Hydrogen Vehicle Post-Crash Fire Research Recommendations

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Introduction

The following recommendations are based on the premise that the on-board hydrogen storage system consists of one or more compressed gas cylinders connected to lower pressure gaseous fuel lines. Each cylinder is assumed to be equipped with a pressure relief device (PRD) and to have successfully passed the bonfire test required in NGV-2. The fuel lines are also outfitted with at least one PRD. One key question is whether or not the fuel lines should have an excess flow valve. My understanding is that neither the early prototype hydrogen vehicles nor the CNG vehicles have excess flow valves.

Post-crash hydrogen fire scenarios of most concern involve either a breach of a fuel line, or a fire exposure that causes the cylinder and/or fuel lines to vent through a PRD. It is assumed that the PRD has a vent line that allows the hydrogen to be vented into a relatively unobstructed open area. Whether the vehicle has a fuel cell engine or internal combustion engine is only relevant insofar as they may require different fuel line pressures and delivery rates.

Since there is not enough time and resources to survey firefighting and regulatory officials about their primary concerns for these fire scenarios, I will attempt to raise the questions I would imagine they would raise themselves. They are as follows.

1. Will the vented hydrogen auto-ignite if it is not vented directly into an exposure fire or some other obvious ignition source?
2. How can emergency responders/firefighters know if/where the hydrogen is burning?
3. If there is a hydrogen jet flame, how long will it be, and will it remain attached to the breach site or will it blow off and possibly self-extinguish?
4. If there is no (stable) hydrogen flame, what is the threat of hydrogen accumulation and a subsequent hydrogen deflagration?

In addition to these questions, there is the more fundamental question of whether or not the fuel line or cylinder can be equipped with a reliable excess flow valve that will automatically shut off the flow of hydrogen in the event of a fuel line breach. This is a crucial question because the firefighting community is well aware that the best way of extinguishing a hydrogen jet fire is by shutting off the flow of hydrogen.

Based on these premises and associated questions, I am recommending the following research projects.

Excess Flow Valves for Hydrogen Lines

The objective of this research project would be to determine how existing excess flow valves function in hydrogen service. This would involve discussions with excess flow valve manufacturers, acquisition and testing of some excess flow valves currently sold for use on natural gas lines, and analysis of valve specifications for compatibility with some prototype hydrogen vehicle fuel systems. The tests would determine the pressure drops across the valves for hydrogen service, and how the trip points (flow rate and pressure) for natural gas service relate to those for hydrogen service. Results would include recommendations on any needed modifications or remaining questions to allow excess flow valves to be used in hydrogen fuel systems.

Hydrogen Auto-Ignition

The objectives of this project would be 1) to review existing data and analyses concerning the propensity for a high-pressure hydrogen release to auto-ignite at temperatures well below the nominal auto-ignition temperature; 2) to conduct hydrogen venting tests at various pressures and release conditions (line size, material, orifice size, and particulate contamination) to determine if there is any consistent set of parameters that could delineate auto-ignition criteria; and 3) to relate the results of the first two tasks to expected post-crash venting from both the fuel line and the fuel tank vent lines. Results from this project would provide an indication of the probability of auto-ignition during post-crash venting, and possible ways to increase or decrease the probability of auto-ignition.

Hydrogen Flame Detection/Visualization

The objectives of this project would be to test the ability of commonly available instrumentation, equipment and materials to facilitate the detection and visualization of a post-crash hydrogen jet fire. The premise is that emergency responders at the scene of a hydrogen vehicle crash hear the sound of a hydrogen release, and want to determine if/where there might be an invisible hydrogen flame. Instrumentation to be tested in this project will include portable UV multi-wavelength flame detectors and portable thermal detectors placed on the end of a telescoping pole. Simpler equipment/materials such as the proverbial rag tied to the end of a pole will also be explored in an effort to identify an assortment of methods that could be used by emergency responders with varying resources and hydrogen knowledge.

Hydrogen Jet Flame Characteristics

The objectives of this project are: 1) to review existing data and analyses of hydrogen jet flames; 2) to conduct laboratory tests of hydrogen jet flames at post-crash hydrogen venting conditions; and 3) to synthesize and generalize the results of previous tests/analyses and the new laboratory tests. The particular aspects of hydrogen jet flames to be studied include flame stability/blowoff conditions, flame lengths, and flame heat fluxes over the range of Froude numbers expected for post-crash venting scenarios. Results of this project will help determine the nature of jet flames to be expected during post-crash hydrogen venting and will help establish appropriate danger zones in which equipment, vehicle components, and people might be vulnerable to jet flame impingement and associated high heat fluxes. Flame stability and blowoff will be studied for both flames attached to the release orifice, and for flames attached to various objects in the path of the hydrogen jet that might serve as flame holders.

Hydrogen Jet Dispersion

The objectives of this project will be to characterize the hydrogen concentration distribution in a vented jet and in the transition region between jet momentum dominated dispersion and buoyancy dominated dispersion. This will be accomplished via laboratory experiments and analyses of existing data correlations for momentum jets. Results can be used to facilitate scenario-specific analyses of hydrogen dispersion following a post-crash un-ignited release. These analyses are complicated by the combination of momentum dominated dispersion in the vicinity of the release site, and the buoyancy and ambient turbulence dominated dispersion in the far field. The ability to separate these two dispersion regimes via data correlations delineating their spatial boundaries, and to provide data correlations for the transition regime, will allow for the use of simplified dispersion analyses in many site-specific and vehicle-specific release scenarios.

Concluding Remarks

The research projects suggested here are intended to directly address and answer the questions raised in the Introduction. To the extent that these questions represent the most important and most general post-crash hydrogen flammability questions, I suggest they should be the highest priorities. Since I have not tried to prioritize the questions, I will also not try to prioritize the research projects.

Although there are many other possible hydrogen post-crash research possibilities, many of them pertain to other, less commonly used, hydrogen fuel storage systems, or to specific vehicle/engine configurations. For example, the issue of hydrogen deflagration-to-detonation transition is important for ignitions of hydrogen-air mixtures and hydrogen-oxygen mixtures in enclosures, but it is well known that the results vary dramatically with enclosure geometry, scale, and mixture composition and concentration. Therefore, I do not think research on hydrogen detection and/or hydrogen deflagrations/detonations will provide the same type of widespread applicability and benefits as the projects suggested here. Nevertheless, I would be happy to entertain and discuss other opinions and suggestions on this subject.