SAE INTERNATIONAL

SURFACE VEHICLE INFORMATION REPORT

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Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks

RATIONALE

Currently, there is no published standard fueling protocol or method for fueling hydrogen powered industrial trucks (HPITs). HPITs include utility vehicles, fork lifts, tugs, and other electric vehicles using H2 fuel cell battery replacement modules (BRMs). As the market for these vehicles expands, there is interest in having a standard fueling method for hydrogen powered industrial trucks.

SAE J2601-3 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

The intent of this document is to provide guidance for a performance-oriented dispenser fueling protocol for hydrogen powered industrial trucks.

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1. SCOPE

This document establishes safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel Hydrogen Powered Industrial Trucks (HPITs). It also describes several example fueling methods for gaseous hydrogen dispensers serving HPIT vehicles.

SAE J2601-3 offers performance based fueling methods and provides guidance to fueling system builders as well as suppliers of hydrogen powered industrial trucks and operators of the hydrogen powered vehicle fleet(s). This fueling protocol for HPITs can support a wide range of hydrogen fuel cell hybrid electric vehicles including fork lifts, tractors, pallet jacks, on and off road utility, and specialty vehicles of all types.

The mechanical connector geometry for H25 and H35 connectors are defined in SAE J2600 Compressed Hydrogen Surface Vehicle Refueling Connection Devices.

Multiple fueling methods are described in this document and include:

1. Fill to Service Pressure with fixed area flow-limiting device

2. Fill to Target Pressure with fixed area flow-limiting device

3. Fill to Target Pressure with variable area flow-limiting device

These three dispensing methods are detailed in Section 6 and include a schematic of control components for vehicle fueling. These methods allow for market differentiation with varied target fill pressures relative to 100% SOC. These methods are examples of how dispensers may function but are not intended to limit options for new dispenser technologies or fueling methods, provided they meet the performance based requirements.

This document is suitable for all vehicle tank fueling systems above 18 L water volume and may be used for fueling of all types of Hydrogen Powered Industrial Trucks (HPIT's), and Battery Replacement modules (BRM's).

The fueling limits shown in Section 5 are harmonized with the fueling assumptions used for on-board fuel systems that comply with CSA HPIT-1.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J2600 Compressed Hydrogen Surface Vehicle Fueling Connection Devices

TIR J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

SAE J2719 Hydrogen Fuel Quality for Fuel Cell Vehicles

SAE J2574 Information Report - Fuel Cell Vehicle Terminology

SAE J2578 Recommended Practice for General Fuel Cell Vehicle Safety

TIR J2579 Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Fueled Vehicles

TIR J2760 Information Report – Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications

2.1.2 CSA Publications

CSA America is currently developing and revising component certification standards applicable to hydrogen filling stations and hydrogen vehicles. Contact CSA America to see if new standards are published and available at CSA America, 8501 East Pleasant Valley Road, Cleveland, OH 44131-5575, Tel: 216-524-4990, www.csa-america.org.

CSA CHMC 1 Material Compatibility for Use in Hydrogen Applications

CSA HPIT-1 System Components for Powered Industrial Trucks

CSA HGV 4.1 Hydrogen Dispenser

CSA HGV 4.2 Hoses

CSA HGV 4.3 Fueling Parameters

CSA HGV 4.4 Breakaway Devices

CSA HGV 4.5 Priority and Sequencing

CSA HGV 4.6 Manual Valves for use in Hydrogen Fueling Station(s)

CSA HGV 4.7 Automatic Valves for use in Hydrogen Fueling Station(s)

CSA HGV 4.8 Fueling Station Compressors

CSA HGV 4.10 Fittings

2.1.3 UL Publications

Available from Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 2267 Fuel Cell Power Systems for Installation in Industrial Trucks

3. DEFINITIONS

3.1 HYDROGEN POWERED INDUSTRIAL TRUCK

3.1.1 Battery Replacement Module (BRM)

A hydrogen powered fuel cell module or hybrid fuel cell/battery power module that provides direct or semi-direct replacement of battery power sources within powered industrial equipment (fork trucks, tugs, etc.).

3.1.2 Hydrogen Powered Industrial Truck (HPIT)

A Powered Industrial Truck (PIT) is a mobile, power-driven vehicle used to carry, push, pull, lift or stack material.

3.1.3 Receptacle

Device connected to the HPIT or BRM that receives the dispenser nozzle and permits transfer of fuel. This may also be referred to as a fueling inlet.

3.2 CAPACITY

3.2.1 Fast Fueling

Fast Fueling is defined as filling a vehicle fuel system at a rate exceeding 1.5 grams per second (1 Nm3/min). Fast Fueling covered by this TIR is typically at fueling speeds of between 6 and 10 grams per second.

3.2.2 Storage Capacity

Total mass of hydrogen contained within the storage vessels of a battery replacement module or hydrogen powered industrial truck when filled to service pressure at 15°C

3.2.3 Slow fueling

Slow Fueling is defined as filling a vehicle fuel system at a rate less than 1.5 grams per second (1 Nm3/min).

3.3 DISPENSER COMPONENTS

3.3.1 Breakaway

A device in the fueling hose assembly that will separate if a vehicle drives away while the dispenser nozzle is connected to the vehicle. The intent of the breakaway is to prevent damage to the vehicle, prevent damage to the dispenser, and to minimize the release of hydrogen.

3.3.2 Communication Connector

An (optional) connector specified by the HPIT manufacturer to enable data transfer from the HPIT to the dispenser. It may also be used to ground the vehicle prior to fueling.

3.3.3 Dewatering Connector

An (optional) connector specified by the HPIT manufacturer to allow for water removal from the HPIT as part of the fueling process.

3.3.4 Dispenser

The equipment that controls each fueling event; a transfer of hydrogen fuel from the station storage systems to HPIT vehicle storage for the purpose of fueling the vehicle.

3.3.5 Hydrogen Supply System

The equipment required to store, condition and transfer hydrogen to the dispensing system for the purpose of fueling HPITs.

3.3.6 Nozzle

Device connected to the dispenser which engages a receptacle on the HPIT or BRM and permits transfer of fuel.

3.4 TEMPERATURE

3.4.1 Ambient Temperature

The ground-level temperature of the air measured at the fueling station, not in direct sunlight.

3.4.2 Bulk Hydrogen Temperature

The mass-average temperature of the hydrogen gas in the vehicle fuel tank.

3.4.3 Calculated Temperature of Vehicle Storage Tank

The temperature of vehicle storage tank during fueling estimated by the dispenser system.

3.4.4 Fuel Delivery Temperature

The temperature of the hydrogen gas measured as immediately upstream of the dispenser hose breakaway as practical.

3.4.5 Vehicle Tank Gas Temperature

The gas temperature as measured within the Vehicle Tank. It is assumed to be the average temperature of the gas in the vehicle tank.

3.5 PRESSURE

3.5.1 Compensated Fill Pressure

The calculated, temperature-adjusted fill pressure at which fueling should cease such that the settled pressure at 15 °C does not exceed the nominal working pressure.

3.5.2 Initial Tank Pressure

The vehicle tank gas pressure as measured by the dispenser at the start of the fill.

3.5.3 Integrity Check

A pressure hold test of the dispenser over a period of at least 5 s.

3.5.4 Maximum Allowable Working Pressure (MAWP)

The MAWP is the maximum gauge pressure of the working fluid (gas or liquid) to which a piece of process equipment or system is rated with consideration for initiating fault management above normal operation.

3.5.5 Maximum Vehicle Pressure Drop

A pressure drop of 5 MPa as measured station pressure of 20 MPa, a fuel temperature of 15 °C and fuel flowing to the vehicle at 10 grams per second.

3.5.6 Overpressure Protection System (OPS)

The OPS shall prevent the supply pressure to the dispenser output from reaching a pressure greater than 1.38 times the Service Pressure.

3.5.7 Pressure Safety Valve (PSV) Pressure activated pressure relief valve

To protect the dispenser fill line and vehicle tank from any upset overpressure condition. Set at not more than 1.38 x SP, when there is a source of hydrogen pressure that is greater than 1.38 times the Service Pressure

3.5.8 Nominal Working Pressure

The NWP is the gauge pressure that characterizes typical operation of a pressure vessel, container, or system. For compressed hydrogen gas containers, NWP is the container pressure, as specified by the manufacturer, at a uniform gas temperature of 15 °C (59 °F) and 100% SOC. NOTE: NWP is also called Service Pressure.

3.5.9 Vehicle Tank Pressure

Pressure of hydrogen gas within a vehicle storage tank.

3.5.10 Target Fill Pressure

The calculated pressure at which the dispenser will stop the fueling event.

3.5.11 Service Pressure

Service Pressure is synonymous with Nominal Working Pressure. For example, a H35 dispenser has a nozzle rated for 350 bar Service Pressure

3.5.12 Settled Pressure

Pressure of hydrogen gas within a vehicle storage tank with gas temperature equilibrated at ambient temperature. A full tank is at NWP when equilibrated at 15 °C.

3.5.13 Pressure Class

SAE and NIST designations for hydrogen fueling pressure classes include H25, H35, H50, and H70.

3.6 STATE OF CHARGE (SOC)

Ratio of hydrogen density within the vehicle storage system to the full-fill density. SOC is expressed as a percentage and is computed based on the gas density as per formula below. Note: P and T are the pressure and temperature of the gas inside the vehicle tank, and ρ is the calculated density

$$SOC\ (\%) = \frac{\rho\,(P,\ T)}{\rho\,(NWP,\ 15°C)}\ x\ 100$$

3.6.1 A standardized equation to calculate hydrogen gas densities is the National Institute of Standards of Technology (NIST) 113,341-350 (2008) with 0.01% accuracy for pressures up to 70MPa [http://nvlpubs.nist.gov/nistpubs/jres/113/6/V113.N06.A05.pdf]. 100% SOC=Density Reference Values at 15˚C and the NWP of the hydrogen storage system

3.6.1.1 H25: Density of H2 at 15°C and 25 MPa = 18.14 g/L

3.6.1.2 H35: Density of H2 at 15°C and 35 MPa = 24.0 g/L

4. ABBREVIATIONS AND SYMBOLS

4.1 Abbreviations

ASOV	Automatic Shutoff Valve
BRM	Battery Replacement Module
DCS	Dispenser Control System
FLD	Flow Limiting Device
H25	H25 pressure class H2 fueling features a 25 MPa Nominal Working Pressure
H35	H35 pressure class H2 fueling features a 35 MPa Nominal Working Pressure
H2	Hydrogen
HSS	Hydrogen Storage System (on board vehicle)
HPIT	Hydrogen Powered Industrial Truck
MAWP	Maximum Allowable Working Pressure
NWP	Nominal Working Pressure
PRD	Pressure Relief Device
PS	Pressure Sensor
PSV	Pressure Safety Valve
OPS	Overpressure Protection System
SAE	Society of Automotive Engineers
SP	Service Pressure
SOC	State of Charge
VSS	Vehicle Storage System

4.2 Symbols

$\rho(P,T)$	Gas density, a function of pressure, P, and temperature, T
P_0	Initial VSS pressure level prior to fueling
P_{target}	Fueling target pressure
$t_{fueling}$	Fueling time
$P_{station}$	Station measurement of pressure at dispenser nozzle
dP	Pressure drop between dispenser measured pressure and actual tank pressure
$\Delta P_{station}$	Uncertainty in station measurement of pressure at dispenser nozzle
$T_{vehicle}$	VSS temperature data received by station from vehicle during communication fueling
$SOC_{station}$	SOC calculated by station dispenser using $P_{station} + \Delta P_{station}$ and $T_{vehicle}$

5. GENERAL REQUIREMENTS FOR FUEL SYSTEM AND INTERFACE

5.1 Operating Conditions of the Vehicle Fuel System

The fueling system is responsible for control of the fueling process and shall provide a mechanical over pressure protection system when the maximum hydrogen system supply pressure to the dispenser is greater than 1.38 times the dispenser nozzle service pressure.

This TIR includes examples of fueling methods for H25 and H35. Performance of the dispenser fueling HPITs or BRMs shall be verified by procedures in Section 9 to confirm that the fueling protocols of the installed dispensers meet the fueling limits for the operating fleet of vehicles.

The performance of the dispenser shall be tested and shown to not exceed the hydrogen storage system limits of the HPIT or BRM. This TIR is based on vehicle fuel systems with the following design constraints.

5.1.1 Maximum pressure within the vehicle fuel system of 125% NWP

5.1.2 Bulk Hydrogen Temperature within the vehicle fuel system less than or equal to 85 °C

5.1.3 Gas density within the vehicle fuel system ≤ 100% SOC

5.1.4 Operating window for pressure and temperature as shown in Figure 5.1.4.

The Fueling Protocol shall be designed such that the gas in the vehicle fuel system during fueling will remain within the operating window as shown in Figure 5.1.4

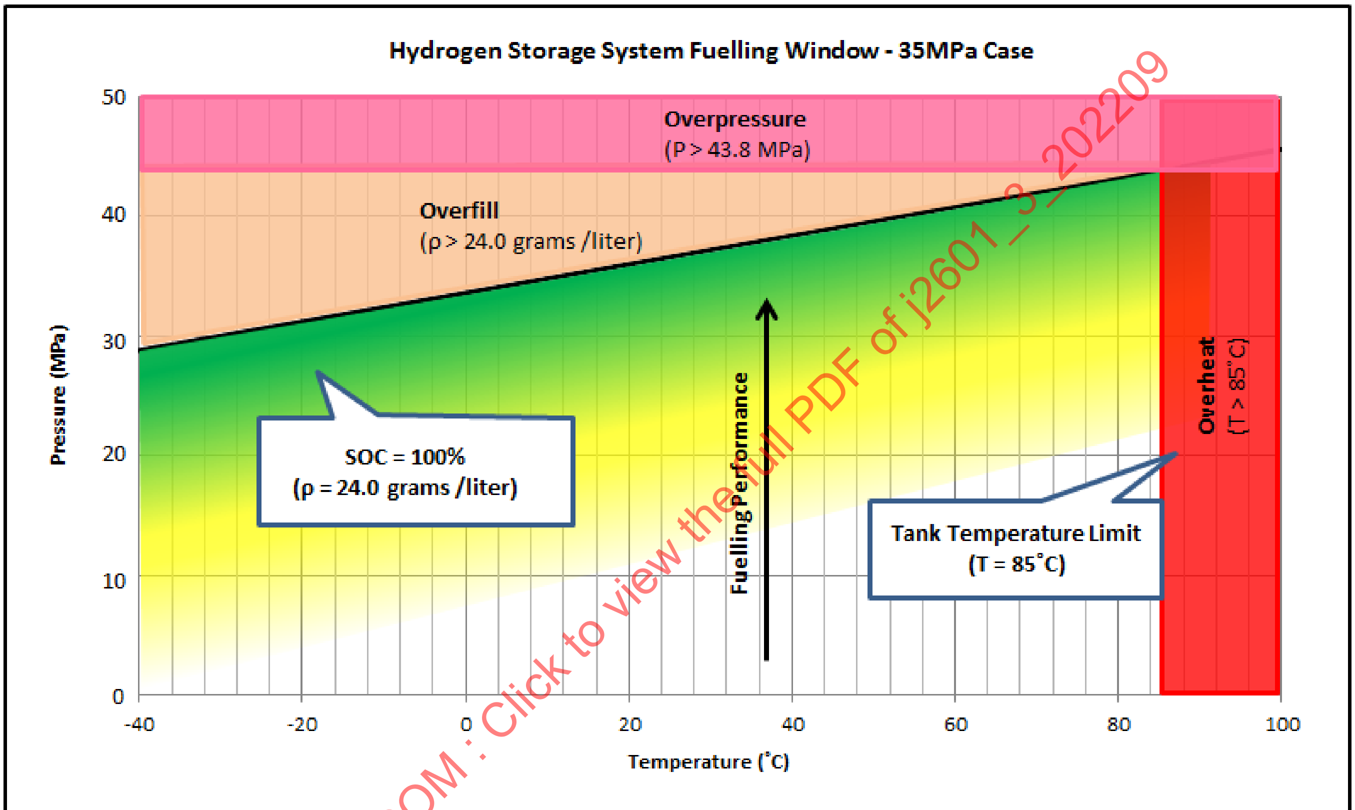

FIGURE 5.1.4 - OPERATING WINDOW OF FUELING PROCESS (35 MPA NWP FUEL SYSTEMS)

5.2 Vehicle Storage Systems (VSS)

5.2.1 This standard TIR is based on assumptions that the VSS of HPITs and BRM's have been designed to minimize the pressure drop from the receptacle to the vehicle tank. The maximum pressure drop from receptacle to the vehicle tank shall be less than 5 MPa as measured at 20 MPa, with a fuel temperature of 15 °C and fuel flowing to the vehicle at 8 grams per second.

5.2.2 Vehicle Storage Systems shall be designed in accordance with CSA HPIT-1 for Compressed Hydrogen Fuel Systems in Fuel Cell Powered Industrial Trucks.

5.3 Fueling Process Limits

Fueling dispensers shall ensure that the fueling process remains within the following limits:

5.3.1 Fueling shall only be conducted with an ambient temperature at the fueling station of between -40 °C and +50 °C.

5.3.2 Pressure at the dispenser sensor shall be less than 125% NWP of the vehicle fuel system

5.3.3 Station overpressure protection set point (if required) shall be less than 1.38 x NWP

5.3.4 The fuel temperature at the dispenser nozzle shall be greater than -40 °C.

5.3.5 The Bulk Hydrogen Temperature in the VSS shall not exceed 85 °C.

5.4 Special Requirements of Fleet Operations

There are numerous options for fueling captive HPIT fleets that support the specific needs of a manufacturing or material handling application.

The hydrogen vehicle fueling infrastructure provider and fleet operators may use multiple fueling methods, including slow fill and fast fill options.

Special environmental conditions, such as fuelling vehicles that operate at lower or higher temperatures than the room in which they are fueled must be considered and accommodation provided.

The fleet operator shall verify using procedures shown in Section 9, that all HPITs in a fleet are being fueled such that the Fueling Process Limits are not being exceeded.

5.5 Special Requirements for Fueling Light Duty Road Vehicles with HPIT dispensers

HPIT dispensers which do not meet the requirements of SAE J2601 shall not be used to fuel light duty surface vehicles.

If the dispenser is only intended to fill HPIT vehicles, and if the HPIT dispenser is located in an area where there is a potential risk of Light Duty Vehicles fueling at the dispenser, then the operator of the dispenser shall ensure that Light Duty Vehicle fueling is prohibited. This can be done mechanically, or electronically, or administratively.

6. HPIT DISPENSER CONTROL METHODS

This section provides details for a series of example fueling methods that meet the requirements outlined in Chapter 5. Other methods may also be appropriate.

6.1 Fill to Service Pressure

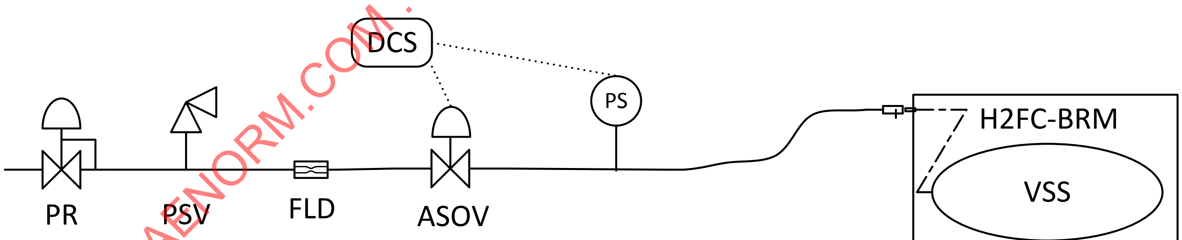

Figure 6.1 – Fill to Service Pressure

The “Fill to Service Pressure” fueling method as shown in Figure 6.1 shall consist of at least the following functional components:

6.1.1 Pressure Regulator (PR) set equal to, or less than, Service Pressure of the VSS.

6.1.2 Overpressure Protection System (OPS) such as a Pressure Safety Valve (PSV) set to not more than 1.38x SP when the supply pressure may exceed 1.38x SP.

6.1.3 Fixed area flow limiting device (FLD) to limit fueling to an average flow rate not to exceed 10 grams per second.

6.1.4 Automatic Shut-Off Valve (ASOV) that serves to control the sequence of the fueling event and to isolate the vehicle tank from the hydrogen supply system.

6.1.5 A Pressure Sensor (PS) to measure the hydrogen dispenser pressure.

6.1.6 A Dispenser Control System (DCS) that integrates the sensors, performs the integrity checks in accordance with Section 7, and controls the sequential actions of the dispenser ASOV during the fueling event.

6.1.7 Where a fleet of vehicles are filled simultaneously from a common dispensing system, each nozzle shall have a device to control fuel flow to each vehicle.

6.1.8 If the service conditions of the dispenser and vehicle being fueled result in a vehicle tank temperature of less than 15 °C at the end of fill, then the pressure regulator must be set below the Service Pressure to maintain SOC below 100%.

6.1.9 The fill to Service Pressure method is also applicable to a compressor discharging directly to a vehicle tank where the compressor mass flow rate serves as the flow limiting device.

6.1.10 The dispensing system shall be tested in accordance with Section 9.

6.2 Fill to Target Pressure with fixed orifice

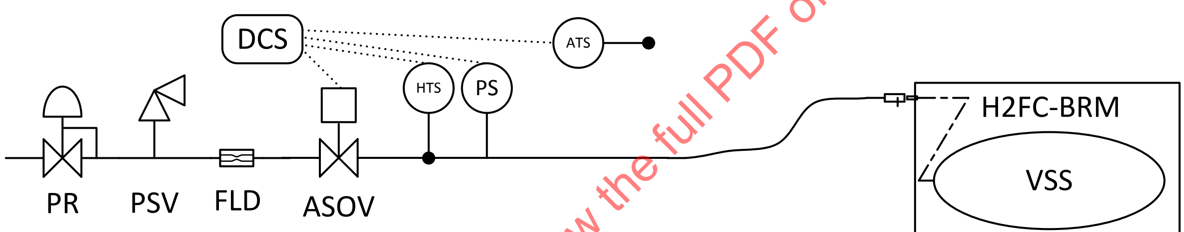

Figure 6.2 – Fill to Target Pressure

The “Fill to Target” fueling method as shown in figure 6.2 consists of at least the following functional components:

6.2.1 Pressure Regulator (PR) set to not more than 1.25 x Service Pressure.

6.2.2 Overpressure Protection System such as a Pressure Safety Valve (PSV) set to not more than 1.38x SP when the supply pressure may exceed 1.38x SP.

6.2.3 A fixed area flow limiting device (FLD) to limit fueling to an average flow rate not to exceed 10 grams per second.

6.2.4 Automatic Shut-Off Valve (ASOV) that shall control the sequence of the fueling event and to isolate the vehicle tank from the hydrogen supply system.

6.2.5 Pressure Sensor (PS) to measure the hydrogen dispenser pressure.

6.2.6 Ambient Temperature Sensor (ATS) to measure ambient temperature of the dispensing area.

6.2.7 Hydrogen Temperature Sensor (HTS) to measure hydrogen fuel temperature.

6.2.8 The Dispenser Control System (DCS) shall integrate the sensors, perform the integrity checks in accordance with Section 7, and control the sequential actions of the dispenser ASOV during the fueling event.

6.2.9 The dispensing system shall be tested in accordance with Section 9.

6.3 Fill to Target Pressure with variable Flow Rate

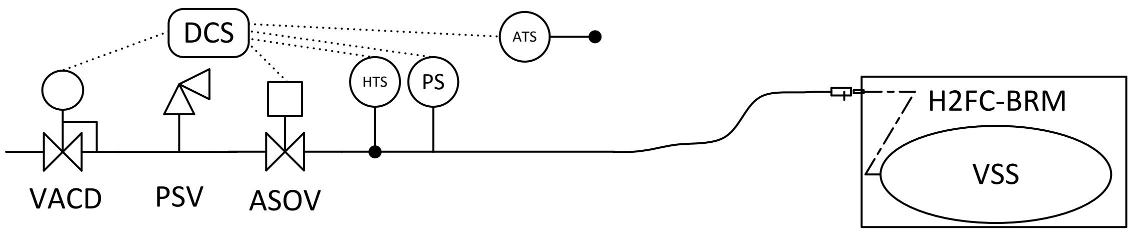

Figure 6.3 – Fast Fill to Target Pressure with Variable Flow Rate

The "Dispenser with a Variable Flow Rate" system as shown in Figure 6.3 shall consist of at least the following functional components:

6.3.1 Overpressure Protection System (OPS) such as a Pressure Safety Valve (PSV) set to not more than 1.38x SP when the supply pressure may exceed 1.38x SP.

6.3.2 A Variable Area Control Device (VACD) incorporates the function of the pressure regulator (PR) and limiting orifice. .The VACD shall be controlled by the DCS.

6.3.3 Automatic Shut-Off Valve (ASOV) that can control the sequence of the fueling event and isolate the vehicle tank from the dispenser and high pressure hydrogen supply system.

6.3.4 Pressure Sensor (PS) to measure the hydrogen dispenser pressure.

6.3.5 The Dispenser Control System (DCS) shall integrate the sensors, perform the integrity check system, control the VACD and control the sequential actions of the dispenser ASOV during the fueling event.

6.3.6 Ambient Temperature Sensor (ATS) to measure ambient temperature of the dispensing area.

6.3.7 Hydrogen fuel Temperature Sensor (HTS) to measure the hydrogen fuel temperature.

6.3.8 The control of the VACD shall limit fueling to an average flow not to exceed 10 grams per second.

6.3.8.1 The VACD may exceed 10 grams per second where a user authorization system is used to limit access to the dispenser to only pre-qualified vehicles.

6.3.9 The dispensing system shall be tested in accordance with Section 9.

7. HPIT AND BRM FUELING PROCESS

All fast fill HPIT dispensing methods shall include the following components and procedures:

7.1 Automatic Shut Off Valve (ASOV)

The fast fill dispenser system shall have at least one automated dispenser isolation valve to terminate the fueling event and isolate the hydrogen supply from the dispensing system. This valve shall actuate upon activation of the dispenser Emergency Shut Down system, activation of flame and gas detection equipment, and activation of overpressure controls.

When fueling indoors, the fast fill dispenser system shall have an additional automated isolation valve. One or both shall be located to terminate flow outside the building.

7.2 Integrity Validation

The fueling process shall include a pressure integrity validation in accordance with Section 7.3 and Section 7.4.

When the dispenser valve (ASOV) is closed the dispenser pressure sensor is monitoring the line to the vehicle tank.

By monitoring the change in pressure (dP/dt) during the fueling process , the pressure sensor may be utilized to monitor for leaks at the dispenser nozzle or vehicle, trigger storage bank switching, sense for isolation valve leakage, sense vehicle storage tank volume as well as other aspects of the fueling event.

7.3 Initial Integrity Check

After the HPIT or BRM is connected to the dispenser system, the dispenser shall perform an integrity check on the dispenser and vehicle fuel system. The system shall wait until the VSS and dispenser hose pressure equalizes then monitor dP/dt for the minimum 5 second time period for the initial test of hose-nozzle-receptacle-vehicle fuel system integrity.

If the dispenser system detects a leak resulting in a pressure loss in the fueling hose and nozzle receptacle interface greater than a rate determined by the dispenser manufacturer, the dispenser shall stop the fueling event, provide an alarm, signal the operator, and record that a leak has been detected.

If the dispenser does not detect a leak, the dispenser may proceed with the refueling process until the high pressure integrity test defined in the next section.

7.4 Integrity Check during Fueling Event

The High Pressure Integrity Test is a performed at higher pressure to catch minor leaks in the dispenser system, hose and nozzle before they become larger leaks. The High Pressure Integrity Test is conducted when the dispenser fueling pressure is between 80 and 90 % of the service pressure. The high pressure integrity check during fueling event is performed as required by local regulations.

Figure 9.1 shows a High Pressure Integrity Check conducted at 20 MPa (3000 psig) from the perspective of the vehicle. In this example, the dispenser switched off the fuel flow when the dispenser pressure sensor was at 3000 psig and the onboard sensor was at 2700 psig. Shortly after valve closure, the on-board pressure sensor equalized to tank pressure of 2450 psig. From the dispenser perspective in this example, there was about 550 psig pressure drop in the first few seconds of the High Pressure Integrity test: this is the combined pressure drop across the dispenser and vehicle fuel system at the flow rate of the dispenser (at ambient conditions).

Different vehicle systems will show a range of pressure drops

7.4.1 The maximum expected pressure drop across the vehicle from receptacle to tank shall be less than 5 MPa (750 psig) as seen by the dispenser at the High Pressure Integrity Check conducted at 20 MPa with a fixed flow rate of 10 grams per second at15 °C

7.4.2 During any integrity test it is common to see a slight pressure decay due to tank and system temperature decay.

7.4.3 If the dispenser dP/dt evaluations show a positive pressure rise during the integrity test the possibly of leakage at the automatic valve must activate an alarm condition.