VI.6 Cooperative Industry-Government Hydrogen Safety Study (New Project)

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Objectives

- To better understand the hazards and risks associated with retailing hydrogen as a fuel.
- To effectively manage risks associated with hydrogen in the retail environment.

Technical Barriers

This project addresses the following technical barriers from the Safety section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A Limited Historical Database for Components
- B. Access to Industry Proprietary Data
- C. Validation of Historical Data
- D. Technical and Scientific Understanding of Systems Limits the Value of Protocols
- E. Obtaining Industry Input and Consensus
- K. Existing Data are Proprietary or Not Easily Accessible
- L. Expense of Data Collection and Maintenance
- M. Quality of Data

Approach

- The study is planned to include four series of experiments.
- Each series is designed to investigate the potential explosion hazard from pressurized hydrogen leaks.
- The study is progressive and as such, the first series builds on earlier work and will be completely defined from the outset.
- The remainder of the project is defined in outline only, with final details to be discussed in the steering committee on the basis of the preceding work

Accomplishments

- Project has not commenced.

Future Directions

- The first series of experiments are designed to establish worst-case overpressures in a well defined, and well understood, repeated pipe congestion geometry. This will be a larger scale version of work already

Figure 1. Testing Facility in Buxton, UK

Figure 2. Testing Array

Figure 3. Testing Sensors with Igniter

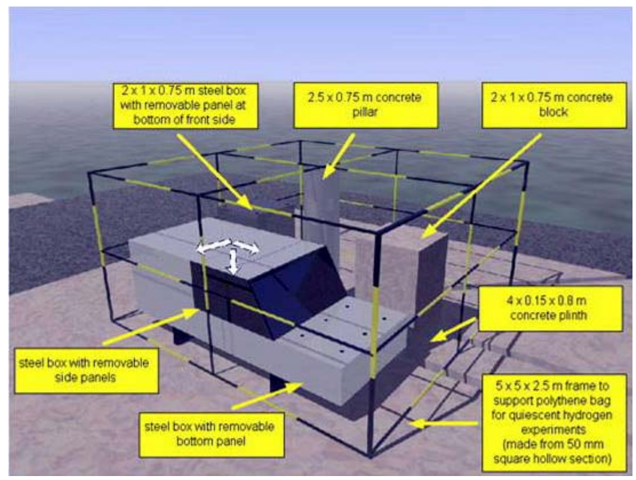

Figure 4. Conceptualization of Congestion Configurations

carried out on hydrogen and provides a link with our wealth of data on hydrocarbons at this scale and geometry. This will be an unconfined congested region 3m x 3m x 2m high, on a 5m square base. The flammable gas cloud will fill the congested region; it will be premixed, homogeneous and quiescent, and retained by polythene sheets. One commissioning test will be carried out with ethylene to retain the link with the past. Ignition will be in the center of the cloud at the base. The parameters to be studied in the first series will be the degree of congestion and the hydrogen concentration. Two degrees of congestion will be studied at three hydrogen concentrations. One repeat test will be carried out, making a total of 8 tests in this series. We have a model that should predict the results. The results will enable others to develop and/or test models of varying degrees of sophistication that will be needed for future hazard and risk studies. Photographs of the facility are shown in Figures 1-3. An overall diagram of the relationship of the various tests is shown in Figure 4.

- The second series of experiments are designed to explore more realistic environments. These will also be unconfined but with a larger footprint of 5m x 5m. This will have the flexibility to be sparsely populated with a variety of box obstacles to represent a dispenser and vehicle, a bank of storage cylinders, an electrolyzer unit, or a compressor unit. The maximum height of the obstacles will be 2.5m and the first experiments will be with premixed, homogeneous and quiescent clouds, 5m x 5m x 2.5m high, retained by polythene sheets as before. The parameters to be studied will be the obstacle arrangement, the hydrogen concentration, and ignition location, including ignition inside some of the obstacles. We propose studying two obstacle layouts, at three hydrogen concentrations, and three ignition locations, a total of 18 tests. A further set of experiments will be carried out with jet releases of hydrogen, but limited to a maximum pressure of 150 bar available from conventional cylinders. The parameters to be studied will be as for the premixed case but also different leak conditions and locations. It is envisaged that three sizes of the leaks will be tested, from holes between 1-10 millimeters in diameter, and that the storage pressure will be allowed to decay, much as would happen in practice. We propose studying two obstacle layouts, three leak sizes, three ignition locations, and two types of ignition (continuous and delayed), a total of 36 tests.

- The third series of experiments will progressively add confining walls 5m high, with and without some of the box obstacles used in the second series. For example, with only one wall and a box obstacle the configuration serves as a representation of a large vehicle alongside a fuel dispenser. The walls will be constructed from massive interlocking concrete blocks. The configurations to be studied in the third series (obstacles, ignition location, premixed or jet release) will depend on the outcome of the second series of tests. The experiments may progress to four walls with an open top, some obstacles, and a cloud that only partly fills the total volume, but this will depend very much on the outcome of the earlier work. For example if detonation were to occur in any experiments we would not explore more onerous conditions. We have planned for a total of 12 tests in this series. All of the experiments described above will be carried out by the Health & Safety Laboratory at their Buxton UK test site.
- The fourth series of experiments will study ultra-high-pressure leaks and will be carried out by Powertech Labs, Inc. in Surrey, British Columbia, Canada. Two of the obstacle arrangements explored in the second series (with 150 bar leaks) will be repeated at pressures up to 700 bar. By this stage we will have a good idea of what to expect, but whatever that is, this series is considered essential to demonstrate that we have covered the full range of possibilities.

Introduction

To better understand the hazards and risks associated with retailing hydrogen as a fuel, Shell Hydrogen has sponsored studies carried out by Shell Global Solutions. Hydrogen's wide limits of flammability, low ignition energy, very high burning velocity and susceptibility to detonate all suggest that hydrogen presents more of a safety challenge than hydrocarbon fuels. Of course, these unique features of hydrogen have been managed on an industrial scale for many years. However, in a retail environment, industrial safety measures would be inappropriate and the close proximity of the public unavoidable.

A jet release in a confined or congested area can create an explosion hazard. In this context this may be a deflagration explosion, or in the worst case, a more damaging detonation explosion. Confinement is best avoided, but congestion caused by obstacles such as pipes, controls, and objects, is often unavoidable. When a high-pressure jet interacts with a congested region, the obstacles enhance turbulence and mixing within the jet. If ignition occurs the obstacles induce even more turbulence as the flame front drives unburned mixture ahead of it, through the obstacles. The rate of combustion is increased by the turbulence in a positive feedback loop and ultimately determines the overpressure produced by the explosion. In extreme cases, this mechanism can result in the transition to detonation, where the overpressure generated is much higher.

Approach

The explosion hazard from a jet release can be expected to increase with system pressure. To date, Shell has studied releases at pressures up to 150 bar, limited by commercially-available hydrogen cylinders. In practice, hydrogen storage systems will operate at ultra-high-pressures, up to 700 bar. By contrast with jet fire hazards, realistic explosion hazards are far more difficult to predict and to extrapolate to higher release pressures. DOE, in cooperation with Shell Hydrogen, ExxonMobil Research and Engineering, BP Gas Marketing, and HSL, will conduct a series of experiments to understand the potential explosion hazard so that it can then be effectively managed in the retail environment.

Results

Shell has previously studied pre-mixed hydrogen/air explosions, in congested regions, at small-scale (~1m^3). Shell also studied un-ignited and ignited jet releases in the open up to 150 bar. The results have been used to validate predictive models for dispersing plumes and jet fires. Further, Shell carried out some tests with jet releases into a congested and partially confined region, again at small-scale (~1m^3). These data serve as the foundation for the current planned study.

The congested region contained an array of pipe obstacles, and a spark ignited the jets, either immediately or after steady state conditions had been established. The results showed that the resulting deflagration explosion generated significant overpressures, albeit in an artificial, congested and partially confined region. Transition to detonation has not been observed in any of the previous Shell hydrogen tests; however these have all been at a small-scale and one cannot exclude the possibility that slightly larger clouds will not detonate. Indeed, other workers have shown that pre-mixed hydrogen/air clouds will detonate at ~5m^3 scale, with a very high degree of congestion. We believe that our work with jet releases of hydrogen into congested regions is both unique, and closer to a realistic incident scenario.

Conclusions

- Experimental work has not commenced.