Secondary Protection for 70 MPa Fueling
A White Paper from the Hydrogen Safety Panel

Executive Summary

In developing a 70 megapascal (MPa) fueling infrastructure, it is critical to ensure that a vehicle equipped with a lower service pressure fuel tank is never filled from a 70 MPa fueling source. Filling of a lower service pressure vehicle at a 70 MPa fueling source is likely to result in a catastrophic event with severe injuries or fatalities. The Hydrogen Safety Panel recommends that DOE undertake a two-step process to address this issue:

1. Perform an independent risk analysis of a 70MPa dispenser filling a lower pressure vehicle tank and develop different approaches for prevention and mitigation to meet an acceptable level of safety. Cost effectiveness, reliability, advantages and disadvantages are among the factors that should be evaluated for each approach considered.

2. Until such time as this analysis is complete and any recommended actions implemented, communicate the potential risk to responsible parties and strongly encourage those parties to add a secondary layer of protection to the existing system of mechanically non-interchangeable nozzles/receptacles. This will reduce the probability of a pressure mismatch during this developmental phase for hydrogen fuel cell vehicles and infrastructure. This step can be reassessed after further analysis is completed and the need and effectiveness of secondary protection methods are evaluated.

This paper provides background discussion of the problem, current safety systems and strategy and examples of potential future solutions to support the above recommendations.

Background

Rise of 70 MPa fueling

One challenge in a hydrogen fueled vehicle is storing enough hydrogen to obtain a reasonable range, usually specified as a minimum of 300 miles. This quest for range has led to increasing on-board hydrogen storage pressures. Storage technology for hydrogen evolved from the compressed natural gas (CNG) industry, where pressures of 3000 psi and 3600 psi (about 20 MPa and 25 MPa) are the current standards. Hydrogen pressure for on-board vehicle storage started at 25 MPa. About seven years ago, hydrogen vehicle storage advanced to 35 MPa (about 5000 psi) tanks, and most fuel stations and many hydrogen vehicles today still operate at this pressure. In the last two years, a large and growing number of vehicles have been equipped with 70 MPa (about 10,000 psi) storage tanks. Most vehicle manufacturers are currently developing vehicle systems at this pressure.

Desire to keep systems safe

It is the desire of all participants in the nascent hydrogen vehicle industry to make sure that there are no significant safety incidents. A reasonable benchmark for safety is the current gasoline fueling business. The public will expect hydrogen fueling to be at least as safe as gasoline fueling is today. The developmental nature of hydrogen fueling and storage technology introduces challenges such as user and operator training, early deployment of demonstration programs, and limited operating history of the technologies. The challenge addressed by this paper is the potential safety issue that arises from the overlapping use of multiple hydrogen storage pressures. The evolution of increasing storage pressures has led to potential tank failure scenarios that have not previously existed in the CNG or hydrogen fuel industries.

Discussion

Catastrophic consequences of filling a lower pressure tank to 70 MPa

This paper addresses the safety concern of putting 70 MPa hydrogen into vehicles designed for 25 MPa or 35 MPa hydrogen, or 3000 or 3600 psi CNG.

Many of the hydrogen vehicles currently on the road are designed with 35 MPa storage systems. Further, there is a much larger fleet of CNG vehicles in use with 3000 psi and 3600 psi storage systems. These fuels are often dispensed at the same location and with dispensing equipment that is very similar in look and function.

It is recognized that it is not desirable to fill a CNG vehicle with hydrogen, or vice-versa. Likewise, it is recognized that there is a need to prevent filling a higher pressure gas into a lower pressure storage tank, e.g., filling a 25 MPa hydrogen tank from a 35 MPa dispenser. To reduce the possible mismatch of pressures and fuels, a system of mechanically-coded nozzles (on the fuel station) and mating receptacles (on the vehicle) has been established. The SAE J2600 [1] and J2799 [2] standards specify the nozzle/receptacle geometries for hydrogen vehicles and NGV-2 [3] standards specify those for CNG vehicles. These mating pairs are made unique for each fuel and each pressure such that a higher pressure nozzle will not fit onto a lower pressure receptacle, nor can hydrogen or CNG nozzles mate to the wrong vehicle receptacle.

It should be noted that hydrogen interface standards are still evolving and that the CNG industry does not exclusively follow the NGV-2 standard. Non-compliant nozzles are in use for both alternative fuels.

The consequence of filling a 25 or 35 MPa hydrogen vehicle, or a 3000 or 3600 psi (20 or 25 MPa) CNG vehicle, at a 70 MPa hydrogen dispenser is likely to be a catastrophic failure of the tank. A mismatch of any currently used hydrogen or CNG pressure combination less than 70 MPa is also clearly undesirable, but would not likely lead to tank failure.

Pressure ratios

The storage systems in CNG vehicles are designed in accordance with NGV-2, and depending on construction type, must be designed with a minimum burst ratio of at least 2.25 times the service pressure. Hydrogen storage systems are not yet built to a particular standard, but generally use the same design requirements as CNG vehicles, including the minimum 2.25 burst ratio. Both CNG and hydrogen tanks are permitted to be filled to 125% of service pressure provided that the settled pressure does not exceed the service pressure at a temperature of 15 C. This is done to accommodate varying ambient temperatures as well as the heating effect that occurs when rapidly pressurizing a tank. Thus, a 35 MPa hydrogen tank can be filled to about 44 MPa at 85C. Its burst pressure must be at least 80 MPa.

Typically, the only pressure protection for the vehicle storage system is provided by the fuel dispenser. This device for a hydrogen dispenser must be set no higher than 140% of the service pressure, or about 48 MPa for a

35 MPa dispenser per NFPA 52 [4]. The vehicle storage tank is NOT equipped with any pressure relief devices that would actuate to protect it from overpressure. Typical fuel station operating pressures are 25% to 50% above nominal service pressure to allow the gas to flow from the station into the vehicle at an acceptable rate and to an acceptable fill pressure.

Table 1 shows the ratios of likely station pressures to nominal service pressures. A pressure ratio of up to 1.25 can be expected under normal operating conditions and up to 1.4 is possible due to the set point of the dispenser relief device. The tank may be able to survive at a pressure ratio of 1.8 after more than 500 fills (to a pressure ratio of 1.25) without bursting (see SAE 2007-01-0691, Tomioka/JARI [5]). The table below indicates that a fill from a 70 MPa dispenser can significantly exceed the minimum 1.8 burst ratio for the lower service pressures used today for CNG and some hydrogen vehicles.

		Station Normal Source Pressure (1.25x service pressure)		
		25 MPa Station	**35 MPa Station**	**70 MPa Station**
		31 MPa	**44 MPa**	**88 MPa**
Vehicle Tank Service Pressure	**25 MPa**	**1.25**	1.75	**3.52**
	35 MPa	0.89	**1.25**	**2.51**
	70 MPa	0.44	0.63	**1.25**

Table 1 - Ratios of Station Normal Source Pressures to Tank Service Pressures

Consequences

The consequence of a tank failure is severe. Air Products' modeling [6] estimates that the overpressure from bursting a 35 MPa tank would cause fatalities to any persons standing within 5.5 meters (m) of the tank when it failed. The radius of likely injury predicted by the model is almost 50m. Note that this consequence is just from the overpressure from the tank contents, and does not include the effects of hydrogen ignition.

The tank is not the only pressure containing device on the vehicle. There is a receptacle, a line connecting the receptacle to the tank, and other various valves and filters. Any of these other components may fail due to overpressure, as well. However, these other components almost always have a higher burst pressure than the tank, and a release due to a component failure would most likely be less severe than the sudden release of the entire tank contents.

Current Safety Systems

Vehicle

Due to the potential of an inadvertent connection, the primary safety system on the vehicle to protect against incorrect pressure supply is the geometry of the receptacle. Similar mechanical protection systems are used in other industrial gas applications to protect against improperly connecting incompatible gases, such as an oxidizer instead an inert or flammable gas. This is governed by standards worldwide. Experience has shown that this method of protection is helpful, but certainly not foolproof. Incidents with mismatched gases still occur, both inadvertently as well as from purposeful action.

Some vehicles are equipped with a shutoff valve on the tank inlet that will close if the vehicle detects excess pressure in the tank. However, most are not, and the valve is not required by code.

Vehicles also have a pressure relief device (PRD) that allows gas in the tank to escape in the event of a fire. These devices are temperature activated, and are NOT pressure activated. No vehicles have relief devices installed to relieve an over pressure.

Station

Station safety also begins with the mechanical non-interchangeable protection.

Currently, all 25 and 35 MPa hydrogen nozzles are Type A, and all 70 MPa nozzles are Type C. This means that a 35 MPa hose will have two connections, one for the supply, and one for the vent, while a 70 MPa nozzle will only have the supply connection. This situation currently makes it harder for maintenance personnel to install an incorrect nozzle. However, this situation is not expected to last since nozzle manufacturers are likely to develop Type A nozzles for 70 MPa in the future.

Failure Scenarios and Probability

Preliminary risk analysis has identified a number of potential scenarios that could lead to the improper filling of a lower pressure vehicle at a 70 MPa dispenser. Some examples are provided below, but this list is not intended to be comprehensive.

Incorrect receptacle installed on a vehicle

It is considered unlikely that a major vehicle manufacturer would deliver a vehicle with the wrong mechanically coded receptacle. However, these parts currently look similar and often use the same internal connections, so a mistake is possible. Also, in a new industry such as hydrogen fueling, there are many small startup suppliers of vehicles who may not be fully aware of the applicable codes and hazards involved. We can expect that there will always be newly trained maintenance personnel and individuals who have the tools to make a mistake, either on purpose or by accident. For example, an individual might want to extend the range of his vehicle by installing a higher pressure receptacle, unaware of the potential danger. While impossible to prevent all actions, the current system is only single-fault tolerant and simple hand tools are sufficient to make an exchange.

Incorrect nozzle installed on station

Similar to the above, it is conceivable that a mistake could be made during manufacturing or maintenance at which time a wrong pressure nozzle is installed. Fuel dispensers for hydrogen and CNG, and for different pressures, often look nearly identical.

Adapters

Adapters can also be used to allow the incorrect fuel to be dispensed. This is more likely early in the rollout of a new fuel when there are fewer available fueling stations.

Experience in hydrogen fueling to date

The experience in the hydrogen fueling industry to date has been limited, but not encouraging. In the fairly limited time (about 10 years) and fairly limited number of fueling events (likely about 200,000), there are several known occasions where mismatches have occurred, fortunately not yet with a 70 MPa dispenser.

- A fleet of five buses with 20 MPa tanks was equipped with 35 MPa receptacles. The owner of the buses was unconcerned and only changed the receptacles after threatened with station shutdown.

- An incorrectly installed nozzle on a hydrogen station. This was caught prior to any fueling.

- An aftermarket conversion vehicle equipped with a 25 MPa tank that had a 35 MPa receptacle because the owner could not find many 25 MPa fuel stations.

Experience in similar industries

It is well known that the CNG industry does not exclusively use the non-interchangeable coding system of NGV-2. A recent example was provided where an individual with a 3000 psi tank routinely fills at a 3600 psi station but shuts the fill off early. Corruption of the non-interchangeable coding system for CNG vehicles is unlikely to result in a catastrophic failure. However, it illustrates the lack of concern for potential pressure mismatches. A similar lack of concern or relaxation of this non-interchangeable requirement for hydrogen-fueled vehicles would be problematic.

Potential Codes Gap

Vehicles are regulated by Federal Motor Vehicle Safety Standards. In addition, the SAE is developing numerous standards that apply to vehicles. Some, such as J2600, are available for use, but others are still in development.

Fuel stations are regulated by the National Fire Protection Association (NFPA) as well as the International Code Council (ICC). Codes and standards such as NFPA 52 and the International Fire Code (IFC) Chapter 22 [7] apply to hydrogen fueling stations.

However, the potential pressure mismatch occurs at the interface between the vehicle and the station. The SAE FCV Committee has been aware of the issue for several years but has not yet reached consensus on how to resolve this matter beyond the recognized need to ensure that all vehicular equipment is properly rated for the duty per SAE J2579 [8]. There is currently a gap in coverage between the organizations writing codes and standards for vehicles and fueling stations. Each has concentrated on their respective areas of expertise and equipment, thereby leaving a potential safety gap in between. It is easy for each to assume the protection lies in the other's domain.

References are available today that discuss the vehicle/station interface for 70 MPa dispensing. Fueling Specification for 70 MPa Compressed Hydrogen Vehicles Release A [9][1] specifies the non-interchangeable hardware, but leaves additional protection through electrical signals as an OEM option. SAE J2799 [2] recommends a nozzle geometry, as well as provides for using an optional IR signal to communicate a tank pressure rating. Other commonly used interface protocols in operation today have also had means of secondary confirmation using hardwired cable and RFID communication methods. There is no industry consensus and many OEMs do not use any form of secondary confirmation.

SAE has a committee that is working on a potential interface standard, but this has been stalled for several years and there is not yet a published standard. The latest draft revision of J2799 also does not fully address the potential failure scenarios. The committee has not been successful in reaching a consensus on the potential

[1] To be superseded by SAE J2601, "Compressed Hydrogen Vehicle Fueling Communication Device," which is currently in progress (see SAE Standards for Works in Progress)

hazards or the need for secondary protection. It has also been noted that many of the potential solutions for secondary protection fall outside of the scope of work of J2799 (e.g. modifications to the storage system on the vehicle, or fool-proofing of connections between fueling hose and fueling station).

Current solutions

Examples of secondary layers of protection currently being practiced are noted below:

1. Vehicle and station communication is a current strategy in use today on some vehicles. This communication consists of a signal from the vehicle indicating that it has a 70 MPa tank installed, which provides a secondary means of confirmation that the vehicle being filled can accept 70 MPa gas. While not perfect, it does provide an additional level of protection against inadvertent installation of wrong componentry and makes it more difficult to purposely provide the wrong fuel pressure. The signal has been communicated either by a resistor on the car, an RF message from the car, or an IR message from the car.

2. Some vehicles are equipped with a shutoff valve on the tank inlet that will close if the vehicle detects excess pressure in the tank.

Possible future solutions

Industry standardization to an appropriate pressure would help diminish the concern over pressure mismatch. However, the prospects for such standardization given the breadth of potential applications (passenger vehicles, off-road vehicles, buses, trucks, etc.) are uncertain.

Pressure confirmation through vehicle-to-station communication is a possible future solution. For vehicles that do not use communication for fueling, some type of tag on the tank or vehicle that serves to confirm 70 MPa capability would serve the intended purpose. The tag may be a bar code or a radio-frequency identification (RFID) tag.

Other benefits

It should also be noted that if information on tank pressure rating is being transmitted from the station to the vehicle, it will also be possible to transmit other useful information such as tank size and thermal characteristics.

Summary and Recommendations

The consequence of a 70 MPa dispenser filling a lower pressure vehicle tank will almost certainly lead to catastrophic failure of that tank, and potential serious injuries or fatalities to those nearby. The intent of this paper is to bring attention to the potential catastrophic consequences of fueling pressure mismatch and to recommend a path forward.

Some thoughtful considerations of this issue have yet to reach consensus; other efforts to date have addressed the issue in an ad hoc, qualitative manner, or dismissed the issue as sufficiently improbable. Some preliminary quantified risk analysis has been performed. The results of this preliminary work indicate that without secondary protection the risk of a pressure mismatch is unacceptably high. Some examples of current practice of secondary protection have been noted. The Hydrogen Safety Panel recommends that a further, formal risk analysis be completed by an industry team of vehicle providers, fueling station providers, and code officials. The

U.S. Department of Energy can provide direction and potential funding for this effort as part of its ongoing hydrogen initiatives.

The Hydrogen Safety Panel provides a two-step recommendation for DOE action:

1. Perform an independent risk analysis of a 70MPa dispenser filling a lower pressure vehicle tank and develop different approaches for prevention and mitigation to meet an acceptable level of safety. Cost effectiveness, reliability, advantages and disadvantages are among the factors that should be evaluated for each approach considered.

2. Until such time as this analysis is complete and any recommended actions implemented, communicate the potential risk to responsible parties and strongly encourage those parties to add a secondary layer of protection to the existing system of mechanically non-interchangeable nozzles/receptacles. This will reduce the probability of a pressure mismatch during this developmental phase for hydrogen fuel cell vehicles and infrastructure. This step can be reassessed after further analysis is completed and the need and effectiveness of secondary protection methods are evaluated.

References

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