VI.4 Codes and Standards Analysis

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Objectives

- Task A - Determine how close an ignition source must be to a hydrogen leak to cause ignition of the leak. Compare that distance to the positions of 4% hydrogen in the plume created by the leak.
- Task B - Determine characteristics of ignition of lean mixtures of hydrogen and air flowing in ducts. Determine the effects of the Reynolds number and any other important parameters.
- Task C - Determine the grounding needs of electrolyzers or fuel cells for use in residential garages.
- Task D - Determine hazards produced by electrical shorts in conjunction with portable fuel cells.

Technical Barriers

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

- N. Lack of Technical Data to Revise NFPA 55 Standard (for underground and aboveground storage)
- P. Current Large Footprint Requirements for Hydrogen Fueling Stations

Approach

- Measure hydrogen concentrations in the quasi-steady state plume created by leaking hydrogen.
- Use Fluent, computational fluid dynamics (CFD) software, to model the plume created by leaking hydrogen.
- Conduct ignition tests at locations in the plume created by leaking hydrogen and in quiescent homogeneous mixtures.
- Conduct ignitability tests on flowing homogeneous mixtures of hydrogen and air in a duct.
- Compare ignitability results to real-world ignition sources.
- Survey manufacturers of electrolyzers and fuel cells to determine grounding needs.
- Survey manufacturers of portable fuel cells to determine what hazards may be produced by electrical shorts.

Accomplishments

- Demonstrated 566 liters/min (20 standard cubic feet per minute [SCFM]) hydrogen leaks could not be ignited at locations containing 6% hydrogen or less.
- Demonstrated the maximum horizontal distance, from a 566 liters/min (20 SCFM) horizontal hydrogen leak at Mach=0.10, at which the leak could be ignited was 57 inches which was significantly closer than the location that contained 4% hydrogen (77 inches).
- Demonstrated the maximum horizontal distance, from a 566 liters/min (20 SCFM) horizontal hydrogen leak at Mach=0.20, at which the leak could be ignited was 47 inches which was significantly closer than the location that contained 4% hydrogen (88 inches).
- Demonstrated the lean limit of combustion is a much stronger function of electrode gap size than of Reynolds number.
- Collected data indicating that if electrode gap size is held constant a higher Reynolds number inhibits ignition for low hydrogen concentrations (less than 8%) but promotes ignition at higher concentrations.
- Demonstrated, electrical appliances produce electric arcs that do not ignite some lean hydrogen air mixtures.
- A toggle light switch was unable to ignite 10% hydrogen.
- An electric shop vac motor required 6% hydrogen to produce ignition.
- A pull chain light switch required 8% hydrogen to produce ignition.
- A garage door opener was unable to ignite 10% hydrogen.
- The survey of fuel cells showed an independent fuel cell operating in a garage in conjunction with the house current should be grounded to prevent any voltage potential between house ground and fuel cell ground.
- The survey of portable fuel cells showed all have short protection from the manufacturer.

Future Directions

The present contract is finished, but two remaining issues are as follows:

- Conduct ignition tests of hydrogen leaks at higher flow rates to determine if the inability to ignite the leak at a location of 6% hydrogen concentration extends to high flow rates.
- Investigate creation of standard similar in concept to UL1500, Ignition Protection Test for Marine Products. This is a performance standard which aids in the prevention of fires in marine environments that are not Class 1 Div 2. It appears that a standard similar in concept could be created which deals with protection from the ignition of hydrogen in other structures that utilize hydrogen but are not Class 1 Div 2. It is envisioned that since different appliances inherently showed different propensities to ignite hydrogen air mixtures, having a means to certify this behavior could improve safety and allow for reduced insurance premiums.

Introduction

Hydrogen is commonly treated as an easily ignited fuel in concentrations as low as 4%. This is supported by quoting the lean flammability limit of hydrogen as 4%, the minimum ignition energy for hydrogen as 0.02 millijoules and the minimum parallel plate quench distance for hydrogen as 0.065 cm (0.026 inches). While each of these statements is true individually, the last two only apply at near stoichiometric fuel-air ratios of hydrogen and not 4% hydrogen in air (Table 1). In particular the parallel plate quench distance for 4% hydrogen concentrations is well over an order of magnitude larger than at near stoichiometric concentrations. The parallel plate quench distance is the minimum distance between two parallel solid surfaces through which a hydrogen flame at a given concentration can

Table 1. Values for Parallel Plate Quenching Distance and Minimum Ignition Energy for Lean Mixtures of Hydrogen and Air

Hydrogen concentration in air	Parallel plate quenching distance cm (in.)	Minimum ignition energy (mJ)
4%	1.32 (0.52)	10.0
5%	0.69 (0.27)	3.0
6%	0.39 (0.15)	1.0
7%	0.28 (0.11)	0.56
8%	0.22 (0.09)	0.33
9%	0.18 (0.07)	0.21
10%	0.16 (0.06)	0.15

pass. Since electric arcs exist between two solid surfaces (electrodes), successful ignition may require more than 4% hydrogen for small gaps. This together with the slow flame speeds of lean hydrogen air mixtures means that hydrogen leaks and homogeneous flowing mixtures of hydrogen air are not as easily ignited as is commonly thought. This work shows how taking the real world behavior of lean hydrogen air mixtures into account could affect the development of codes and standards for separation distances and electrical appliance requirements.

Approach

Task A - The following approach was used to determine the maximum horizontal distance at which a horizontal hydrogen leak can be ignited. A device was constructed to produce a measured 566 liters/min (20 SCFM) leak horizontally through the center of an aluminum clad eight-foot by eight-foot wall. The pure hydrogen leak was allowed to continue until it produced a relatively steady-state plume. The concentration of hydrogen was measured at various locations and compared to a computational fluid dynamics model of the plume. Electric arcs were utilized at various locations to determine those locations that would produce full ignition of the leak. The experimentally determined location, farthest from the wall, at which the leak could be ignited, was then compared to the computational and experimentally determined location of 4% hydrogen-air mixture in the plume (Figure 1).

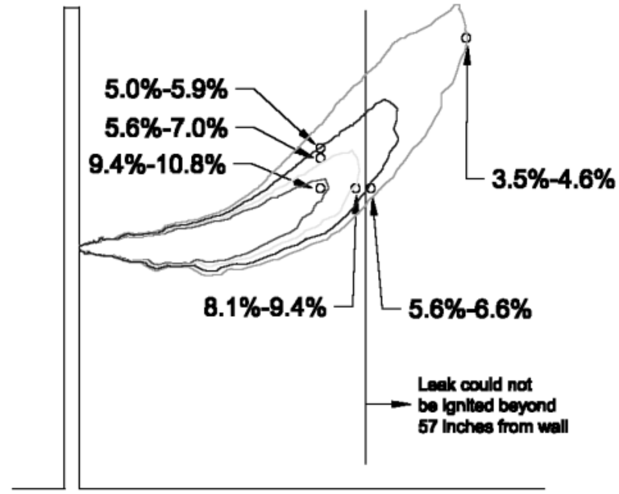

Figure 1. CFD Model of Hydrogen Plume with Experimental Data

Task B - Experiments to determine what the lean limit of combustion was for lean homogeneous hydrogen-air mixtures flowing in ducts were conducted. Homogeneous mixtures of hydrogen and air were passed down a 6.1 m (20 foot) duct and ignition was attempted at various flow rates (different Reynolds numbers) and with varied electrode gap sizes and spark energies.

Task C - A survey of manufacturers was conducted to determine grounding needs of electrolyzers and fuel cells that might be used in garages.

Task D - A survey of manufacturers was conducted to determine the potential hazards that may occur due to electric shorts when utilizing a portable fuel cell.

Results

Task A - Hydrogen at a flow rate of 566 l/min (20 SCFM) was passed perpendicularly through the center of an eight-foot by eight-foot vertical wall creating a hydrogen plume. Ignition of the leak was attempted with an electric arc in the plume beginning after either 30 seconds or 45 seconds of flow. This length of time allowed a stable plume to be created. The position of a successful ignition of the plume was compared to the position of 4% hydrogen in the plume. A CFD model of the plume was created and the model results were superimposed over the experimental results (Figure 2).

The primary findings of Task A were that the distance at which a hydrogen leak can be ignited is much closer to the leak than the distance at which the leak creates a concentration of 4% hydrogen. A leak at Mach = 0.1 could not be ignited at a distance 75% of the distance to 4% hydrogen concentration and a leak at Mach = 0.2 could not be ignited at 55% of the distance to 4% hydrogen concentration.

Communications with Chris Moen of Sandia National Labs indicated that this is consistent with the additional rapid mixing of gases that occurs as hydrogen leak velocity is increased. All the leaks required ignition at a location of approximately 10% hydrogen to ignite the full leak plume with one or two attempts. Ignition of the entire plume at locations with 10% to 6% hydrogen concentrations was probabilistic, requiring up to hundreds of arc strikes. The probability of igniting the leak, in the 10% to 6% zone, decreased with increasing leak velocity.

These results assist in the determination of whether to use 6%, 4%, or 2% hydrogen concentration to define the jet flammability envelope from gaseous storage tank leaks when developing separation distances. This work indicates the choice of 6% hydrogen concentration to define the point at which the leak can be ignited is the more reasonable choice.

Task B - A 9.7 cm (3.8 inch) diameter 6.1 m (20 foot) long duct was constructed to allow measured homogeneous mixtures of hydrogen and air to pass an ignition source. Tests were conducted at two flows, 850 l/m (30 SCFM) and 1416 l/m (50 SCFM), which represent the range of design flow rates used for air-conditioning ducts. More than 1,416 l/m (50 SCFM) would increase in the air pump requirements to an excessive level and less than 850 l/m (30 SCFM) increases duct cost to excessive levels. Tests were conducted with ignition 10.2 mm (0.40 inches) away from the wall and ignition at the wall. Tests were conducted with a range of electrode gaps of 0.25 mm (0.010 inches), 0.38 mm (0.015 inches), 0.51 mm (0.020 inches), 0.76 mm (0.030 inches), and 1.5 mm (0.060 inches). Typical results are

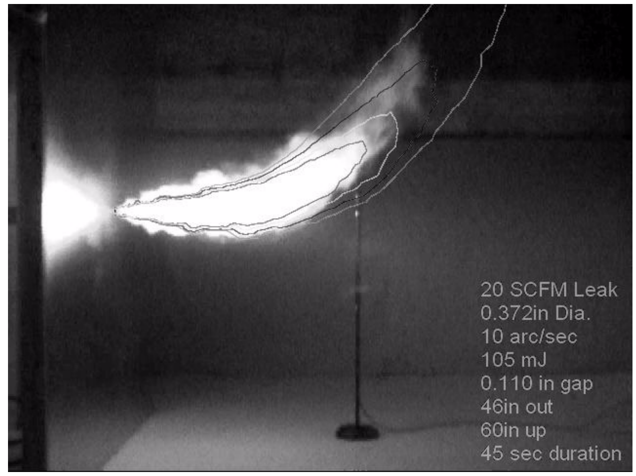

Figure 2. Hydrogen Leak Ignition Superimposed with CFD Modeling Results

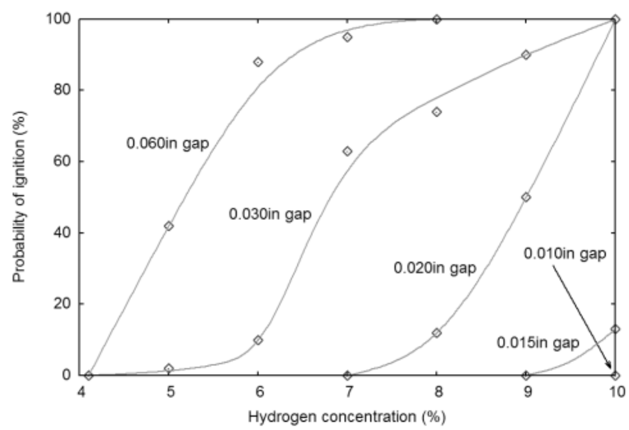

Figure 3. Experimentally Determined Probability of Ignition versus Hydrogen Concentration for Various Spark Gaps Sizes, 0.4 inches from Wall of Duct

shown in Figure 3. Figure 3 shows the results for attempted ignition at a site 10.2 mm (0.40 inches) away from the wall of the duct. It can be seen that the probability of ignition is a strong function of electrode gap size. This behavior is consistent with the initial flame kernel being quenched by the electrodes. Figure 4 is a typical plot of ignition energy versus quenching distance for electric arcs[1,2,3]. Figure 4 shows that the ignition energy required for flame propagation increases if the electrode gap is too large (right hand side) or too small (left hand side). When an electric arc discharges in a combustible mixture a small flame

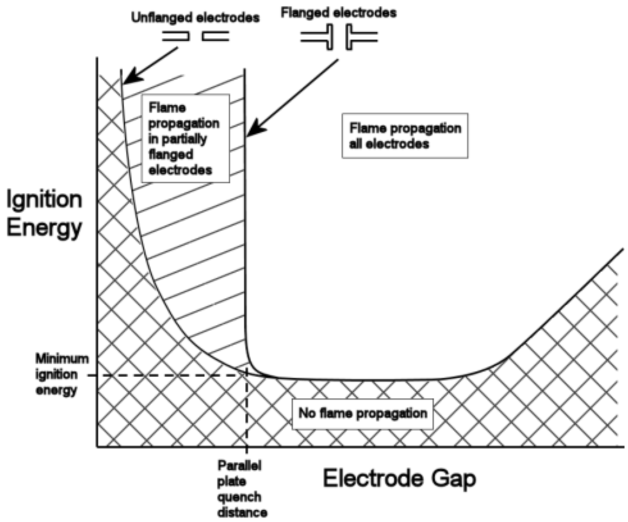

Figure 4. Behavior of Flame Propagation as a Function of Ignition Energy, Electrode Gap Size and Gap Geometry

kernel is created. If the chemical heat release in the flame kernel is sufficiently greater than the heat lost, the flame can propagate. Heat is lost from the flame kernel either to the electrodes or to the surrounding unburned gas. If the electrode gap is less than the parallel plate quenching distance, the majority of the heat loss is to the electrodes and would require an increase in the ignition energy to create a propagating flame. It can be seen that the increase in ignition energy is a function of the shape of the electrodes. In the case of flanged electrodes the energy must be increased many orders of magnitude to allow flame propagation out of the gap. The results of the testing showed the probability of ignition to be a strong function of gap size and a small function of Reynolds number and a still smaller function of ignition energy. The ignition energies tested were at least an order of magnitude greater than the minimum ignition energy for the hydrogen concentration in the test.

The electrode gaps used during this testing were felt to represent the range of electrode gaps created by common electrical appliances. The assumption that these represent common electrode gaps distances was tested by also attempting ignition with four common electrical appliances (Figure 5). The same behavior was observed.

Figure 5. Electrical Appliance Test Apparatus

These results (see Accomplishments bullets 7-10) indicate that electrical appliances are not as likely to ignite hydrogen air mixtures as commonly thought.

Task C - A survey of manufacturers was conducted to determine grounding needs of electrolyzers and fuel cells that might be used in garages. It was found that fuel cells should share a common ground with the house circuit. This probably should be handled during certification of the appliance.

Task D - A survey of manufacturers was conducted to determine the potential hazards that may occur due to electric shorts when utilizing a portable fuel cell. It was found that all the manufacturers include short protection on their units.

Conclusions

- Though further verification is needed, 6% hydrogen concentration by volume is probably the appropriate level for determination of horizontal jet flammability envelope.
- It would be useful if a classification service such as Underwriter's Lab developed tests to determine what concentration of hydrogen a given electrical appliance can ignite.
- Fuel cells used for auxiliary power in homes should be grounded to the home circuit. This should probably be handled during the process of certifying fuel cell units.

- Portable fuel cells presently have short protections provided by the manufacturers. Can be addressed during the process of certifying portable fuel cells.

References

1. Bernard Lewis and Guenther von Elbe, "Combustion, Flames and Explosions of Gases", Academic Press Inc., 1987.

2. Roger A. Strehlow, "Fundamentals of Combustion", International Textbook Company, 1968.

3. Gary L. Borman and Kenneth W. Ragland, "Combustion Engineering", McGraw Hill, 1998.

FY 2004 Publications/Presentations

1. DOE Office of Hydrogen, Fuel Cells, and Infrastructure Technologies Annual Program Review for FY04 Presentation.

2. Hydrogen and Fuel Cells Summit VIII Presentation.

3. DOE Office of Hydrogen, Fuel Cells, and Infrastructure Technologies Annual Program Review for FY04 Report.