Discussion of lessons learned from a hydrogen release

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Abstract

Just in-line with any emerging alternative transportation fuel incidents involving hydrogen used as transportation fuel are learning opportunities for this new and growing industry. This paper includes discussion of many topics in hydrogen safety surrounding the installation, operation and maintenance of commercial hydrogen stations or compression, storage, and dispensing systems

Introduction

Hydrogen use as fuel for consumer fuel cell electric vehicles continues to increase, be it lift truck, passenger vehicle or transit bus. Numerous references provide this background. L. Klebanoff et al. provide an updated synopsis of the advantages of hydrogen as a transportation fuel [1].

Hydrogen has long been considered a potential transportation fuel. For nearly as long, research has investigated the safety of hydrogen in transportation applications. Several authors provide insight into incidents related to hydrogen when used as a fuel. P.M. Ordin reviewed hydrogen accidents and incidents at NASA [2]. T.L. Bowen reviews an incident summary as part of a hazard assessment for military applications [3]. Cadwallader and Herring review safety issues and past experiences for all applications [4]. More recently two databases, HIAD, presented by Galassi et al. [5] and H2incidents.org presented by Weiner et al. [6] now provide a living history of incidents easily accessed online focused on the European Union and the United States respectively.

This paper will provide some general lessons learned from an unintended hydrogen release from a publicly accessible hydrogen fueling station.

The safety culture in hydrogen fuel continues to evolve. The culture surrounding fueling infrastructure is the offspring of two established industries: industrial gas and retail fuel. These two industries possess robust but dissimilar safety cultures and best practices with substantial experience. Each has evolved over many decades with important lessons learned along the way. Industrial gas safety culture focuses on safely handling a wide variety of products including highly hazardous chemicals in unique and sometimes technical applications in tightly controlled settings. Retail fuel safety culture endeavors to simplify to the maximum extent feasible the technical aspects of providing a limited number of chemicals to any member of the general public..

The hydrogen fuel industry must appropriately balance and adapt the rigor of industrial gas process safety with the simplified approaches of retail fuel. This paper makes some recommendations based on industrial gas best practices, such as process safety management and change management. This will cause some initial concern from the hydrogen infrastructure community who envision that the safety culture must emulate retail fuel. The authors hopes the recommendations set forth in this paper are seen as informal suggestions to consider rather than strict requirements.

Lesson 1 - Stakeholder Identification and Involvement

Hydrogen compression, storage and dispensing systems require substantial and lengthy planning efforts. The station itself requires planning the installation of traditional industrial gas processing equipment (most of the station hardware), specific hydrogen fuel transfer equipment and architectural embellishments such as visual barriers, landscaping, sound dampening and other compliance to local aesthetics requirements. Through repetition this portion of the process is becoming more commonplace. Aside from detailed architectural, civil and mechanical engineering designs, the identification and interaction with all project stakeholders, both internal and external to the project is a critical early activity.

Many station equipment installers have identified the additional effort spent interacting with local and regional authorities as an unexpected challenge and financial burden to their projects [7]. For most local jurisdictions the concept of hydrogen as a fuel is rather new. It is important to note for many installations in the United States the local officials have much more authority than many other places in the world. For example there are over 30,000 individual fire departments in the US, each having some level of authority to approve projects [8]. A further complication arises from regional authorities such as county and state officials with respect to public health, weights and measures and other public safety officials. Each of these entities will likely present their own perspective on the project. Early on, affected officials should, at a minimum be invited to both an educational effort on “an introduction to hydrogen” as well as a briefing on the specific project plans including the benefits for their community.

Any project briefing activity should be well documented, with particular attention paid to individuals in leadership positions in potential approval authorities. Often, regional and state officials may see their role as reactionary (only take actions after an incident or complaint). This is not the best position for them to take. To the best extent possible, these individuals should be identified, invited to attend educational sessions and offered multiple opportunities to receive project updates. Non-participation by these officials should be documented, tactfully, but accordingly such that in the case of an incident the conversation will not begin with, “I didn’t even know this facility existed.”

Hydrogen fuel stations must be considered to be unique. This will continue to be the case for many years to come. Those engineers and designers with industrial gas experience may be caught off guard by local permitting requirements for retail applications, such as aesthetics, landscaping or public art. Many components of a hydrogen storage system use established industrial gas codes and standards that specify safety distances. Meanwhile, however it may often be equally important that the facility look safe and refrain from looking "too industrial". Seasoned retail fuel station engineers and designers may feel constrained by the industrial gas requirements particularly with regard to storage. Many existing service stations will not accommodate hydrogen storage since there may be too little space to meet both current safety distances and aesthetic requirements. Waivers and exemptions to the local requirements may be the only option for siting hydrogen fuel in early market retail sites. These waivers and exemptions are often at the discretion of the local authority making identification and inclusion of those specific stakeholders critical to early elements of the planning phase.

Lesson 2 – Technical Responsibility or "Process Ownership"

A key tenant of process safety is identification of technical responsibility and decision authority for a process or system, a "process owner." The DOE Handbook on Process Safety Management (PSM) states, "The effectiveness of PSM programs depends on the employees' sense of ownership and accountability."[9] A technically competent process owner must retain up-to-date knowledge of the process and possess sufficient operational authority to manage process changes.

Identification of the technical process owner should be established at the very beginning of the project. However, it is particularly important during a transition of technical responsibility such as: construction transitioning to commissioning, commissioning to operation and instances when the process is returned to service after maintenance. All of these require a smooth transition of process ownership between both the specific individuals as well as their respective business organizations. The use of a straightforward but simple communication protocol for such transitions should be established and followed. The transition should also include relevant inspections or system tests with accompanied documentation.

The planning phase of the project is the appropriate time to draft such communication protocols, with the understanding that such protocols are permanent, living documents subject to periodic change as the process matures.

Lesson 3 - Change Management [10]

Change management is another process safety concept that works in tandem with technical ownership. The management of change refers to the process and the form of documentation that will be used to control updates, upgrades, maintenance or other changes. The process often includes approvals ensuring that all project partners or each shift supervisor understands and assumes responsibility for the change. Early in the project planning, a change management process should be established that ensures agreement to changes by appropriate internal and external stakeholders. This change management should be the responsibility of the process owner. Ensuring that change management responsibility passes smoothly from a planning phase owner to construction phase owner and finally to the operations phase owner is critical to reducing the effects of system malfunctions or failures.

Change management is more than a documentation exercise or liability driven necessity. Change management is effective, methodical communication. This communication of specific process details or necessary changes are best handled by technically competent “process owners.”

Lesson 4 - Quality Control

A process of quality control should be the responsibility of all participants. Quality control isn’t intended to suggest quality processes such as ISO 9001, rather an intentional effort by project participants to review detailed information of select equipment to ensure correct components are selected and installed. Particular attention should be given to those components with known significant safety vulnerability. Vulnerable components could be identified in the hazard assessment. For example, components in those systems where a single point failure may result in a significant release of hydrogen should be considered vulnerable, and worthy of detailed quality inspections. The results of the hazard assessment should be provided to all process owners to facilitate independent quality control activities based on that process owner’s safety bias. In turn, process owners should assert their responsibility, again particularly in transition of “ownership” to inspect detailed information with specific attention to these vulnerabilities.

The level of detail for individual component inspection varies; however, material compatibility is a particular concern for hydrogen systems. Material compatibility must be considered as a correct pairing of material selection and appropriate design under the expected service conditions.

Hydrogen effects in materials such as hydrogen embrittlement occur in many commonly used materials. These effects present a safety concern only when such material effects are considered with the anticipated stress and service environment. Material compatibility alone is a poor material selection criteria. For instance, commonly used high-pressure hydrogen cylinders are made of 4130X, a material with relatively low hydrogen resistance similar to 4140 shown in Fig 1. It is the design and manufacture of these cylinders, particularly tight control on the material strength and corresponding design requirements such as wall thickness prescribed in the associated regulations [11] that ensures safety.

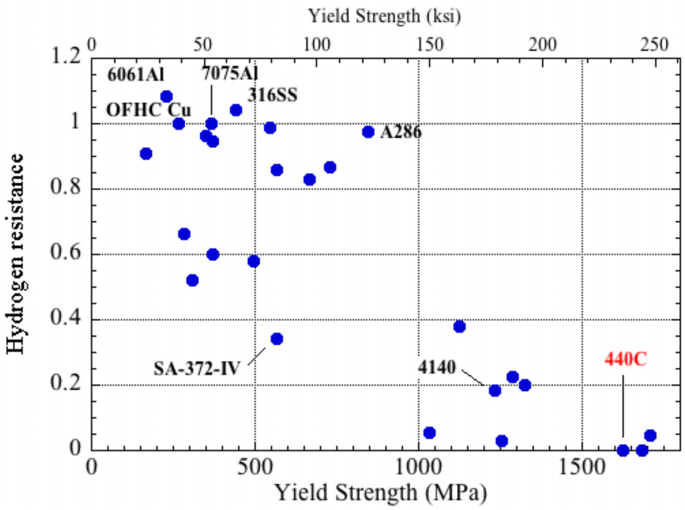

Figure 1 Hydrogen susceptibility as a function of yield strength for a range of structural alloys. The susceptibility is the ratio of reduction of area in a tensile test measurement in gaseous hydrogen at pressure of 69MPa relative to helium at the same pressure.[12]

Another notable caution with regard to materials compatibility is the fact that there is a relative lack of available components specifically certified for hydrogen service. This lack of appropriate components to select from can result in confusion as there are abundant available components for other flammable gases, particularly for compressed natural gas (CNG). This creates opportunities for potential mistakes in material selection and unsafe substitution. Such mistakes could lead to unpredicted failures. Detailed inspection of components, particularly those contributing to significant safety vulnerabilities is a worthwhile countermeasure to protect this industry.

Lesson 5 - Training

Fueling infrastructure facilities should consider as standard operating procedure, the offering of safety training to local first responders. This is an essential element as part of a broader outreach to the general public. It is important that training for first responders include drills either as "table-top" exercises or full training evolutions. Particular attention should be focused on ensuring participation by line and command officers of local and neighboring jurisdictions as these are the individuals who will likely serve as incident commanders in the event of an unplanned significant release.

Explaining new technology to stakeholders is often tedious and distracting for the construction phase process owner. When available, training and outreach resources specific to the hydrogen industry, such as the California Fuel Cell Partnership's first responder course or similar outreach efforts should be used. These general training programs are good at familiarizing stakeholders with the properties of hydrogen, common equipment at fueling stations and presenting generic incident scenarios. In addition these groups are already working to establish regional, state or broader programs with the first responder community. This broader connection can form a much needed context for the local first responder groups, public officials and approval authorities (Lesson 1.)

In addition to general safety program training, facility owners should also strongly encourage participation by local and regional authorities in the table-top or full scale training evolutions. These exercises should be specific to the actual site as opposed to a generic fueling station. This site-specific focus will provide opportunities to explore unique challenges presented by the location of equipment present, relative to the immediate geographical surroundings and availability of resources and existing facility emergency procedures.

There is a logical fallacy prevalent in the hydrogen community with regard to the recommendation on training. *If hydrogen fueling systems are "commercially ready" then why do they require so much extra effort, specifically training? We don't do this for industrial hydrogen installations?* This fallacy affects both the process owner as well as the authorities having jurisdiction. The process owner may feel that required training could promote undue concern of an incident or additional delays in permitting. The authorities may see general and site-specific training as an over commitment of their time to a particular installation or doubt the readiness of the technology. Both stakeholders must understand the difference between the technology being 'ready' for general public use and the technology being "commonplace" or well understood. The technology is 'ready', it will not be "commonplace" for many years. .

Summary

Hydrogen use in commercial and retail settings will generate incidents. Adoption of less stringent versions of industrial gas safety practices, such as process ownership and change management, to the retail hydrogen application is worth the additional effort. Thorough appreciation of shortcomings and potential pitfalls in the system supply chain including the effect of hydrogen in materials must be considered. Finally stakeholders should resist the temptation to minimize training out of fear that robust training efforts might make the technology appear less commercially ready.

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