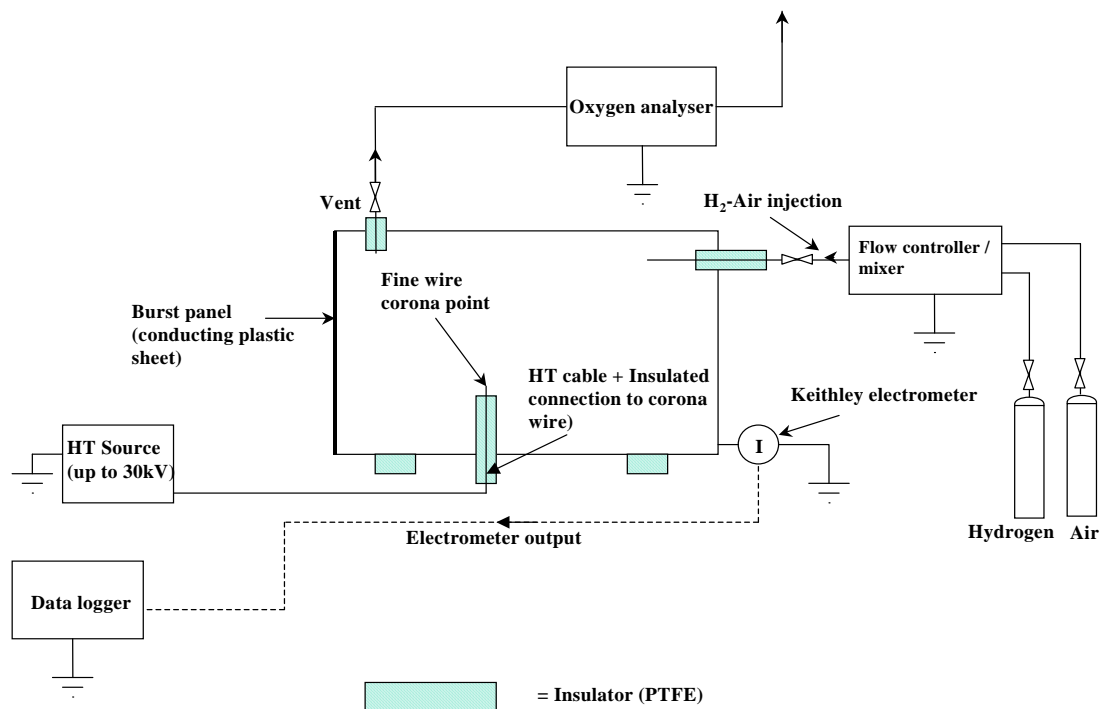
### 3.1 Experimental programme Phase 2 part 1– Ignition of hydrogen/air mixtures by generated corona discharge

A cylindrical vessel of dimensions (1.22m dia × 1.70m long) was used to investigate the conditions under which H<sub>2</sub>-air mixtures may be ignited by corona discharges. The vessel was fitted with explosion relief consisting of physically weak electrically conducting plastic film that was physically and electrically bonded to the vessel to avoid potential spark and brush discharges. The vessel was enclosed by a Faraday cage formed by an iron wire mesh supported on a frame to block out external electric fields. Despite this very small currents were detected from the vessel (about 100 pA), due to dust impingement.

Attempts were made to ignite known concentrations of H<sub>2</sub>-air mixtures by inducing a corona discharge within the gas mixture. The H<sub>2</sub> concentrations used in the tests were within a range around the concentration for which the lowest spark ignition energy is observed (i.e. 28% v/v) with a concentration of H<sub>2</sub> between 26% v/v and 33% v/v in air being employed. Figure 4 shows a schematic of the experimental arrangement used for these tests.

## 4 Corona Wire Arrangement

It was considered unlikely that in a well-earthed H<sub>2</sub> handling system a situation would arise where two conducting items were close to each other but at significantly different potentials. Therefore, initially, the wire was positioned centrally in the vessel, using the vessel walls (approximately half a metre away) as the “earthed” electrode. When no ignitions occurred with this arrangement, an electrode (a metal plate electrically bonded to the vessel) was placed approximately 30 mm away from the corona point to generate higher corona currents.



**Figure 4: Schematic of the experimental arrangement used for ignition of H<sub>2</sub>-Air mixtures from generated corona discharges.**

Summarising the results from the generated corona discharge experiments, the only condition that resulted in ignition of the H<sub>2</sub>-air mixtures was with a positive potential of > 20 kV applied to the wire and with a 30 mm gap between the wire and the earthed electrode, the discharge having a current of approximately 150  $\mu$ A. It is possible that the corona had transitioned into an arc by this stage. This ignition was repeated with H<sub>2</sub>-air gas mixtures of 28% v/v and 30% v/v of H<sub>2</sub>. No ignitions were obtained with a negative potential up to -28 kV and -290  $\mu$ A (the maximum used in the tests).

#### 4.1 Experimental programme Phase 2, part 2– Investigation of corona discharges during high-pressure H<sub>2</sub> releases

Experiments were performed to investigate whether the release of pressurised H<sub>2</sub> could result in incendive corona discharges and, ultimately, ignition of the released H<sub>2</sub>.

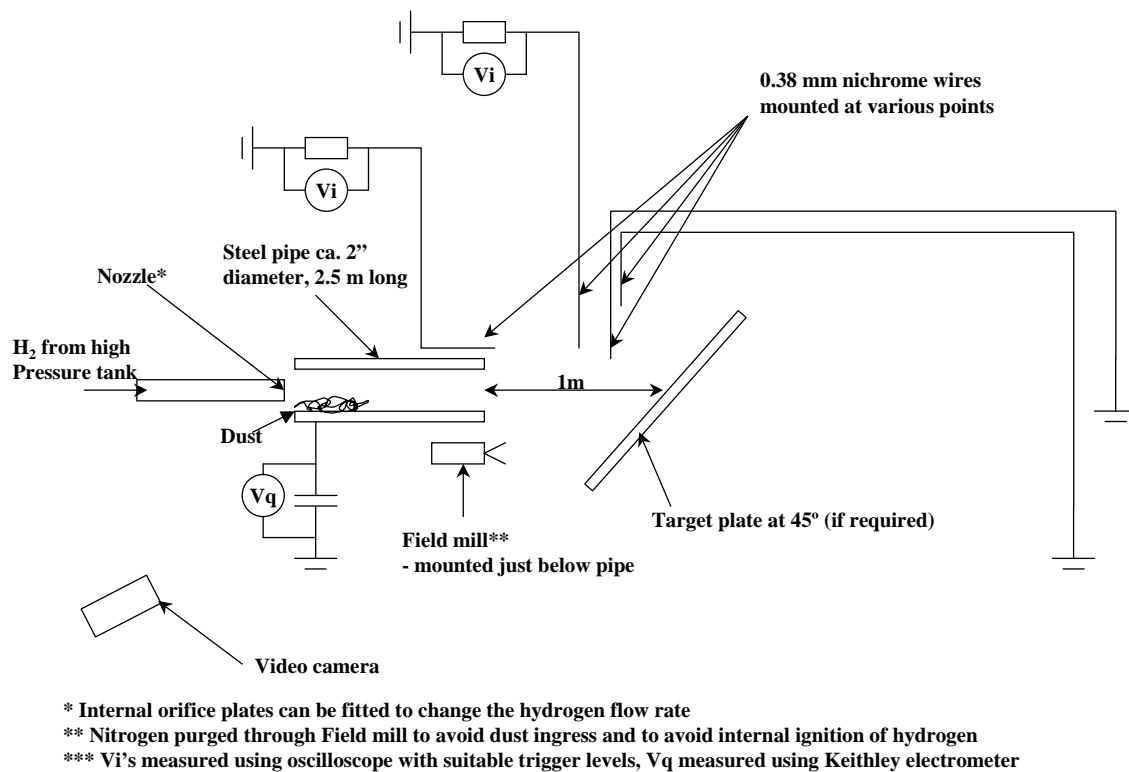
The electrostatic field was measured during horizontal high pressure hydrogen releases into air both for pure hydrogen and for hydrogen with dust added.

An electrostatic field mill was positioned just below a stainless steel pipe, which had a 2" nominal bore and length of 2.5 m, to measure the electric field in the direction of the H<sub>2</sub> release. Fine wires (0.38 mm diameter nichrome) were placed at various positions in an attempt to promote corona discharges.

H<sub>2</sub> was released from the high-pressure H<sub>2</sub> facility, for a duration of four seconds from a starting nominal pressure of 200 barg (i.e. typical pressure for commercially available cylinders). The released gas was directed into a stainless steel pipe with 2-inch nominal bore and length of 2.5 m. In some cases, powder was placed inside the pipe to be dispersed

by the H<sub>2</sub> flow in order to increase the electrostatic effects. Two different dusts were used: a plastic powder consisting of coarse (1-2 mm) and fine particles of a few hundred microns, and a fine (ca. 10 µm) iron (III) oxide powder (rust).

The amount of charge on the dispersed dust was inferred by measuring the charge (of opposite polarity) transferred to the pipe. The charge was measured using two methods: a JCI178 charge meter for charge of <20 µC, and by measuring the potential on a 1 µF capacitor attached to the pipe for charges > 20 µC. No corona discharges sufficient to ignite hydrogen air mixtures were measured with dust dispersions of up to 160g in hydrogen releases from 200 bar storage. A schematic of the experimental arrangement is shown in figure 5.



**Figure 5: Schematic of the experimental arrangement used for investigating corona discharges during high-pressure H<sub>2</sub> releases.**

## 5 Conclusions

For the first phase of experimental programme, the following conclusions were made for diffusion ignition tests involving bursting discs and pipe work downstream of a boundary failure.

- No ignitions were observed below a cavity pressure of 8.8 barg.
- Ignitions always occurred above a cavity pressure of 27 barg.
- Releases of H<sub>2</sub> to atmosphere with no restrictive and reflective downstream geometry present resulted in no ignitions up to a burst pressure of 831 bar.

- Tests which included reflective downstream geometry always produced ignitions at disc burst pressures above 260 bar.
- The lowest burst pressure for ignition was 35.5 bar with a reflective geometry configuration and vent area of 17.3 mm<sup>2</sup> and soft ductile bursting discs were less likely to produce an ignition than a non-ductile disk.
- Whether ignition occurs appears to be related to the rise time of the pressure pulse produced by the disc failing. The rise time is related to the burst pressure and also the extent of downstream constriction after the bursting disc.
- When H<sub>2</sub> leaked into cavity before a burst, no ignitions occurred.
- No ignitions were observed when weakened pipes were used for open geometry tests at pressures of up to 417 bar.

In the second phase of experimental programme the following conclusions for tests involving corona discharges were attained.

- H<sub>2</sub>-air mixtures were ignited by corona discharges generated by raising a fine wire to a high potential.
- Ignitions occurred with positive corona discharges at a current of approximately +150  $\mu$ A and potential of +20kV for a wire point and plate electrode system with a 30mm separation.
- No ignition was observed with negative currents of up to approximately -290  $\mu$ A and potential of -28 kV.
- Dispersion of dusts up to 160g with H<sub>2</sub> released from 200 barg did not appear to generate hazardous electric fields, in terms of incendive corona discharges.
- Ignition can be produced by corona discharges of the type that might be produced where fine points may be at a potential of several tens of kV above the surrounding atmosphere. Such situations could be expected at the top of tall vent stacks (Bradburn, and McBrien 1983, ICI 1977, Astbury 2007), tens of metres above ground, in the presence of large atmospheric electric fields (e.g. during snow fall). Such incendive corona discharges appear to be unlikely in horizontal releases of H<sub>2</sub> close to ground level.

### Acknowledgements

This publication and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

### References

- [1] Astbury, G. R., and S. J. Hawksworth, 2005, Spontaneous ignition of hydrogen leaks: A review of postulated mechanisms: Proceedings of International Conference on Hydrogen Safety.
- [2] Astbury, G. R., 2007. Venting of low pressure hydrogen gas - A critique of the literature. Process safety and environmental protection, 85, 289-304.
- [3] Bradburn, F., and D. McBrien, 1983, Discussion of Hydrogen Vent Ignitions, Technical Visit report No. TVR194.

- [4] Dryer, F. L., M. Chaos, Z. Zhao, J. N. Stein, J. Y. Alpert, and C. J. Homer, 2007, Spontaneous Ignition of Pressurized Releases of Hydrogen and Natural Gas into Air: *Combustion Science and Technology*, v. 179, p. 663-694.
- [5] Golub, V. V., T. V. Bazhenova, M. V. Bragin, M. F. Ivanov, and V. V. Volodin, 2006, Hydrogen Auto-Ignition During Accidental or Technical Opening of High Pressure Tank: *Proceedings of the 6th International Symposium on Hazards, Prevention and Mitigation of Industrial Explosions*.
- [6] Gummer, J., and S. H. Hawksworth, 2007, Spontaneous Ignition of Hydrogen: Literature Review, Health and Safety Laboratory.
- [7] ICI, 1977, Thunderclouds, Lightning, Corona Discharges and the Ignition of Hydrogen Vents by Static, ICI Mond Division Report No. MD18641.