SURFACE VEHICLE STANDARD	J2601®	MAY2020
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(R) Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

RATIONALE

SAE J2601 has been revised in order to incorporate an extension of the compressed hydrogen storage system sizes above 248.6 L (>10 kg) for H70 only. Additionally, revisions have been made to clarify certain requirements and to enhance the usability of the protocols, based on field experience.

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1. SCOPE

SAE J2601 establishes the protocol and process limits for hydrogen fueling of vehicles with total volume capacities greater than or equal to 49.7 L. These process limits (including the fuel delivery temperature, the maximum fuel flow rate, the rate of pressure increase, and the ending pressure) are affected by factors such as ambient temperature, fuel delivery temperature, and initial pressure in the vehicle's compressed hydrogen storage system. SAE J2601 establishes standard fueling protocols based on either a look-up table approach utilizing a fixed pressure ramp rate, or a formula-based approach utilizing a dynamic pressure ramp rate continuously calculated throughout the fill. Both protocols allow for fueling with communications or without communications. The table-based protocol provides a fixed end-of-fill pressure target, whereas the formula-based protocol calculates the end-of-fill pressure target continuously. For fueling with communications, this standard is to be used in conjunction with SAE J2799.

An important factor in the performance of hydrogen fueling is the station's dispensing equipment cooling capability and the resultant fuel delivery temperature. There are three fuel delivery temperature categories denoted by a "T" rating: T40, T30, and T20, where T40 is the coldest. Under reference conditions, SAE J2601 has a performance target of a fueling time of 3 minutes and a state of charge (SOC) of 95 to 100% (with communications), which can be achieved with a T40-rated dispenser. However, with higher fuel delivery temperature dispenser ratings (T30 or T20) and/or at high ambient temperatures, fueling times may be longer.

Table 1 depicts the scope of SAE J2601 and potential work items for future revisions within this or other documents of the SAE J2601 series. SAE J2601 includes protocols which are applicable for two pressure classes (35 MPa and 70 MPa), three fuel delivery temperatures categories (-40 °C, -30 °C, -20 °C) and compressed hydrogen storage system sizes (total volume classification) from 49.7 to 248.6 L (35 MPa → H35, and 70 MPa → H70), and from 248.6 L and above (H70 only). Future versions of SAE J2601 work may incorporate warmer fuel delivery temperatures (-10 °C and ambient) and smaller total volume capacities for motorcycles and other applications.

The fueling protocols herein were developed based on a set of key assumptions described in Section 7 and Appendix A. These assumptions should be carefully considered in the development and implementation of an on-board compressed hydrogen storage system. In particular, hydrogen storage systems with properties which do not fall within the parameters in Table A3 should be further evaluated to confirm compatibility with the protocols herein.

Table 1 - Content of the SAE J2601

<table>
<tr><td colspan="2">Pressure Class Designation</td><td colspan="3">H35</td><td colspan="3">H70</td></tr>
<tr><td colspan="2">CHSS Capacity Range (Liters)</td><td>< 49.7</td><td>49.7 to 248.6</td><td>> 248.6</td><td>< 49.7</td><td>49.7 to 248.6</td><td>> 248.6</td></tr>
<tr><td colspan="2">CHSS Capacity Range (kg)</td><td>< 1.19</td><td>1.19 to 5.97</td><td>> 5.97</td><td>< 2.0</td><td>2.0 to 10.0</td><td>> 10.0</td></tr>
<tr><td colspan="2">CHSS Capacity Categories (nomenclature)</td><td>TBD</td><td>A, B, C</td><td>D</td><td>TBD</td><td>A, B, C</td><td>D</td></tr>
<tr><td colspan="2">Maximum Flow Rate (g/s)</td><td>≤ 60</td><td>≤ 60</td><td>≤ 60</td><td>≤ 60</td><td>≤ 60</td><td>≤ 60</td></tr>
<tr><td rowspan="5">Fuel Delivery Temperature Category</td><td>T40</td><td rowspan="5">Not Included</td><td rowspan="3">Included</td><td rowspan="5" colspan="2">Not Included</td><td rowspan="3" colspan="2">Included</td></tr>
<tr><td>T30</td></tr>
<tr><td>T20</td></tr>
<tr><td>T10</td><td rowspan="2"></td><td rowspan="2" colspan="2"></td></tr>
<tr><td>Ambient</td></tr>
</table>

1.1 Background

Stations should only be identified as SAE J2601 after demonstrating acceptance criteria (which is discussed in Appendix C), in conjunction with a hydrogen station test apparatus (HSTA). It is strongly recommended that stations be validated that the protocol is in compliance before fueling vehicles, as described in CSA HGV 4.3 or other equivalent document.

This standard establishes a formal industry-wide fueling standard that is meant to replace all previous protocols such as the SAE TIR J2601, protocols established by non-ANSI-certified organizations, vehicle manufacturer (OEM) fueling specifications, and all Clean Energy Partnership (CEP) and California Fuel Cell Partnership (CaFCP) fueling protocols.

It is understood, however, that other non-standard, development fueling protocols that differ from the protocols specified in this standard may be used when the station provider has (a) an agreement from a vehicle manufacturer that the protocol is appropriate for a particular vehicle system, and (b) a reliable method of identifying the particular vehicle is utilized in the station design and operation.

2. REFERENCES

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 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

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 +1 724-776-4970 (outside USA), www.sae.org.

SAE J2574 Fuel Cell Vehicle Terminology

SAE J2578 Recommended Practice for General Fuel Cell Vehicle Safety

SAE J2579 Standard for Fuel Systems in Fuel Cell and Other Hydrogen Fueled Vehicles

SAE J2600 Compressed Hydrogen Surface Vehicle Fueling Connection Devices

SAE J2719 Hydrogen Quality Standard for Fuel Cell Vehicles

SAE J2799 Hydrogen Surface Vehicle to Station Communications Hardware and Software

Mathison, S., Handa, K., McGuire, T., Brown, T. et al., “Field Validation of the MC Default Fill Hydrogen Fueling Protocol,” *SAE Int. J. Alt. Power.* 4(1):130-144, 2015, doi:10.4271/2015-01-1177.

Mathison, S., Harty, R., Cohen, J., Gupta, N. et al., “Application of MC Method-Based H2 Fueling,” SAE Technical Paper 2012-01-1223, 2012, doi:10.4271/2012-01-1223.

Monde, M. and Kosaka, M., “Understanding of Thermal Characteristics of Fueling Hydrogen High Pressure Tanks and Governing Parameters,” *SAE Int. J. Alt. Power.* 2(1):61-67, 2013, doi:10.4271/2013-01-0474.

Schneider, J., Mathison, S., Ward, J., Taha, E. et al., “Gaseous Hydrogen Station Test Apparatus: Verification of Hydrogen Dispenser Performance Utilizing Vehicle Representative Test Cylinders,” SAE Technical Paper 2005-01-0002, 2005, doi:10.4271/2005-01-0002.

Schneider, J., Meadows, G., Mathison, S., Veenstra, M. et al., “Validation and Sensitivity Studies for SAE J2601, the Light Duty Vehicle Hydrogen Fueling Standard,” *SAE Int. J. Alt. Power.* 3(2):257-309, 2014, doi:10.4271/2014-01-1990.

2.1.2 API Publications

Available from API, 1220 L Street, NW, Washington, DC 20005-4070, Tel: 202-682-8000, www.api.org.

API RP 2003 Protection against Ignitions Arising Out of Static, Lightning, and Stray Currents

2.1.3 CSA Publications

Available from CSA International, 178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3, Tel: 416-747-4000, www.csa-international.org.

ANSI/CSA HPRD 1-2013	Thermally Activated Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers
ANSI/CSA HGV 4.1-2013	Standard for Hydrogen Dispensing Systems
ANSI/CSA HGV 4.2-2013	Standard for Hoses for Compressed Hydrogen fuel Stations, Dispensers, Vehicle fuel Systems
ANSI/CSA HGV 4.4-2013	Standard for Break-away Devices for Compressed Hydrogen Dispensing Hoses and Systems
ANSI/CSA HGV 4.5-2013	Standard for Priority and Sequencing Equipment for Hydrogen Vehicle Fueling
ANSI/CSA HGV 4.6-2013	Manually Operated Valves for use in Gaseous Hydrogen Vehicle Fueling Stations
ANSI/CSA HGV 4.7-2013	Automatic Valves for use in Gaseous Hydrogen Vehicle Fueling Stations
ANSI/CSA HGV 4.8-2012	Hydrogen Gas Vehicle Fueling Station Compressor Guidelines
ANSI/CSA HGV 4.10-2012	Standard for Fittings for Compressed Hydrogen Gas and Hydrogen Rich Gas Mixtures
CSA/ANSI HGV 4.3:19	Test Methods for Hydrogen Fueling Parameter Evaluation
CSA HGV 3.1-2013	Fuel System Components for Compressed Hydrogen Gas Powered Vehicles

2.1.4 FCHEA Papers (Formerly NHA)

"Optimizing Hydrogen Vehicle Fueling," 2005, Schneider, J. Ward, J. et al. Available from http://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/543e7eeae4b0983640ec4b93/1413381866875/NHA+2005+-+Optimizing+Hydrogen+Vehicle+Refueling.pdf.

"70 MPa Hydrogen Storage and Fueling Testing and Future Prospects," 2009, Schneider, J., Sutherland, I. et al. Available from: http://www.fchea.org/members/TWG/LD-Hydrogen-Vehicle-Fueling-Protocol-Final.pdf.

"Improving Hydrogen Tank Refueling Performance Through The Use Of An Advanced Fueling Algorithm - The MC Method," Harty, R., Mathison, S., Proceedings of the National Hydrogen Association Conference, May 4, 2010, Long Beach, CA. Available from: https://nha.confex.com/nha/2010/webprogram/Paper4917.html.

2.1.5 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61508	Application of Safety Instrumented Systems for the Process Industries
IEC 61511	Functional Safety - Safety Instrumented Systems for the Process Industry Sector
IEC 62061	Safety of Machinery - Functional Safety of Safety Related Electrical, Electronic and Programmable Electronic Control Systems

2.1.6 IrDA Publications

Available from http://www.irda.qc.ca/en/

IrDA IrPHY 1.4	IrDA Serial Infrared Physical Layer Specification
IrDA IrLAP 1.1	Serial Infrared Link Access Protocol

2.1.7 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO 14687-2	Hydrogen Fuel - Product Specification - Part 2: Proton Exchange Membrane (PEM) Fuel Cell Applications for Road Vehicles
ISO 17268	Gaseous Hydrogen Land Vehicle Refueling Coupling Devices
ISO 19880-1	Gaseous Hydrogen Fueling Stations Specification
ISO 23273	Fuel Cell Road Vehicles - Safety Specifications - Protection Against Hydrogen Hazards for Vehicles Fueled with Compressed Hydrogen

2.1.8 U.S. Government

Copies of these documents are available online at https://quicksearch.dla.mil/.

MIL-HDBK-310	Global Climatic Data for Developing Military Products
MIL-STD-810G	Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests

2.1.9 WE-NET Publications

WE-NET Task 7A-13	Communications Between Vehicle Onboard Tanks and a Hydrogen Fueling System, 2002, Lynch, F.

2.1.10 Japan JPEC Standards

Japan Petroleum Energy Center, "Technical Standard for Compressed Hydrogen Fueling

(Applied to Hydrogen Fueling Station) JPEC-S 0003 (2016), Rev. March 4, 2016

3. DEFINITIONS

3.1 AVERAGE PRESSURE RAMP RATE (APRR)

The average increase in pressure (MPa/min) from the start of fueling to the end of fueling.

3.2 COMPRESSED HYDROGEN STORAGE SYSTEM (CHSS)

The Compressed Hydrogen Storage System CHSS (refer to SAE J2579) consists of the pressurized containment vessel(s), pressure relief devices (PRDs), shut off device(s), and all components, fittings and fuel lines between the containment vessel(s) and the shut off device(s) that isolate the stored hydrogen from the remainder of the fuel system and the environment.

3.3 CHSS CAPACITY

The total water volume of the CHSS in liters, or the total mass of hydrogen stored in the CHSS at the nominal working pressure (at 15 °C), which is equivalent to the CHSS 100% state of charge.

3.4 CHSS CAPACITY CATEGORIES

The CHSS capacity category is a range of CHSS capacities which may fuel in a similar manner by a fueling protocol.

3.5 DISPENSER COMPONENTS

Any component of the dispenser that carries pre-cooled hydrogen to the CHSS. In most cases, this is any component downstream of the heat exchanger up to and including the nozzle; e.g., hose breakaway, dispenser hose, and nozzle.

3.5.1 HYDROGEN DISPENSING EQUIPMENT

The equipment required to condition and transfer fuel from the station to vehicle CHSS for the purpose of fueling the vehicle.

3.5.2 CONNECTOR OR COUPLING

A joined assembly of a nozzle and receptacle which permits rapid coupling (or connecting) and decoupling (or disconnecting) of fuel supply nozzle to the vehicle fueling receptacle, as per SAE J2600.

3.5.3 NOZZLE

Device connected to a fuel dispensing system which engages the hydrogen surface vehicle (HSV) receptacle and permits transfer of fuel (see CONNECTOR or COUPLING).

3.5.4 RECEPTACLE

Device connected to a vehicle or storage system that receives the dispenser nozzle and permits transfer of fuel. This may also be referred to as a fueling inlet (see CONNECTOR or COUPLING).

3.5.5 DISPENSER HOSE

The flexible hose assembly which transfers hydrogen between the dispenser and nozzle.

3.5.6 HOSE BREAK-AWAY

A device which allows the hose to separate from the dispenser if exposed to a sufficient mechanical stress. Typically, the hose is the only component between the nozzle and hose break-away.

3.6 FUELING WITH COMMUNICATIONS AND NON-COMMUNICATIONS

3.6.1 COMMUNICATIONS

Communications fueling means that a valid data connection has been established from vehicle to fueling station dispenser as described in SAE J2799.

3.6.1.1 NON-ASIL/SIL COMMUNICATIONS ASSUMPTION FOR SAE J2601

The IrDA communications defined in SAE J2799 2014 has not been ASIL/SIL classified to any standard at the time of publishing this standard. This means until ASIL/SIL certification is achieved, the signals are not guaranteed to be accurate and the station is responsible to ensure that process requirements are followed if it uses the communications signals.

The following are some of the guidelines that may be used to qualify components and systems for the station side SIL: IEC 61508/61511 and for vehicle side ASIL: ISO 26262.

3.6.2 NON-COMMUNICATIONS

Non-communications means that no valid data connection from vehicle to fueling station dispenser as per SAE J2799 exists, or that the received data has not been recognized as valid (or wished to be used) by the dispenser.

3.7 FUELING PROTOCOL CATEGORIES

Station fueling protocol will be defined by the vehicle's nominal working pressure (NWP) and the station's fuel delivery temperature category. The category is denoted by the letter H followed by the nominal working pressure in MPa, a hyphen, and the letter T followed by the absolute value of the fuel delivery temperature category in degrees celcius. For example, H70-T40 is the station category for a hydrogen fueling protocol with a NWP of 70 MPa and a fuel delivery temperature category of -40 °C.

3.8 FUELING PROTOCOL STANDARDIZATION

3.8.1 STANDARD FUELING PROTOCOL

A fueling protocol which has been reviewed and approved by the SAE Fuel Cell Standards Interface Task Force and is defined in the main body of SAE J2601. In this current version of SAE J2601, the standard fueling protocols are the table-based (Section 8), and MC Formula-based (Section 9).

3.8.2 NON-STANDARD, DEVELOPMENT FUELING

A fueling protocol which has not yet been reviewed and approved by the SAE Fuel Cell Standards Interface Task Force and thus is not defined in the main body of SAE J2601.

3.9 FUELING TIME AND FUELING EVENTS

Figure 1 illustrates the fueling time definitions for the main and overall fueling time as described in 3.9.1 to 3.9.8.

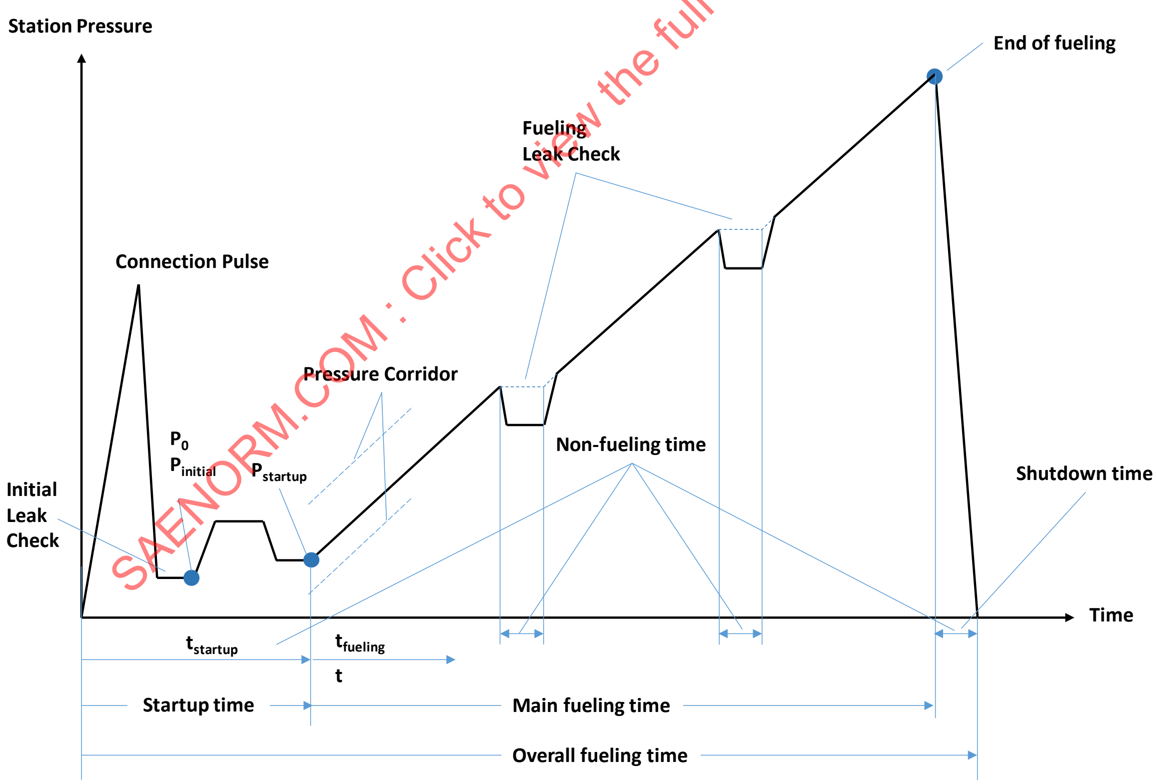

Figure 1 - Representative hydrogen fueling time diagram

3.9.1 OVERALL FUELING TIME

The total amount of time between when the user initiates the fueling at the dispenser until the nozzle can be removed. It includes the startup time, main fueling time, and shutdown time.

3.9.2 NON-FUELING TIME

The amount of time during the overall fueling time when fueling pressure ramp rate is not applied. The non-fueling time includes the startup and shutdown time, plus any planned interruptions during the main fueling time. However, non-fueling events do not include stopping or pausing fuel flow due to safety issues, lack of performance, etc. See 3.9.3.1 through 3.9.3.4 for examples of events during the non-fueling time.

3.9.3 INTENDED NON-FUELING EVENTS

A planned event when gas does not flow during the overall fueling time in order to test the integrity of the system or to change the source of fuel. See 3.9.3.1 through 3.9.3.4 for examples of intended non-fueling events. Intended non-fueling events do not include stopping or pausing fuel flow due to safety issues or lack or performance.

3.9.3.1 CONNECTION PULSE

The first flow of hydrogen from the station to the CHSS after connection of the nozzle, whereby the minimum amount of hydrogen necessary to open the check valve is dispensed into the CHSS. The purpose of the connection pulse is to equalize the station pressure with the CHSS pressure under static conditions so that the initial pressure can be measured.

3.9.3.2 INITIAL LEAK CHECK

The initial leak check may be implemented after the nozzle is connected and prior to the start of main fueling time. This can be accomplished by pressurizing the fueling path and measuring any decrease in pressure.

3.9.3.3 FUELING LEAK CHECK

A fueling leak check may be implemented during fueling to determine if there are any leaks in the system. This can be accomplished by pausing the fueling and measuring any decrease in pressure.

3.9.3.4 BANK SWITCHING

Bank switching occurs when the station changes the flow source from one storage bank to another. During bank switching, there may be a flow rate variation or short-term pause in fueling.

3.9.4 STARTUP TIME

This period begins after the user initiates fueling and ends when the main fueling time begins. The startup time includes a connection pulse and initial pressure measurement, and may also include a CHSS capacity category determination, as well as a leak check.

3.9.5 START OF FUELING

Immediately after the startup time when the station initiates the main fueling at the prescribed ramp rate and the upper and lower tolerances on pressure are applied.

3.9.6 END OF FUELING (INTENDED)

Occurs when the station stops fueling at the target pressure or SOC.

3.9.7 MAIN FUELING TIME

The period of gas flow between the start of fueling and the end of fueling. The prescribed ramp rate and the upper and lower tolerances on pressure are applied during the main fueling time. The main fueling time does not include the startup and shutdown times, but can include other non-fueling times.

3.9.8 SHUTDOWN TIME

This period begins at the end of fueling (after main fueling time) and ends when the user can remove the nozzle.

3.9.9 TERMINATE FUELING

This can occur prior to the end of fueling in the event that the station or vehicle has detected that a process requirement has been exceeded, the abort command is issued by the vehicle, or the user terminates the fueling.

3.10 HYDROGEN SURFACE VEHICLE (HSV)

Any surface vehicle which stores and uses hydrogen as a fuel. An example of an HSV is a fuel cell vehicle.

3.11 PRESSURE

3.11.1 CHSS PRESSURE ($P_{vehicle}$)

Pressure of hydrogen gas within the vehicle CHSS.

NOTE: For vehicles with multiple vessels, this standard assumes all vessels are at equal pressure, at all times.

3.11.2 STATION PRESSURE ($P_{station}$)

The pressure of the hydrogen gas supplied to the vehicle by the station, measured near the hose break-away (see 6.2.1.1).

3.11.3 INITIAL PRESSURE (P_0 or $P_{initial}$)

The pressure in the CHSS as measured by the station immediately after the connection pulse during the startup time when there is no flow.

3.11.4 STARTUP PRESSURE ($P_{startup}$)

The pressure in the CHSS as measured by the station at the end of the startup time when there is no flow.

3.11.5 TARGET PRESSURE (P_{target})

The station pressure at which the hydrogen fueling protocol targets for the end of fueling.

3.11.6 NOMINAL WORKING PRESSURE (NWP)

The NWP is the gauge pressure that characterizes typical operation of a vehicle pressure vessel, container, or system. For compressed hydrogen gas containers, NWP is the vehicle vessel pressure, as specified by the manufacturer, at a uniform gas temperature of 15 °C and 100% SOC.

3.11.7 MAXIMUM OPERATING PRESSURE (MOP)

The MOP is the highest gauge pressure of a component or system that is expected during normal operation including starts, stops, and transients (e.g., the MOP = 1.25 x NWP).

3.11.8 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 (e.g., the MAWP = 1.38 x NWP).

3.11.9 PRESSURE CLASS

The pressure class will be defined by the protocol's nominal working pressure. The class is denoted by the letter H followed by the nominal working pressure in MPa. For example, H70 is the pressure class for a hydrogen fueling protocol with a NWP of 70 MPa.

3.12 STATE OF CHARGE (SOC)

The ratio of CHSS hydrogen density to the density at NWP rated at the standard temperature 15 °C. SOC is expressed as a percentage and is computed based on the gas density per Equation 1.[1]

$$SOC\ (\%) = \frac{\rho\,(P,\ T)}{\rho\,(NWP,\ 15°C)}\ x\ 100 \qquad \text{(Eq. 1)}$$

The densities of the two major pressure classes at 100% SOC are

- Density of H35 at 35 MPa and 15 °C = 24.0 g/L
- Density of H70 at 70 MPa and 15 °C = 40.2 g/L

3.13 $SOC_{vehicle}$

SOC calculated with CHSS pressure and CHSS temperature.

3.14 $SOC_{station}$

SOC calculated with station pressure and CHSS temperature.

3.15 STATION DESIGNATION

Stations are to be designated by their pressure class and fuel delivery temperature category. For example, a station with a NWP pressure class of 70 MPa and fuel delivery temperature category of T40 is designated to be H70-T40.

3.16 TEMPERATURE

3.16.1 AMBIENT TEMPERATURE (T_{amb})

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

3.16.2 CHSS AVERAGE VEHICLE GAS TEMPERATURE ($T_{vehicle}$)

The average temperature of the hydrogen gas in the vehicle CHSS.

NOTE: If the vehicle contains a temperature measurement device for the purpose of sending a temperature signal to the dispenser during fueling, this temperature is also assumed to be the average temperature of the gas in the vehicle. Due to the accuracy of the sensor, the vehicle manufacturer should consider the tolerances of the temperature measurement and include them as criteria for the abort and measured temperature signals.

3.16.3 CHSS MEASURED TEMPERATURE (MT)

The measured temperature of the gas in the vehicle CHSS.

3.16.4 CHSS SOAK TEMPERATURE

The temperature of the CHSS after being exposed to a temperature greater or less than ambient temperature. The CHSS soak temperature may differ from the ambient temperature. In Appendix A, Figure A5 shows the range of soak temperatures relative to ambient temperature due to hot or cold soak conditions.

[1] The ρ(P,T) function for hydrogen is available from the National Institute of Standards and Technology (NIST) at https://www.nist.gov/publications/fundamental-equations-state-parahydrogen-normal-hydrogen-and-orthohydrogen. Note that the accuracy of the NIST equation has been quantified up to 200 MPa at the publishing of this standard.

3.16.5 FUEL DELIVERY TEMPERATURE (T_{fuel})

The temperature of the hydrogen gas supplied to the vehicle by the station, measured near the hose break-away during fueling, and labeled as T_{fuel}. T_{fuel} is a generic term for the fuel delivery temperature and may be represented by the instantaneous fuel delivery temperature $T_{fuel-inst}$ or the mass average of the fuel delivery temperature ($T_{fuel-ave}$ or $T_{fuel-ave-roll}$ for table-based protocol, MAT_0, MAT_{30}, or MAT_C for MC Formula protocol).

3.16.5.1 INSTANTANEOUS FUEL DELIVERY TEMPERATURE ($T_{fuel-inst}$)

The instantaneous fuel delivery temperature.

3.16.5.2 TOTAL MASS AVERAGE FUEL DELIVERY TEMPERATURE ($T_{fuel-ave}$)

The fuel delivery temperature weighted by the mass dispensed during the main fueling time after a total of 30 seconds of mass flow have elapsed from the start of the main fueling time. See 8.1.2.2.2.

3.16.5.3 ROLLING MASS AVERAGE FUEL DELIVERY TEMPERATURE ($T_{fuel-ave-roll}$)

The fuel delivery temperature weighted by the mass dispensed over a rolling 30 second period of time, beginning after a total of 30 seconds of mass flow have elapsed from the start of the main fueling time (see 8.1.2.2.3).

3.16.5.4 MASS AVERAGE FUEL DELIVERY TEMPERATURE (MAT_0)

The fuel delivery temperature weighted by the mass dispensed from the beginning of the main fueling time. Used only for the MC Formula protocol. See H.2.4 and J.2.3.1.

3.16.5.5 EXPECTED MASS AVERAGE FUEL DELIVERY TEMPERATURE ($MAT_{expected}$)

The expected end of fill fuel delivery temperature weighted by the mass dispensed from the beginning of the main fueling time (MAT_0). Used only for the MC Formula protocol. $MAT_{expected}$ is only utilized during the first 30 seconds of mass flow from the start of the main fueling time. See H.2.4 and J.2.3.1

3.16.5.6 THIRTY SECOND MASS AVERAGE FUEL DELIVERY TEMPERATURE (MAT_{30})

The fuel delivery temperature weighted by the mass dispensed after a total of 30 seconds of mass flow have elapsed from the start of the main fueling time. Used only for the MC Formula protocol. See H.2.4 and J.2.3.1.

3.16.5.7 CONTROL MASS AVERAGE FUEL DELIVERY TEMPERATURE (MAT_C)

A mathematical combination of $MAT_{expected}$, MAT_0, and MAT_{30} which is used as the control input to the t_{final} equation, which determines the pressure ramp rate. Used only for the MC Formula protocol. See H.2.4 and J.2.3.1.

3.16.6 FUEL DELIVERY TEMPERATURE CATEGORY

The fuel delivery temperature category identifies the range of allowable temperatures of the hydrogen gas. The fuel delivery temperature category is designated by the letter “T” followed by the gas fuel delivery temperature representing the category. For example, as per Tables 3 and 8, the fuel delivery temperature category for the range from -40 to -33 °C is designated as T40.

3.16.7 DISPENSER COMPONENT TEMPERATURE MEASUREMENT

A temperature measurement which considers the temperature of the dispenser components.

4. ABBREVIATIONS AND SYMBOLS

4.1 Abbreviations

APRR	Average Pressure Ramp Rate (MPa/min)
CD	Cold Dispenser
CHSS	Compressed Hydrogen Storage System
FC	Fueling Command
FCEV	Fuel Cell Electric Vehicle
H_2	Hydrogen
HSTA	Hydrogen Station Test Apparatus
HSV	Hydrogen Surface Vehicle
ID	Protocol Identifier
IrDA	Infrared Data Association
MAWP	Maximum Allowable Working Pressure
MOP	Maximum Operating Pressure
MP	Measured Pressure
MT	CHSS Measured Temperature
NIST	National Institute of Standards and Technology
NWP	Nominal Working Pressure
OD	Optional Data
PRV	Pressure Relief Valve
RT	Receptacle Type
SOC	State of Charge
TV	Tank Volume
VN	Version Number

4.2 Symbols

4.2.1 Table-Based Protocol Symbols

$APRR_{actual}$	Interpolated value of the average pressure ramp rate (MPa/min) from a look-up table
$APRR_{target}$	Target average pressure ramp rate (MPa/min)
$APRR_{sec}$	Prescribed pressure ramp rate at the beginning of the main fueling time (MPa/s)
$APRR_{final}$	APRR from fallback look-up table (based on ambient temperature and P_0)
$\rho(P,T)$	Gas density, a function of pressure, P, and temperature, T
$m_{startup}$	Mass dispensed during startup time
P_0	Initial CHSS pressure level prior to fueling
P_{target}	Target fueling pressure
$P_{station}$	Fueling pressure as measured by station
$P_{startup}$	Startup pressure
$P_{vehicle}$	CHSS pressure
$t_{fueling}$	Main fueling time; does not include intended non-fueling time during the main fueling time
t_{end}	Shutdown time
$t_{startup}$	Startup time measured in seconds
$T_{vehicle}$	CHSS temperature data received by station from vehicle during communications fueling
T_{fuel}	Fuel delivery temperature
T_{fuel_inst}	Instantaneous fuel delivery temperature
$T_{fuel-ave}$	The total mass average of the fuel delivery temperature after a total of 30 seconds of mass flow during the main fueling time
$T_{fuel-ave-roll}$	A 30 second rolling mass average of the fuel delivery temperature after a total of 30 seconds of mass flow during the main fueling time
T_{amb}	Ambient temperature as measured by fueling station, not in direct sunlight
$SOC_{station}$	SOC calculated by using $P_{station}$ and MT
$SOC_{vehicle}$	SOC calculated by using $P_{vehicle}$ and MT
V_{CHSS}	Volume of the CHSS measured or otherwise determined by the station
$V_{station\_D}$	Station volume value to be set between 137 to 174 in liters (for use with CHSS Capacity Category D)

4.2.2 MC Formula-Based Protocol Symbols

a, b, c, d	Coefficients utilized in the t_{final} equation
AC, BC, GC, KC, JC	Five constants utilized in the MC Equation
c_{v_cold}	Specific heat capacity of hydrogen at constant volume
CD	An optional flag variable that when TRUE, indicates that the “cold dispenser” criteria is met
$CHSS_{Capacity\_Category}$	An indicator of the CHSS Capacity Category as defined in Table 8
h	The enthalpy measured at the dispenser outlet. A function of T_{fuel} and $P_{station}$
h_{ave}	The mass average of the dispenser outlet enthalpy calculated from the start of the main fueling time (i.e., from t = 0 seconds)
i	A calculation time step counter, which advances every 5 seconds
Indicator Cons RR	A flag variable, which when TRUE, indicates that the CHSS Capacity Category is indeterminate
j	A calculation time step counter, which advances every second
m	The total mass dispensed from the beginning of the main fueling time up to the current time
$\dot{m}$	The mass flow rate of dispensed hydrogen
m_{init_cold}	The initial cold case mass in the 1 kg Type III vessel used in the MC Method ending pressure control option
m_{final_cold}	The mass corresponding to 100% SOC of the 1 kg Type III vessel used in the MC Method ending pressure control option
m_{add}	The mass of hydrogen required to be added to the cold case initial mass to achieve m_{final_cold}
$m_{startup}$	Mass dispensed during startup time
$MAT_{expected}$	The expected mass average of the fuel delivery temperature at the end of the fill
MAT_0	The mass average of $T_{fuel\text{-}inst}$ calculated from the start of the main fueling time (i.e., t = 0 seconds)
MAT_{30}	The mass average of $T_{fuel\text{-}inst}$ calculated starting after a total of 30 seconds of mass flow have elapsed
MAT_C	A mathematical combination of $MAT_{expected}$, MAT_{30}, and MAT_0 utilized as the control input for the t_{final} equation
MC_{cold}	A parameter representing a lumped heat capacity of the cold case CHSS; used to calculate T_{cold}
MT	The CHSS measured temperature communicated via IRDA according to SAE J2799
MP	The CHSS measured pressure communicated via IRDA according to SAE J2799
n	A counter which advances at the same frequency as time step counter j, but only if there is mass flow; it is utilized to determine the point in the fill at which the calculation of MAT_{30} commences

$P_{control}$ The dispenser outlet pressure which the dispenser control targets throughout the fill

P_{final} The final pressure used in the derivation of the t_{final} equation coefficients

$P_{initial}$ Initial pressure of hydrogen in the CHSS as per the definition in 3.11.3

P_{limit_comm} An upper limit on pressure for communication fills to provide protection against a fault in MT

P_{limit_high} The upper boundary of the pressure corridor which $P_{station}$ must stay within

P_{limit_low} The lower boundary of the pressure corridor which $P_{station}$ must stay within

ΔP_{low} An input to the equation for β; it replaces ΔP_{tol_low} in the β equation to reduce excess margin

P_{min} The initial pressure used in the derivation of the t_{final} equation coefficients

ΔP_{offset} An offset pressure added to P_{ramp} to determine the control pressure $P_{control}$

P_{ramp} The pressure upon which the PRR is based; used to define P_{limit_high}, P_{limit_low}, and $P_{control}$

$P_{station}$ Fueling pressure as measured by station at the dispenser outlet

$P_{startup}$ Startup pressure

$P_{target\_non\_comm}$ The target end of fill pressure for non-communication fills

P_{target_comm} The target end of fill pressure for communication fills

ΔP_{tol_high} A delta pressure added to P_{ramp} to define P_{limit_high}; also used in calculating β

ΔP_{tol_low} A delta pressure subtracted from P_{ramp} to define P_{limit_low}; also used in calculating β

P_{trans} A parameter which determines the weighting of MAT_0 and MAT_{30} in the MAT_C equation

PRR Pressure ramp rate; this represents the rate of change of P_{ramp} (MPa/s)

PRR_{CAP} A cap on the PRR to limit the maximum flow rate and to prevent α from becoming too large

PRR_{CAP_Factor} A factor utilized in the equation to calculate PRR_{CAP} which determines the magnitude of PRR_{CAP}

RR_{max} The maximum calculated pressure ramp rate throughout the fill

RR_{min} The minimum calculated pressure ramp rate throughout the fill

SOC_{target} The end of fill target SOC, used in calculating P_{target_comm}; expressed in percentage

t Fueling time, representing the total time elapsed since the initiation of the main fueling time, including the time elapsed during intended non-fueling events

t_{final} The time required to fill from P_{min} to P_{final} under hot case conditions; input to the PRR equation

t_{final_min} The minimum value for t_{final}; t_{final_min} is a function of P_{min} and the $CHSS_{Capacity\_Category}$

$t_{final\_min\_A}$ The minimum value for t_{final} for the $CHSS_{Capacity\_Category}$ A

$t_{final\_min\_B}$	The minimum value for t_{final} for the $CHSS_{Capacity\_Category}$ B
$t_{final\_min\_C}$	The minimum value for t_{final} for the $CHSS_{Capacity\_Category}$ C
$t_{final\_min\_cons}$	The minimum value for t_{final} when the $CHSS_{Capacity\_Category}$ is indeterminate
t_{min_cold}	A parameter used in MC equation representing the time elapsed after which Δt_{cold} is calculated
$t_{startup}$	Startup time measured in seconds
Δt_{cold}	The difference between the fueling time t and t_{min_cold}
t_{tol_low}	The time at which ΔP_{low} is measured to determine if $P_{station}$ is less than P_{ramp}
$T_{adiabatic\_cold}$	The cold case adiabatic temperature used in the MC Method ending pressure control option calculations
T_{amb}	Ambient temperature as measured by fueling station, not in direct sunlight
T_{cold}	The MC Method ending pressure control option cold case gas temperature; used to determine $P_{target\_non\_comm}$ and P_{limit_comm}
T_{fit_1}, T_{fit_2}	Regression equations used to calculate T_{init_cold}
T_{fuel}	Fuel delivery temperature
T_{fuel_inst}	Instantaneous fuel delivery temperature measured at the dispenser outlet
$T_{fuel\_inst\_A}$, $T_{fuel\_inst\_B}$	Two independent measurements of the instantaneous fuel delivery temperature for redundancy
T_{init_cold}	The initial gas temperature in the cold case CHSS; T_{init_cold} is a function of T_{amb} and $P_{initial}$
TopOff	An optional flag variable that when TRUE, caps PRR at 0.33 MPa/s to reduce the pressure drop
$u_{adiabatic\_cold}$	The MC Method ending pressure control option cold case adiabatic specific internal energy
$U_{adiabatic\_cold}$	The MC Method ending pressure control option cold case adiabatic internal energy
u_{init_cold}	The MC Method ending pressure control option cold case initial specific internal energy
U_{init_cold}	The MC Method ending pressure control option cold case initial internal energy
V_{CHSS}	Volume of the CHSS measured or otherwise determined by the station
V_{cold}	The volume of the 1 kg Type III vessel used in the calculation of T_{cold} in the MC Method ending pressure control option
ρ_{init_cold}	The MC Method ending pressure control option cold case initial density calculated based on $P_{initial}$ and T_{init_cold}
α	A parameter which is multiplied by t_{final} to compensate for non-linearity in the PRR during the fill
β	A parameter which is multiplied by t_{final} to allow tolerance on pressure, i.e., the pressure corridor

5. GENERAL FUELING PROTOCOL DESCRIPTION

SAE J2601 establishes a gaseous hydrogen fueling protocol for hydrogen surface vehicles with CHSS capacities between 49.7 L and 248.6 L (H35 and H70) and above 248.6 L (H70 only) and a maximum flow rate of 60 g/s. The standard assumes that a station will perform fueling from its high pressure storage into the vehicle after successful vehicle connection and completion of initial checks. The fueling station is responsible for controlling the fueling process within the operating boundaries described below. Variables that affect the fueling process include, but are not limited to:

- Ambient temperature
- Dispenser pressure class and fuel delivery temperature
- CHSS size, shape, material properties, starting temperature, and pressure
- Dispenser to vehicle pressure drop and heat transfer

A representative fueling profile is shown below in Figure 2. The profile consists of a startup time which begins when the nozzle is connected to the vehicle and includes a connection pressure pulse. During the startup time, the station measures the initial CHSS pressure and CHSS capacity category and may also check for leaks. The main fueling begins when gas starts flowing into the vehicle. During this period, the pressure rises and the temperature of the CHSS increases. The fueling protocol should be designed such that the CHSS does not exceed the maximum operating temperature at any point during the fill. The final stage is the shutdown, which occurs after hydrogen gas has stopped flowing and ends when the nozzle can be disconnected.

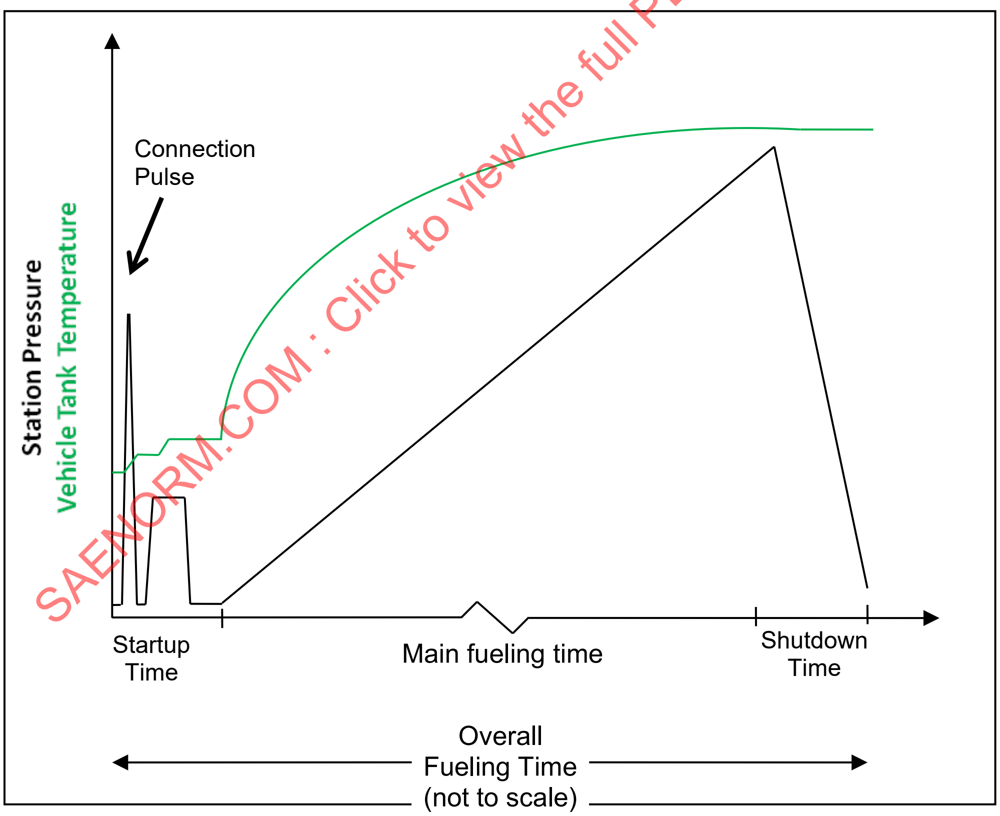

Figure 2 - Representative vehicle CHSS temperature and pressure profile during a fueling

5.1 Performance Goals

In general, the goal of SAE J2601 is to provide a high density fueling as fast as possible while staying within the process limits. The state of charge target when fueling with communications is 95 to 100% SOC under all operating conditions.

The fueling time can vary widely depending on ambient temperature, initial CHSS pressure, size of CHSS, final SOC, and other conditions. In order to establish a fueling time goal, the SAE team agreed to define the parameters of a "reference" fueling:

- Communications fueling tables
- Dispenser category = H70-T40
- Ambient temperature = 20 °C
- Initial CHSS pressure = 10 MPa
- Final SOC = 95%

Under these "reference" conditions, the goal of the fueling protocols in SAE J2601 is that the main fueling time is 3 minutes or less.

5.2 Normal Operating Boundaries

The fueling protocols in SAE J2601 are designed to ensure the hydrogen gas in the CHSS does not operate outside of the normal operating boundaries which are defined by the process requirements listed in Section 6. These limits include the CHSS maximum temperature and MOP.

For a H70 CHSS, these temperature and pressure limits are -40 to 85 °C and 0.5 to 87.5 MPa, respectively. Figure 3 shows the boundaries for a H70 fueling. The maximum CHSS gas temperature and MOP are fixed limits at the right (overheat) and top (overpressure) portions of the graph. The maximum density (100% SOC) provides an additional boundary.

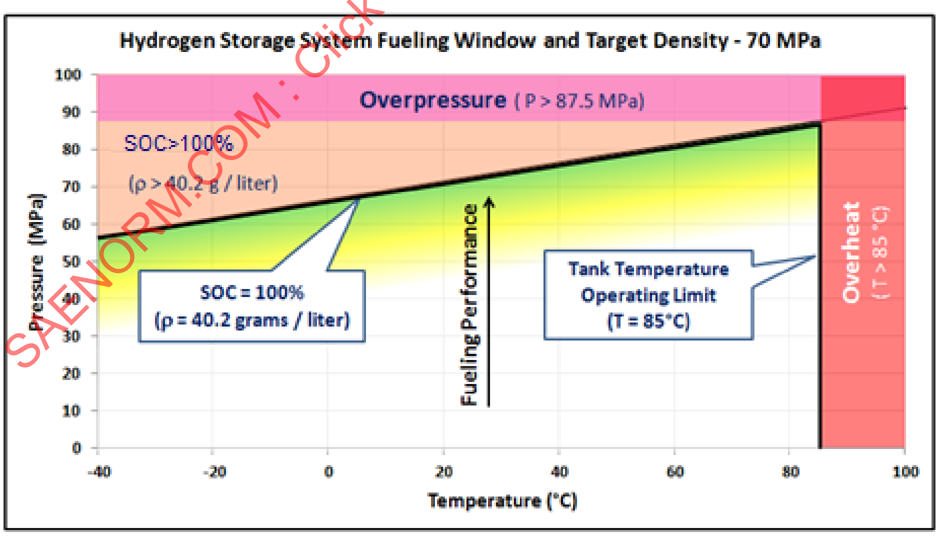

Figure 3 - SAE J2601 normal H70 boundary conditions

In order to keep the CHSS within its operating boundaries (i.e., Figure 3), the station must adjust the flow of the gas depending on the full set of initial conditions. For example, if a vehicle is fueled on a hot day, the initial CHSS temperature may be warmer, so the station must fuel more slowly to ensure the CHSS does not exceed the maximum vehicle CHSS operating temperature.

For more details on maximum operating limits for normal and fault operation boundaries, see F.2.

5.3 Standard Protocol

A Standard Protocol is defined as a protocol which:

- Complies with the general fueling protocol description of Section 5; and
- Complies with the general process requirements in Section 6; and
- Takes into account both the station and vehicle CHSS assumptions defined in Section 7 and Appendix A; and
- Has demonstrated the ability to keep the CHSS within its operation boundary limits under all conceivable operating conditions via computer modeling and bench testing; and
- Has been tested and validated in the field at representative real world hydrogen stations; and
- Has been reviewed and approved by the SAE Fuel Cell Standards Committee Interface Task Force.

The table-based protocol described in Section 8 and the MC Formula-based protocol described in Section 9 each meet the definition of a standard protocol, and therefore, either protocol may be utilized in satisfying the requirements of SAE J2601.

It is recommended that standard protocols and any non-standard protocols not be offered in the same station in order to minimize any risk of CHSS overheating in a subsequent fueling.

6. GENERAL PROCESS REQUIREMENTS FOR HYDROGEN FUELING

This section is intended to cover the general hydrogen fueling process requirements and does not contain all the detailed requirements for the dispenser and station. Each fueling protocol may have additional requirements and process limits which are discussed in subsequent sections. The requirements in this document are minimum requirements. Manufacturers may take additional safety precautions.

6.1 CHSS Storage Limits

This standard applies to fueling HSV with compressed hydrogen storage system capacity from 49.7 to 248.6 L (1.2 to 6.0 kg) for H35 (35 MPa), and from 49.7 to 248.6 L (2 to 10 kg) and greater than 248.6 L (>10 kg) for H70 (70 MPa). See Tables 4 and 8 for a breakdown of storage categories.

6.2 Process Requirements for Measurement and Sensors

6.2.1 Location

6.2.1.1 Station Pressure and Fuel Delivery Temperature

The sensors measuring the station pressure and fuel delivery temperature shall be located upstream of and as close as possible to the dispenser hose break-away. The flow length between sensor and hose break-away shall be no greater than 1 m.

6.2.1.2 Ambient Temperature

The sensor used to measure the ambient temperature shall be protected from environmental conditions that may affect its accuracy.

6.2.2 Accuracy

The station pressure, fuel delivery temperature, and ambient temperature shall account for the sensor accuracy to ensure the general process requirements in Section 6, as well as protocol specific process requirements in Sections 8 and 9, are not exceeded[2].

6.2.3 Frequency

The station pressure shall be recorded at a frequency to ensure the general process requirements in Section 6 are not exceeded and the performance of the station can be verified[2].

6.2.4 Reliability

As the station pressure, fuel delivery temperature, and ambient temperature measurements are safety relevant, the dispenser manufacturer should implement means to ensure their reliability. This may include redundancy or other means. If redundancy is utilized, the most conservative value should be used. IEC 61508/61511 may be referenced to provide guidance.

6.3 Temperature Process Requirements

6.3.1 Fuel Delivery Temperature

The instantaneous fuel delivery ($T_{fuel\text{-}inst}$) temperature shall always be greater than or equal to -40 °C. The station shall terminate vehicle fueling as soon as possible but within 5 seconds if $T_{fuel\text{-}inst}$ is less than -40 °C.

Although an upper limit on the instantaneous fuel delivery temperature is not provided as a process requirement, the standard protocols in this document were designed based on the assumption that the station components are soaked at the ambient temperature (see A.3.3). The station should implement an approach to ensure that temperature of the station components does not exceed the ambient temperature (e.g., via protection from radiant heating due to exposure to sunlight).

6.3.2 Vehicle CHSS Gas Temperature

For communications fuelings, the station should not fuel or should terminate vehicle fueling as soon as possible but within 5 seconds if the CHSS gas temperature signal is greater than 85 °C.

6.4 Pressure Process Requirements

6.4.1 Initial Pressure

The initial pressure shall be used as P_0 in applying the table-based protocol and $P_{initial}$ in applying the MC Formula-based protocol. If the initial pressure is less than 0.5 MPa or greater than the pressure class nominal working pressure (35 MPa or 70 MPa), then the station shall terminate the fueling procedure as soon as possible but within 5 seconds.

6.4.2 Operating Pressure

For communications fuelings, the station should not fuel or should terminate fueling as soon as possible but within 5 seconds if the CHSS pressure is greater than or equal to 125% NWP.

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[2] Specific sensor accuracy and frequency requirements are not specified in this document because this standard focuses on fueling protocol requirements and tries to minimize the station requirements. The Task Force did not want to limit sensor options as long as all general process requirements are maintained. Station providers should ensure that the worst-case accuracy of all sensors is taken into account.

6.5 Other Process Requirements

6.5.1 State of Charge

In communication fueling, the station should terminate fueling as soon as possible but within 5 seconds if the SOC is greater than or equal to 100%. The station may use $SOC_{vehicle}$ or $SOC_{station}$ (more conservative value) based on the station dispenser fueling methodology. Equation 1 of 3.12 or equivalent methods may be used to comply with this requirement.

6.5.2 Flow Rate

Fueling protocols shall be designed to not exceed a maximum flow rate of 60 g/s. After the initial connection sequence, the station shall terminate fueling as soon as possible but within 5 seconds if the measured maximum flow rate of the hydrogen gas exceeds 60 g/s.

6.5.3 Startup Time

6.5.3.1 Maximum Hydrogen Mass During Startup

The total mass of hydrogen transferred to the vehicle during startup shall be less than 200 g.

6.5.4 Tolerances

Station dispensers shall consider appropriate tolerances in their protocol implementation methodology to ensure a fueling is performed safely and accurately. Vehicles that communicate to the station should consider appropriate tolerances for their signals.

7. KEY MODELING ASSUMPTIONS

Thermodynamic modeling was used to develop the table-based fueling protocol and several assumptions were made based upon feedback from the station and vehicle manufacturers. This section and Appendix A (Tables A2 and A3) contain these assumptions. If the vehicle parameters are outside these bounds (see Appendix A), then the CHSS should be validated with respect to the standard protocols (and non-standard protocols, if applied) to ensure that CHSS operating boundaries are not violated and that there are no performance or other concerns.

7.1 Reference Conditions

In developing these protocols, the maximum total reference pressure drop from break-away to CHSS (see Appendix A) has been assumed under the following reference conditions: CHSS pressure of 10 MPa, and a fuel temperature of -15 °C at the break-away.

7.2 Vehicle and Station Dispenser Assumptions

The vehicle reference pressure drop is 20 MPa from receptacle to CHSS and the station dispenser reference pressure drop is 15 MPa from the break-away to the nozzle exit (combined total pressure drop of 35 MPa) at a mass flow 1.5 times the average mass flow required to fuel the entire storage capacity in 3 minutes; e.g., for a capacity of 5 kg: mass flow = 5000 g/180 s * 1.5 = 41.67 g/s.

8. TABLE-BASED FUELING PROTOCOL

The table-based fueling protocol uses the station fuel delivery temperature, ambient temperature, CHSS capacity category, and CHSS initial pressure to select appropriate fueling parameters. Modeling has been used to develop a series of parameter look-up tables that optimize the fueling process while ensuring that the process requirements of Section 6 are satisfied at all times. Note that the key modeling assumptions are presented in Section 7, and details are provided in Appendix A.

The station selects the correct look-up table based on fuel delivery temperature, CHSS capacity category, and the absence or presence of a communications signal from the vehicle. Once the proper table is selected, the station determines the specific fueling event parameters of average pressure ramp rate (APRR) and target pressure, based on ambient temperature and CHSS initial pressure. Detailed instructions on how to use the tables are provided in Appendix G.

For vehicles without communications, the station will fuel based on the look-up table APRR until the look-up table target pressure is reached. For vehicles with communication, the same APRR will be applied. The station may use vehicle data, including the communicated CHSS temperature, to calculate the SOC and fuel up to a pressure corresponding to an SOC of 95 to 100%. However, the communications fueling tables target pressure takes precedence over the SOC calculation to ensure that the CHSS stays within its operational boundaries.

A sample fueling table is shown in Table 2 and the complete set of standard fueling tables are included in Appendix D. It should also be noted that for any given station fuel delivery temperature, ambient temperature, and CHSS capacity category, the look-up tables provide the same APRR for both H35 and H70 fueling (for the same CHSS volume); only the ending target pressures are different. This was done to address concerns about overheating if an H70 vehicle first fuels at an H35 dispenser and then immediately has an H70 fueling.

The table-based fueling protocol also contains a "top-off" method for increasing the final SOC if the initial pressure is lower than 5 MPa.

Table 2 - Sample fueling table, CHSS Capacity Category B/H70-T40 with communications

H70-T40 Capacity Category B comm	APRR [MPa/min]	Target Pressure Ptarget [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	5,1	78,2	87,5	2,6	see Top-Off	see Top-Off	80,8	85,7	86,8	86,5	85,8	85,0	84,0	82,7	81,1	no fueling
45	8,1	76,3	87,5	4,0	see Top-Off	see Top-Off	81,1	86,9	86,6	86,2	85,3	84,3	83,0	81,6	79,7	no fueling
40	11,5	73,2	87,5	5,4	see Top-Off	see Top-Off	81,1	86,9	86,4	85,9	84,7	83,5	82,0	80,3	78,3	no fueling
35	12,4	72,9	87,5	5,6	see Top-Off	see Top-Off	81,2	86,9	86,4	85,9	84,7	83,4	81,9	80,2	78,2	no fueling
30	15,3	70,6	87,5	6,6	see Top-Off	see Top-Off	81,0	86,8	86,3	85,6	84,3	82,8	81,2	79,4	77,2	no fueling
25	18,5	69,0	87,4	7,2	see Top-Off	see Top-Off	81,0	86,8	86,1	85,4	83,8	82,2	80,4	78,5	76,1	no fueling
20	21,8	67,9	87,4	7,6	see Top-Off	see Top-Off	81,2	86,8	85,9	85,1	83,3	81,5	79,6	77,5	75,1	no fueling
10	28,0	66,3	87,4	9,0	see Top-Off	see Top-Off	81,2	86,8	85,7	84,7	82,6	80,5	78,3	76,1	73,4	no fueling
0	28,5	no Top-Off	no Top-Off	no Top-Off	78,4	84,6	86,8	85,6	84,4	83,1	80,6	78,1	75,6	73,1	no fueling	no fueling
-10	28,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,9	75,4	72,9	no fueling	no fueling
-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,6	75,1	72,7	no fueling	no fueling
-30	28,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,2	74,9	72,5	no fueling	no fueling
-40	28,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,0	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

There are optional "cold dispenser" (CD) tables which can improve fueling times (faster APRR) and may be implemented with a high utilization station (performing back-to-back fuelings). They may only be applied by a station that meets the CD criteria. See 8.12 for further details.

8.1 General Hydrogen Fueling Requirements

Stations using the table-based protocol shall meet all of the requirements in Section 6.

8.1.1 Station Designators

Table 3 illustrates the fuel delivery temperature categories per pressure classes for the table-based fueling protocol. A station is defined by the pressure class of fuel it delivers and its fuel delivery temperature capability. For example, the fuel delivery temperature category for the range from -40 to -33 °C is designated as T40. There are three fuel delivery temperature categories, designated by T40, T30, or T20. For CHSS Capacity Category D (see 8.2), the fuel delivery temperature categories are designated by T40D, T30D, or T20D, and generally have a wider operating range of fuel delivery temperatures.

Although a station may offer more than one combination of pressure class and fuel delivery temperature category with multiple dispensers, it is recommended that stations utilize common fuel delivery temperature categories for all dispensers (see A.3.9 for rationale). A dispenser shall not fuel a vehicle of a lower pressure class.

Table 3 - Fuel delivery temperature categories per pressure classes

Fuel Delivery Temperature Category		$-40\ ℃ \le T_{fuel} \le -33\ ℃$	$-33\ ℃ < T_{fuel} \le -26\ ℃$	$-26\ ℃ < T_{fuel} \le -17.5\ ℃$	$-40\ ℃ \le T_{fuel} \le -26\ ℃$	$-40\ ℃ \le T_{fuel} \le -17.5\ ℃$
Station Designator	35 MPa NWP	H35-T40	H35-T30	H35-T20	N/A	N/A
	70 MPa NWP	H70-T40/H70-T40D	H70-T30	H70-T20	H70-T30D	H70-T20D

8.1.2 Fuel Delivery Temperature

This section defines the fuel delivery temperature requirements for the table-based fueling protocol. The overall temperature requirements are listed in 6.3.

8.1.2.1 Fuel Delivery Cool-down Requirement

The instantaneous fuel delivery temperature $T_{fuel\text{-}inst}$ shall fall within the fuel delivery temperature range listed in Table 3 for its designated category after a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time. If an intended non-fueling event occurs within the last 10 seconds of this 30 second period, a total of 40 seconds of mass flow is allowed. If the station cannot meet this requirement, it shall do one of the following: (a) follow the fuel delivery temperature fallback procedure listed in 8.10 (if applicable); (b) pause (no flow) for a minimum of 60 seconds before resuming the fill with the main fueling time $t_{fueling}$ set back to zero and $P_{startup}$ set to the most recent station pressure prior to resuming the fill; (c) terminate the fueling as soon as possible but within 5 seconds.

NOTE: The dispenser manufacturer should implement an approach which monitors the rate of change of the instantaneous fuel delivery temperature, $T_{fuel\text{-}inst}$, to ensure that it is decreasing at a rate which is expected. By doing so, the dispenser may be able to detect a fault condition at an earlier time than waiting until the full 30 seconds of mass flow has elapsed.

NOTE: Depending on dispenser and cooling system design, there may be conditions under which the requirement for the fuel delivery temperature to reach the upper boundary of the pre-cooling window within 30 seconds is impractical to achieve. Conditions which exacerbate this difficulty are high ambient temperatures, and small CHSS volumes. The SAE FC Standards Committee Interface Task Force plans to review data from the field to consider if any changes to this requirement are necessary in a future revision to SAE J2601.

8.1.2.2 Fuel Delivery Temperature Tolerance

For any fuel delivery category, after a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time (except if an intended non-fueling event occurs within the last 10 seconds of this 30 second period, then a total of 40 seconds of mass flow is allowed), the fuel delivery temperature shall maintain its corresponding temperature range listed in Table 3 by adhering to the requirements in 8.1.2.2.1, 8.1.2.2.2, or 8.1.2.2.3. If the station cannot hold the fuel delivery temperature within these fuel delivery temperature ranges, then it shall follow the fallback procedure in 8.10 (if applicable) or terminate the fueling as soon as possible but within 5 seconds.

The station may use any one of the three temperature measurement methods listed in 8.1.2.2.1 to 8.1.2.2.3 to monitor the fuel delivery temperature during the entire fueling.

8.1.2.2.1 Instantaneous Fuel Delivery Temperature

After a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time (except if an intended non-fueling event occurs within the last 10 seconds of this 30 second period, then a total of 40 seconds of mass flow is allowed), the instantaneous fuel delivery temperature ($T_{fuel\text{-}inst}$) shall be within its corresponding temperature category range shown in Table 3, except for during and within 10 seconds after an intended non-fueling event.

8.1.2.2.2 Total Mass Average Fuel Delivery Temperature

$T_{fuel\text{-}ave}$ is defined as the total mass average of $T_{fuel\text{-}inst}$, beginning after a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time, and is mathematically defined by Equation 2. In Equation 2, i represents a single calculation cycle with a duration of 1 second.

$$If\ i > 30$$

$$T_{fuel-ave(i)} = \frac{\sum_{30}^{i}\left[\left(m_{(i)}-m_{(i-1)}\right)\times 0.5\left(T_{fuel\_inst(i)}+T_{fuel\_inst(i-1)}\right)\right]}{\sum_{30}^{i}\left(m_{(i)}-m_{(i-1)}\right)} \quad \text{(Eq. 2)}$$

After a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time (except if an intended non-fueling event occurs within the last 10 seconds of this 30 second period, then a total of 40 seconds of mass flow is allowed), $T_{fuel\text{-}ave}$ shall stay within the range shown in Table 3 at any time that the mass flow rate is greater than 0.6 g/s for more than 10 seconds. An additional requirement is that ($T_{fuel\text{-}inst}$ - $T_{fuel\text{-}ave}$) <10 °C at any time that the mass flow rate is greater than 0.6 g/s for more than 10 seconds. This mass flow value is 1% of the maximal mass flow rate described in 6.5.2 (i.e., 0.01 * 60 g/s = 0.6 g/s).

8.1.2.2.3 Rolling Mass Average Fuel Delivery Temperature

$T_{fuel\text{-}ave\text{-}roll}$ is defined as a 30 second rolling mass average of $T_{fuel\text{-}inst}$, beginning after a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time, and is mathematically defined by Equation 3. In this equation, i represents a single calculation cycle with a duration of 1 second.

$$If\ 30 < i \le 60$$

$$T_{fuel-ave-roll(i)} = \frac{\sum_{30}^{i}\left[\left(m_{(i)}-m_{(i-1)}\right)\times 0.5\left(T_{fuelint(i)}+T_{fuelinst(i-1)}\right)\right]}{\sum_{30}^{i}\left(m_{(i)}-m_{(i-1)}\right)} \quad \text{(Eq. 3)}$$

$$If\ i > 60$$

$$T_{fuel-ave-roll(i)} = \frac{\sum_{i-30}^{i}\left[\left(m_{(i)}-m_{(i-1)}\right)\times 0.5\left(T_{fuelinst(i)}+T_{fuelinst(i-1)}\right)\right]}{\sum_{30}^{i}\left(m_{(i)}-m_{(i-1)}\right)}$$

After a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time (except if an intended non-fueling event occurs within the last 10 seconds of this 30 second period, then a total of 40 seconds of mass flow is allowed), $T_{fuel\text{-}ave\text{-}roll}$ shall stay within the range shown in Table 3 at any time that the mass flow rate is greater than 0.6 g/s for more than 10 seconds. An additional requirement is that ($T_{fuel\text{-}inst}$ - $T_{fuel\text{-}ave\text{-}roll}$) <10 °C at any time that the mass flow rate is greater than 0.6 g/s for more than 10 seconds.

8.1.3 Minimum Startup Time

The startup time, $t_{startup}$, shall satisfy the following requirement.

$$t_{startup} \geq \frac{aV^b m_{startup}^c}{(APRR_{sec})} \quad \text{(Eq. 4)}$$

where:

$APRR_{sec}$ = prescribed pressure ramp rate at the beginning of the main fueling time (MPa/s)

V = CHSS volume (if CHSS volume is indeterminate, the smallest CHSS volume shall be used, i.e., 49.7 L)

$m_{startup}$ = mass dispensed during startup time (grams)

a = 1.717

b = -0.9773

c = 0.9828

8.2 CHSS Capacity

Table 4 contains the allowable CHSS capacity categories for the table-based fueling protocol.

Table 4 - CHSS capacity categories

Pressure Class	Total Amount of Hydrogen in CHSS at 100% SOC (kg)	Water Volume of CHSS (L)	CHSS Capacity Category Identifier
H35	1.19 to 2.39	49.7 to 99.4	A
H35	2.39 to 4.18	99.4 to 174.0	B
H35	4.18 to 5.97	174.0 to 248.6	C
H70	2.00 to 4.00	49.7 to 99.4	A
H70	4.00 to 7.00	99.4 to 174.0	B
H70	7.00 to 10.00	174.0 to 248.6	C
H70	>10.00	>248.6	D

The station may choose to implement all CHSS capacity categories (H35 A through C, H70 A through D), or may choose to implement a sub-set of the CHSS capacity categories (e.g., A, B, and C, but not D).

Where a station is capable of determining the CHSS capacity using a method that is accurate to within ±15%, the CHSS capacity category can be used to select the appropriate fueling look-up table.

If the station cannot guarantee this degree of accuracy, or if the CHSS capacity category is indeterminate (for example, if the measured CHSS capacity is 4.01 kg, but the accuracy is ±15%, then the CHSS capacity category is indeterminate), then the station shall use more conservative values. See G.2 for a detailed explanation of this conservative approach, along with examples.

8.3 Pressure Requirements

8.3.1 Initial Pressure

The initial pressure shall be used as P_0 in applying the table-based protocol. If the initial pressure is less than 0.5 MPa or greater than the pressure class nominal working pressure (35 MPa or 70 MPa), then the station shall terminate the fueling procedure as soon as possible but within 5 seconds.

NOTE: The initial pressure is measured by the station (see definition in 3.11.3). A communicated pressure from the vehicle <0.5 MPa prior to the connection pulse is acceptable provided the initial pressure measured after the connection pulse exceeds 0.5 MPa.

8.3.2 Pressure Tolerances for APRR

During the main fueling period, the station applies a pressure, targeting an average pressure ramp rate value ($APRR_{target}$) based on the fueling look-up tables, or in the case of CHSS Capacity Category D, the lesser of the fueling look-up table value and a calculated value (see 8.7.1).

The pressure applied shall fall within upper and lower tolerance as defined below, based on the main fueling period elapsed time ($t_{fueling}$). The resulting tolerance corridor is depicted graphically in Figure 4. During the main fueling time, with an exception for the first 15 seconds, the station shall maintain the station pressure within the upper and lower tolerances. If the station pressure exceeds the upper pressure tolerance by 5 MPa or less, it shall come back within the tolerance within 5 seconds of the initial excursion, or shall stop fueling within 5 seconds of the initial excursion. If the magnitude of the excursion is greater than 5 MPa, the station shall stop fueling within 5 seconds of the initial excursion. If the station pressure falls below the lower pressure tolerance, it shall come back within the tolerance within a total of 15 seconds of the initial excursion, not counting intended non-fueling time, and if it does not, the station shall stop fueling within a total of 15 seconds of the initial excursion.

Upper pressure tolerance:

(CHSS Capacity Categories A, B, C, D): $P_{station} \leq P_{startup} + (APRR_{target})\ (t_{fueling}) + \Delta P_{upper}$, where $\Delta P_{upper} = 7.0$ MPa

Lower pressure tolerance:

(CHSS Capacity Categories A, B, C): $P_{station} \geq P_{startup} + \text{Max}\ [((APRR_{target})\ (t_{fueling}) - \Delta P_{lower}), 0]$, where $\Delta P_{lower} = 2.5$ MPa

(CHSS Capacity Category D): $P_{station} \geq P_{startup} + \text{Max}\ [((1\ \text{MPa/min})\ (t_{fueling}) - \Delta P_{lower}), 0]$, where $\Delta P_{lower} = 2.5$ MPa

Intended non-fueling time (e.g., for bank switch or leak check) is not included in the main fueling period elapsed time (i.e., $t_{fueling}$ does not advance during intended non-fueling time). The station pressure must stay above the lower pressure tolerance only when mass is flowing, which excludes intended non-fueling events.

Figure 5 depicts an actual fueling that is interrupted by intended non-fueling time for CHSS Capacity Categories A, B, and C. When these non-fueling times are removed from Figure 5, it reverts to Figure 4 and therefore satisfies the pressure ramp requirements. Figure 6 depicts the pressure tolerances when fueling under CHSS Capacity Category D, where the lower pressure tolerance is based on an APRR of 1 MPa/min.

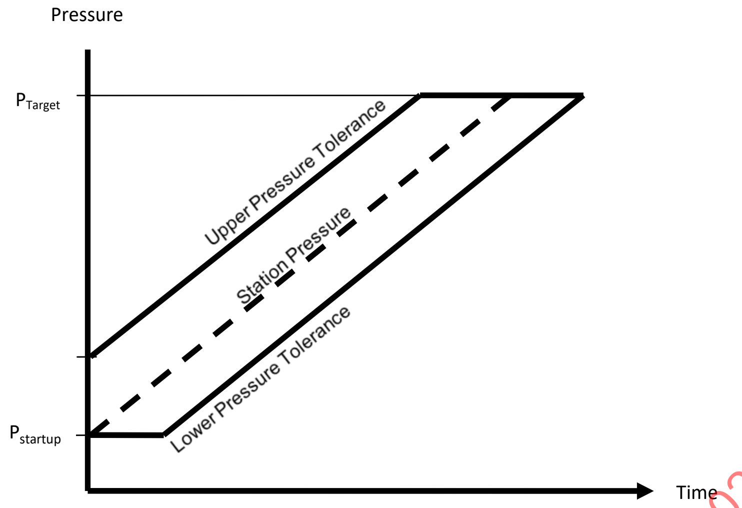

Figure 4 - Pressure ramp boundaries (CHSS Capacity Categories A, B, C)

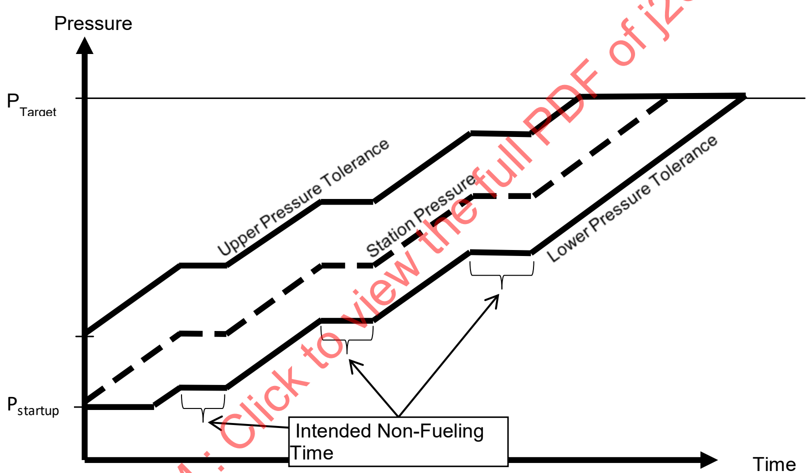

Figure 5 - Pressure ramp boundaries with non-fueling time (CHSS Capacity Categories A, B, C)

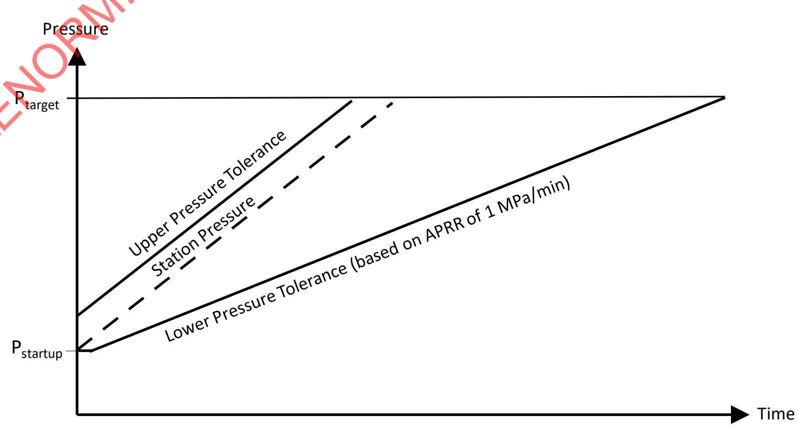

Figure 6 - Pressure ramp boundaries (CHSS Capacity Category D)

8.4 Cycle Control

The dispenser shall not control hydrogen flow in a cyclic manner by repeatedly starting and stopping the fueling. The station shall not decrease the flow of gas below 1% of the maximum flow rate more than ten times during the main fueling period. This requirement includes the non-fueling events (leak checks, bank switching, etc.) during the main fueling period.

8.5 Abort Signal from Vehicle

If the dispenser utilizes communications, whether the fueling procedure is using communications or not, the station shall continue to monitor the communications interface and shall terminate fueling as soon as possible but within 5 seconds upon detection of an “abort” signal from the vehicle. The vehicle may use the abort signal to stop the fueling for any reason. This allows the vehicle to monitor the fueling process and complement the station operation with a secondary layer of control.

8.6 Tolerances

The station shall account for its tolerances in applying this fueling protocol. Tolerances shall be applied to ensure that the pressure ramp rate and ending pressure remain within their specified boundaries or limits.

8.7 Table-Based Fueling Flow Chart

Figure 7 illustrates a general flow chart for communications and non-communications, table-based, fueling. More detailed flow charts with subroutines are contained within Appendix B.

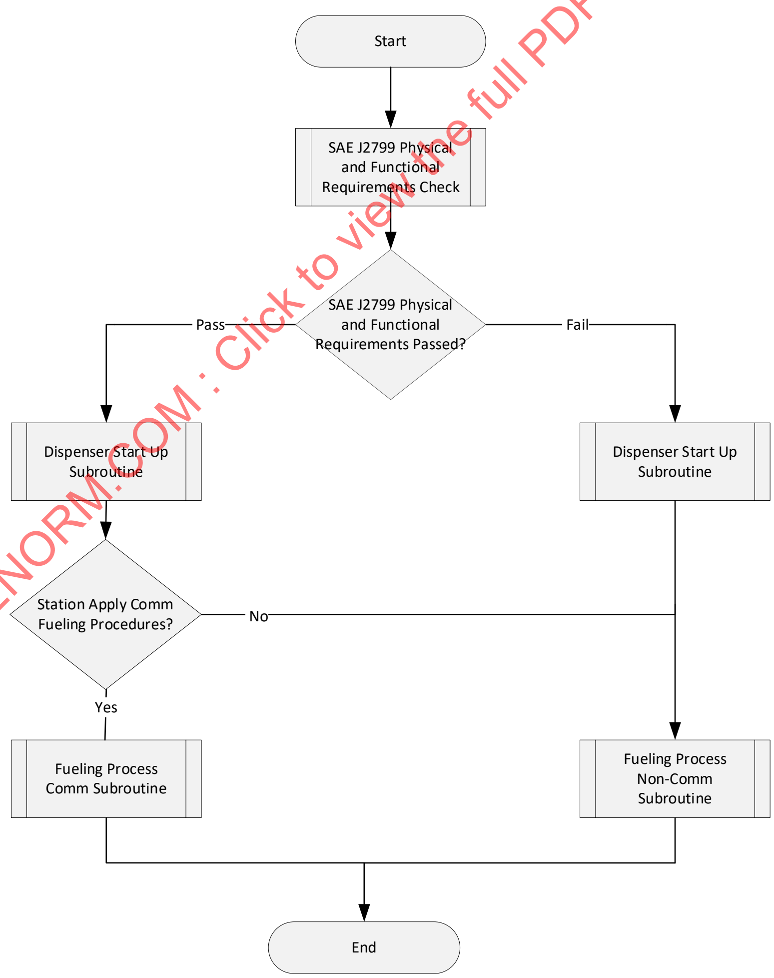

Figure 7 - General flow chart for communications and non-communications fueling

At the start of fueling, the station shall monitor the communications interface for SAE J2799 signals from the vehicle. If no signal is present or if signals received do not pass the physical and functional requirements, as defined in SAE J2799, then the station shall apply the non-communications fueling procedure as described in 8.8. If a signal is present and passes the physical and functional requirements, then the station should apply the communications fueling procedure as described in 8.9.

NOTE: In Figure 7, the station dispenser startup routine may begin before the SAE J2799 physical and functional requirements check, based on the station dispenser fueling methodology.

8.7.1 Determination of Fueling Table and Fueling Parameters

At the end of the fueling startup period, the station has all the information (rated dispenser fuel delivery temperature, communications, determined CHSS capacity category, etc.) it requires to select the proper fueling look-up table and to calculate the appropriate fueling parameters based on table values. Figure B6 provides an example of the inputs and logic used by the station in table selection.

After the station determines the appropriate fueling look-up table, the values of the measured ambient temperature (T_{amb}) and the initial CHSS pressure (P_0) will be used to determine the resulting APRR and target pressure (P_{target}).

Linear interpolation shall be used to derive actual fueling parameters from table values. This will be one-dimensional interpolation for the $APRR_{actual}$ (based on ambient temperature) and two-dimensional interpolation for the target pressure or pressure limit (based on ambient temperature and CHSS initial pressure). If one of the interpolation values is in the “no fueling” zone of the table, then the dispenser should not fuel the vehicle. Appendix G provides guidance for interpolation.

For CHSS Capacity Categories A, B, and C, during the main fueling period, the station applies a pressure, targeting an average pressure ramp rate value ($APRR_{target}$) equal to the $APRR_{actual}$ value. For CHSS Capacity Category D, during the main fueling period, the station applies a pressure, targeting an average pressure ramp rate value ($APRR_{target}$) calculated as the lower of two values: (a) $APRR_{actual}$ based on the appropriate fueling look-up table; (b) $APRR_{calculated}$ based on Equation 5.

$$IF\ CHSS\ Capacity\ Category = D \qquad \text{(Eq. 5)}$$

$$APRR_{calculated} = 28.5 \times \frac{V_{station\_D}}{V_{CHSS}}$$

$$APRR_{target} = Minimum(APRR_{calculated}, APRR_{actual})$$

where:

$V_{station\_D}$ = a volume set by the station to be a value between 137 to 174 (liters)

V_{CHSS} = the volume of the CHSS being fueled (liters)

$APRR_{actual}$ = the APRR value from the applicable CHSS Capacity Category D look-up table

8.8 Non-Communications Fueling

All stations using the table-based fueling protocol shall have the ability to fuel according to the non-communications fueling protocol.

The non-communications table-based fueling protocol assumes that no data is being passed from the vehicle to the station. For a given CHSS volume category and ambient temperature, the APRR is the same as communications fueling procedure. The primary difference is the end of fueling is defined only by target pressure.

8.8.1 Fueling Procedure

The non-communications fueling process uses the general description discussed in 8.7 to select the fueling parameters. A non-communications fueling process flow is represented in Figures B1 and B2. Figures B5 and B8 provide additional detail of operation within the fueling process non-communications subroutine.

8.8.2 End of Fueling

All non-communications fuelings shall end the fueling when the station pressure equals the selected non-communication table target pressure (P_{target}). The station may apply a methodology to measure or calculate the pressure loss between $P_{station}$ and $P_{vehicle}$ and adjust the station pressure by this value. If this approach is used, the station shall take appropriate measures to ensure that under all conditions, $P_{vehicle}$ does not exceed the target pressure (P_{target}).

8.9 Communications Fueling

The communications table-based fueling protocol shall use the IrDA signal as defined in SAE J2799 to provide information from the vehicle to the station. For the standard communications fueling procedure and for a given CHSS volume and ambient temperature, the APRR is the same as non-communications fueling procedure. The primary difference is that the station uses the SAE J2799 vehicle signals to determine the end of fueling at a higher SOC than non-communications. In the communications case, the target pressure is an upper limit.

If applicable, the use of communications should consider 3.6.1.1, as well as local codes.

8.9.1 Fueling Procedure

The communications fueling process uses the general description discussed in 8.7 to select the fueling parameters.

In Appendix B, a communications fueling process flow is represented in Figures B1, B3, and B4. Figures B5 and B8 provide additional detail of operation within the fueling process communications subroutine.

Figure B7 describes the optional fallback procedure that may be applied in communications fueling in cases where the station cannot maintain its fuel delivery temperature.

8.9.2 Establishing Communications

The dispenser shall attempt to receive communications from the vehicle, based on SAE J2799, throughout the fueling process. To prevent communications faults while the operator is connecting the fueling nozzle, the dispenser shall not consider communications as having been fully established until the nozzle is in place and the fueling startup procedure has begun. Once communications are established, the dispenser shall proceed to fuel using the communications fueling process for as long as valid signals continue to be received.

8.9.3 Loss of Communications

If the data signal from the vehicle is lost or fails the physical and functional requirements as defined in SAE J2799, then the dispenser shall terminate the fueling as soon as possible but within 5 seconds or shall optionally continue fueling the vehicle using the non-communications fueling procedure described in 8.8, assuming the station determines it is appropriate to continue with fueling after the loss of the fuel command signal.

If the station chooses to continue with a non-communication fueling after a loss in communications, the station shall determine a new non-communication target pressure based upon a new initial pressure determination.

8.9.4 Communications Data Fields Definition

SAE J2799 defines the IrDA communications data fields. This section defines their values and use for the table-based fueling protocols. The data fields to be sent from the vehicle to the station are listed below and described in the following sections. They should be placed in the order as follows:

ID: Protocol Identifier

VN: Version Number

TV: Tank Volume

RT: Receptacle Type

FC: Fueling Command

MP: Measured Pressure

MT: Measured Temperature

OD: Optional Data

8.9.4.1 Protocol Identifier

|ID=SAE␣J2799|

The vehicle shall transmit the Protocol Identifier ID=SAE J2799. The "␣" symbol is to denote a space and used after SAE in the identifier. The dispenser shall not fuel the vehicle if the Protocol Identifier from the vehicle does not match the Protocol Identifier of the table-based fueling protocol used by the dispenser.

8.9.4.2 Data Communications Software Version Number

For the table-based fueling protocol, the following are the communication version numbers

VN=01.00 or 01.10 are valid communications protocol as defined in SAE J2799.

The data field definitions are found in 8.9.4.

The dispenser shall not fuel the vehicle if the Version Number from the vehicle does not match VN=01.00 or VN=01.10.

VN=01.00 applicable stations shall be able to receive and use VN=01.00 data communications.

VN=01.10 applicable stations shall be able to receive and use both VN=01.00 and VN=01.10 data communications.

8.9.4.3 Tank Volume

Range: 0000.0 to 5000.0

The vehicle shall transmit the storage volume of the vehicle CHSS in liters (water volume at the nominal working pressure) to the dispenser.

8.9.4.4 Receptacle Type

|RT=H35| or |RT=H70|

The vehicle shall transmit the SAE J2600 pressure class for the vehicle's original fuel receptacle which shall also correspond to the CHSS NWP. The dispenser shall not dispense fuel if the RT is less than the pressure class of the station dispenser.

8.9.4.5 Fueling Command

The vehicle shall use the following fueling commands

|FC = Dyna|

When the vehicle transmits |FC = Dyna| and no optional data command, the dispenser shall dispense fuel based on the table-based communications fueling protocol defined in 8.9.

|FC = Stat|

|FC = Stat| shall not be used. If this command is received by the station, then the station shall consider communications to have failed the physical and functional requirements.

|FC = Halt|

|FC = Halt| is optional for vehicles. If a station does not implement the |FC = Halt|, then the station shall respond to this command by terminating the fueling process.

If the station uses this fueling command |FC = Halt|, then it shall pause the fueling. The station shall re-start the fueling process if the fueling command |FC = Dyna| is received for at least 2 seconds. The station shall end the fueling process if the fueling command |FC = Halt| is received for over 60 seconds.

|FC = Abort|

When the vehicle transmits |FC = Abort|, the dispenser shall terminate the fueling process as soon as possible but within 5 seconds.

8.9.4.6 Measured Pressure

Range: 000.0 to 100.0

The vehicle shall transmit the measured CHSS gas pressure in MPa. If the dispenser monitors the measured pressure, it should terminate the fueling as soon as possible, but within 5 seconds, if the measured pressure exceeds the MOP as defined in 3.11.7.

8.9.4.7 Measured Temperature

Range: 16.0 to 425.0

The vehicle shall transmit its CHSS measured gas temperature in Kelvin. The measured temperature should be representative of the average CHSS gas temperature. If the dispenser monitors the measured temperature, it shall terminate the fueling as soon as possible but within 5 seconds if the measured temperature exceeds the maximum operating vehicle CHSS gas temperature as defined in 6.3.2.

8.9.4.8 Optional Data

For the SAE table-based fueling protocol, the optional data command is ignored.

8.9.5 Communications Overfueling Density Limit

The tables for the communication fueling protocol include a communication end pressure which is used to ensure the density of the CHSS never exceeds 120% SOC. These precautions by the station are similar to the non-communications fueling protocol. See Figure A9 for further detail.

8.9.6 End of Fueling

The station may use vehicle data, including the communicated CHSS temperature, to calculate the SOC and should end the fueling at a pressure corresponding to an SOC of 95 to 100%. However, the pressure targets in the communications fueling tables take precedence over the SOC calculation to ensure that the CHSS stays within its operational boundaries.

8.10 Fuel Delivery Temperature Fault and Fallback Procedure

For communications fueling only, if a station cannot maintain the requirement of its fuel delivery temperature category as described in 8.1.2 then it shall either terminate fueling (as soon as possible but within 5 seconds) or “fallback” to a warmer fuel delivery temperature category. If the fallback option is chosen, then the station shall choose the appropriate fueling table and calculate a new target pressure using the same ambient temperature and CHSS initial pressure as were measured during fueling startup. The station shall calculate the new fallback pressure ramp rate ($FPRR_{target}$) using Equation 6:

$$FPRR_{\text{target}} = \frac{\left(P_{\text{final target}} - P_1\right)}{\left[1 / APRR_{\text{final}} * \left(P_{\text{final target}} - P_0\right) - t_{\text{station fallback}}\right]} \quad \text{(Eq. 6)}$$

where:

$APRR_{final}$ = APRR from fallback look-up table (based on ambient temperature and P_0)

$FPRR_{target}$ = target fallback pressure ramp rate

$P_{finaltarget}$ = target fueling pressure at the warmer fuel delivery temperature category

P_1 = pressure at fallback point

P_0 = CHSS initial pressure as measured during fueling startup

$t_{stationfallback}$ = main fueling time at fallback point

If the fallback pressure ramp rate $FPRR_{target}$ is less than the topoff pressure ramp rate (see 8.11), then $FPRR_{target}$ may be set to the topoff pressure ramp rate, when a topoff ramp rate is available.

Fallback shall not be allowed for non-communications fueling. If communications is lost during fallback, the station shall terminate the fill within 5 seconds. Stations shall not use the fallback procedure to switch to a colder fuel delivery temperature (and faster APRR), including switching back to the original APRR if the station returns to the initial fuel delivery temperature category. The fallback procedure can only be used once during a fueling and the station shall terminate the fueling (as soon as possible but within 5 seconds) if the fuel delivery temperature exceeds a fallback fuel delivery temperature upper limit. Where the station fuel delivery temperature has returned to the initial fuel delivery temperature category after a fallback, the fill can continue, provided that the fill profile uses the target pressure and APRR associated with the warmer (fallback) temperature category.

Figure 8 shows an example of the fallback procedure where the station begins fueling at the T40 fuel delivery temperature category then later falls back to the T30 fuel delivery temperature category when the fuel delivery temperature exceeds -33 °C. Figure B7 provides an example of the station fallback fueling process flow.

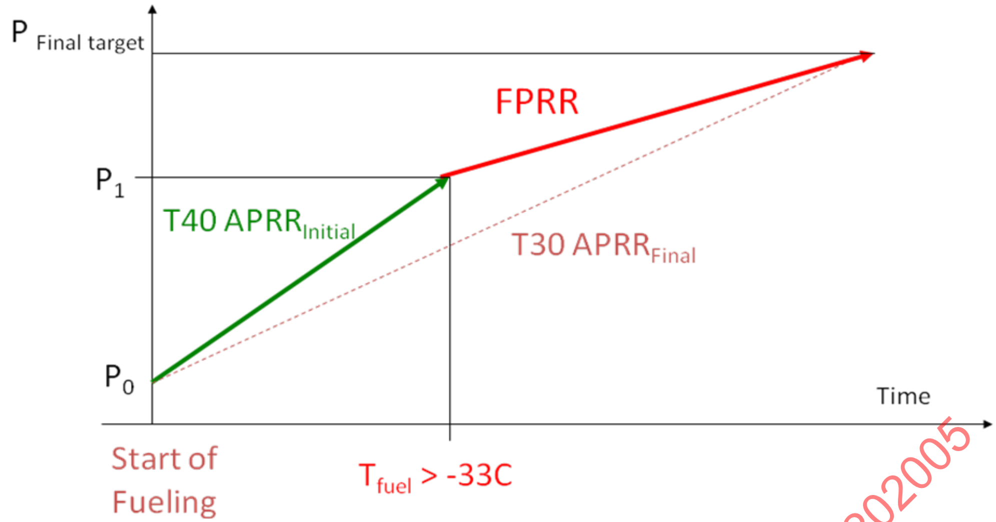

Figure 8 - Fallback procedure example - T40 to T30

8.11 Top-Off Fueling

Stations shall use the top-off fueling procedure to increase the SOC if the initial pressure is less than 5 MPa. The top-off fueling procedure is defined in this section. The flow diagrams are in Appendix B, and fueling tables are found in part of the H70 communication tables in Appendices D and E. Once the target pressure is achieved, the station shall fuel the vehicle at a slower $APRR_{target}$ until target SOC is achieved, an abort signal is received, or the target pressure is reached. For conditions where the fueling table does not provide clear instructions (such as in the H70 T40 CHSS Capacity Category B Table, 5 °C T_{amb} and 1 MPa P_0), the dispenser should utilize the values for the next warmest explicitly described conditions (using the same example of the H70 T40 CHSS Capacity Category B Table, use 10 °C T_{amb} and 1 MPa P_0). See Appendix G, Examples C and D for additional examples of how to utilize the tables for top-off fueling.

The top-off procedure shall only be used for H70 pressure class and communications fueling protocol.

Top-off fueling provides two benefits. By starting with a faster APRR and later shifting to a slower APRR, the CHSS temperature rise is accelerated, causing more heat to transfer out of the fuel sooner and resulting in faster overall fill times. The faster initial APRR also provides the customer with a faster partial fill followed by a slower top-off. The customer who intervenes to end the fill early will then have received a significant partial fill in a reasonable amount of time. These benefits are important when fueling from low initial pressure, as CHSS heat development in these cases requires slow fueling pressure ramp rates.

8.12 Cold Dispenser Fueling Look-Up Tables

For communications fueling only and for CHSS Capacity Categories A, B, and C only, stations may optionally use the CD fueling procedure which allows for increased APRR when all of the dispenser components are at sufficiently cold temperature. The CD fueling procedure can use a higher APRR because if the dispenser components begin the fueling at a lower temperature, less heat is generated within the CHSS. Colder dispenser components can occur when two or more vehicles are fueled consecutively with minimal time in between.

The CD fueling procedure shall only be used for the H70 pressure class and the T30 and T40 gas delivery temperature categories. The CD fueling procedure shall only be used when the temperature of the dispenser components and T_{fuel} at the start of fueling are colder than either 0 °C or -10 °C following the guidance below. The CD fueling procedure shall only be used with communications fuelings. The station shall use the same procedure to select appropriate APRR and target pressure as for standard communications fuelings. However, stations shall select the appropriate CD table, determined using Table 5. The CD tables are listed in Appendix E.

Table 5 - Cold dispenser (CD) look-up tables overview for Appendix E

Maximum Station Component and T_{fuel} Temperature	**Cold Dispenser Communications**	
°C	**H70-T30**	**H70-T40**
0	Comm H70-T30 CD0	Comm H70-T40 CD0
-10	Comm H70-T30 CD-10	Comm H70-T40 CD-10

As this is a safety-relevant, information-based (station temperature sensors, etc.) decision made by the dispenser, IEC 61508/61511 or equivalent shall be adhered to which includes safety integrity levels (SIL) as well as requirements for the specification, design, installation, operation, and maintenance of a safety instrumented system. Lastly, correct operation should be field tested in accordance with CSA HGV 4.3 or equivalent.

Station manufacturers and operators should be aware that accurate temperature measurement on the station side is critical to ensuring that the CHSS temperature does not exceed its maximum operating temperature. Furthermore, environmental conditions, such as sunlight, may affect the accurate temperature measurement of the station.

The dispenser component temperature measurement(s) shall consider the effects of dispenser component temperature on fuel cooldown. The dispenser component measurement(s) should be in a location(s) where the hydrogen is expected to be warmest, which will generally be closest to the vehicle and downstream of the T_{fuel} measurement. The measurement location should consider the mass of the component, its heat transfer properties, and environmental factors. An example is a temperature measurement of the nozzle component or an in-stream hydrogen temperature measurement in the nozzle flow path. The dispenser component temperature measurement shall be used in accordance with Figure B6.

The CD fueling procedure tables were generated using the same modeling approach as the standard fueling tables. However, the CD tables were not tested and verified to the same level as the standard fueling tables. Therefore, station manufacturers should perform these tests prior to using the procedure in the field.

An example of a second optional cold dispenser fueling table is shown in Table 6 and the complete set of tables is included in Appendix E.

Table 6 - Sample fueling table, cold dispenser,
CHSS Capacity Category B/H70-T40 with communications

H70-T40 CHSS Capacity Category B comm CD0		APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	9,7	76,5	87,5	3,9	see Top-Off	see Top-Off	81,1	87,2	86,8	86,5	85,7	84,7	83,5	82,3	80,8	no fueling
	45	13,5	74,0	87,5	5,2	see Top-Off	see Top-Off	81,4	87,1	86,6	86,1	85,1	83,9	82,6	81,1	79,4	no fueling
	40	17,1	71,2	87,5	6,3	see Top-Off	see Top-Off	81,1	87,0	86,4	85,8	84,5	83,1	81,5	79,9	78,0	no fueling
	35	17,6	71,3	87,4	6,3	see Top-Off	see Top-Off	81,2	87,0	86,4	85,8	84,5	83,0	81,5	79,9	78,0	no fueling
	30	20,2	69,8	87,4	6,7	see Top-Off	see Top-Off	81,1	87,0	86,3	85,5	84,0	82,5	80,8	79,0	77,0	no fueling
	25	22,9	68,7	87,4	7,2	see Top-Off	see Top-Off	81,1	86,9	86,1	85,3	83,6	81,9	80,1	78,2	76,0	no fueling
	20	25,7	67,6	87,4	8,0	see Top-Off	see Top-Off	81,1	86,9	86,0	85,0	83,2	81,3	79,3	77,3	74,9	no fueling
	10	28,5	68,4	87,4	7,9	see Top-Off	see Top-Off	83,9	86,6	85,6	84,5	82,4	80,3	78,1	75,9	73,3	no fueling
	0	28,5	no Top-Off	no Top-Off	no Top-Off	78,4	84,6	86,8	85,6	84,4	83,1	80,6	78,1	75,6	73,1	no fueling	no fueling
	-10	28,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,9	75,4	72,9	no fueling	no fueling
	-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,6	75,1	72,7	no fueling	no fueling
	-30	28,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,2	74,9	72,5	no fueling	no fueling
	-40	28,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,0	74,6	72,3	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

9. MC FORMULA-BASED FUELING PROTOCOL

The MC Formula-based fueling protocol uses the station fuel delivery temperature and pressure, ambient temperature, CHSS capacity category, and CHSS initial pressure to calculate appropriate fueling parameters, in real-time for the duration of the fill. Modeling has been used to derive the parameters and coefficients utilized by the MC Formula-based protocol in order to optimize the fueling performance while ensuring that the process requirements of Section 6 are satisfied at all times. The key modeling assumptions are presented in Section 7, and details are provided in Appendix H.

The station selects the appropriate parameters and coefficients based on the pressure class, the fuel delivery temperature category, the CHSS initial pressure, the CHSS capacity category, and the ambient temperature. These are used to calculate the pressure ramp rate (PRR) and target pressure, which are both updated periodically throughout the fill. There are two options provided for ending pressure control (i.e., determination of the target pressures): The MC Method, or ending pressure tables. Either option may be utilized. Appendix H provides a detailed explanation and rationale for each option.

For vehicles without communications, the station will stop the fill when the calculated non-communication target pressure is reached. For vehicles with communication, the station will stop the fill at a pressure corresponding to a CHSS SOC of 95 to 100%. The station may use vehicle data, including the communicated CHSS temperature, to calculate the communication target pressure corresponding to the target SOC. However, the MC Formula-based protocol also calculates a limit pressure, which takes precedence over the communication target pressure to ensure that the CHSS stays within its operational boundaries. SAE J2799 defines the fueling messages utilized for communications fills. Section 9.9 defines the use of the communications signals for the MC Formula-based protocol.

As with the table-based protocol, for any given station fuel delivery temperature, ambient temperature, and CHSS capacity category, the MC Formula-based protocol utilizes the same PRR for both H35 and H70 fueling; only the ending target pressures are different. This is done to address concerns about overheating if an H70 vehicle first fuels at an H35 dispenser and then immediately has an H70 fueling.

There are optional “cold dispenser” (CD) coefficients which can improve fueling times during back-to-back fueling events (only applicable to the H70 pressure class). They shall only be applied by a station that meets the CD criteria. See 9.10 for further details.

The MC Formula-based flow charts and control logic are detailed in Appendix I. The subroutines containing the equations and coefficients utilized are detailed in Appendix J.

9.1 General Hydrogen Fueling Requirements

Stations using the MC Formula-based protocol shall meet all of the requirements in Section 6.

9.1.1 Station Designators

Table 7 illustrates the fuel delivery temperature categories per pressure class for the MC Formula-based protocol. A station is defined by the pressure class of fuel it delivers and its fuel delivery temperature capability. For example, the fuel delivery temperature category for the range from -40 to -33 °C is designated as T40. There are three fuel delivery temperature categories, designated by T40, T30, or T20. Although a station may offer more than one combination of pressure class and fuel delivery temperature category with multiple dispensers, it is recommended that stations utilize common fuel delivery temperature categories for all dispensers (see A.4 for rationale). A dispenser shall not fuel a vehicle of a lower pressure class.

MAT_{30} represents the mass average of T_{fuel} calculated starting after a total of 30 seconds of mass flow have elapsed. MAT_{30} is defined in more detail in H.2.4. The station designator for the MC Formula-based protocol is based on the capability of the station to achieve a value of MAT_{30} less than or equal to the upper boundary temperature of the fuel delivery temperature category by the end of the main fueling time.

In addition to being used as a station designator, the fuel delivery temperature category is also used to determine the ending pressure targets when ending pressure tables are used as the ending pressure control option. In this case, for the purpose of determining the correct pressure target to use, the fuel delivery temperature category is based on MAT_C instead of MAT_{30}, where MAT_C represents the mass average of T_{fuel} used as the control input (see H.2.4 for an explanation of how MAT_C is determined). There may be fueling scenarios where MAT_{30} meets the intended fuel delivery temperature category for station designation, while MAT_C does not. This is more likely to occur when the initial SOC in the CHSS is high because MAT_C includes the warm gas from the cool-down period in its calculation whereas MAT_{30} does not.

Table 7 - Fuel delivery temperature categories per pressure classes

Fuel Delivery Temperature Category		$-40\ °C \le MAT_{30} \le T40limit$	$-33\ °C < MAT_{30} \le -26\ °C$	$-26\ °C < MAT_{30} \le -17.5\ °C$
Station Designator	35 MPa NWP	H35-T40	H35-T30	H35-T20
	70 MPa NWP	H70-T40	H70-T30	H70-T20

where

T_{amb} (°C)	$T40limit$ (°C)
≥20	-33
15	-32.5
10	-32
0	-29
-10	-28
-20	-27
-30	-26.5
-40	-26

9.1.2 Fuel Delivery Temperature

This section defines the fuel delivery temperature requirements for the MC Formula-based fueling protocol. These are additional to the overall temperature requirements listed in 6.3.

9.1.2.1 Fuel Delivery Temperature Tolerance

For any fuel delivery category, $T_{fuel\text{-}inst}$ shall always be ≥-40 °C, and after a total of 30 seconds of mass flow have elapsed from the beginning of the main fueling time, MAT_{30} shall be ≤-17.5 °C at any time that the mass flow rate is greater than 0.6 g/s for more than 10 seconds. If an intended non-fueling event occurs within the last 10 seconds of this 30 second period, a total of 40 seconds of mass flow is allowed (i.e., MAT_{30} shall be ≤-17.5 °C after a total of 40 seconds of mass flow have elapsed). If the station cannot meet these requirements, it shall do one of the following: (a) pause (no flow) for a minimum of 60 seconds before resuming the fill with the main fueling time t and parameters n, j, and i set back to zero and $P_{startup}$ set to the most recent station pressure prior to resuming the fill; or (b) terminate the fueling as soon as possible, but within 5 seconds.

NOTE: The dispenser manufacturer should implement an approach which monitors the rate of change of the instantaneous fuel delivery temperature $T_{fuel\text{-}inst}$, to ensure that it is decreasing at a rate which is expected. By doing so, the dispenser may be able to detect a fault condition at an earlier time than waiting until the full 30 seconds of mass flow has elapsed.

9.1.3 Minimum Startup Time

The startup time, $t_{startup}$, shall satisfy the following requirement.

$$t_{startup} \geq \frac{aV^{b}m_{startup}^{c}}{(PRR)} \qquad \text{(Eq. 7)}$$

where:

PRR = prescribed pressure ramp rate at the beginning of the main fueling time (in MPa/s)

V = CHSS volume (if CHSS volume is indeterminate, the smallest CHSS volume shall be used, i.e., 49.7 L)

$m_{startup}$ = mass dispensed during startup time (in grams)

a = 1.717

b = -0.9773

c = 0.9828

9.2 CHSS Capacity

Table 8 defines the allowable CHSS capacity categories for the MC Formula-based fueling protocol. The CHSS capacity category will be used to select the proper t_{final} value, and if ending pressure tables are utilized, the pressure targets.

The station shall determine the CHSS capacity using a method that is accurate to within ±15%. The station then determines the t_{final} value using one of two methods: (a) the higher of two calculated t_{final} values for the upper and lower CHSS sizes which bound the CHSS capacity category; or (b) interpolating between the two calculated t_{final} values for the upper and lower CHSS sizes which bound the CHSS capacity category, based on the measured CHSS capacity. See H.2.2 and J.2.4.

If the station cannot guarantee the ±15% accuracy, or if the CHSS capacity category is indeterminate, then the station shall utilize the most conservative (highest) t_{final} value for CHSS Categories A, B, and C, and, when ending pressure tables are employed, utilize the lowest calculated pressure target. For example, if the measured CHSS capacity is 4.01 kg, but the accuracy is ±15%, then the CHSS capacity category is indeterminate.

The station may choose to implement all CHSS capacity categories (H35 A through C, H70 A through D), or may choose to implement a sub-set of the CHSS capacity categories (e.g., A, B, and C, but not D).

Table 8 - SAE J2601, CHSS capacity categories

Pressure Class	Total Amount of Hydrogen in CHSS at 100% SOC (kg)	Water Volume of CHSS (L)	CHSS Capacity Category Identifier
H35	1.19 to 2.39	49.7 to 99.4	A
H35	2.39 to 4.18	99.4 to 174.0	B
H35	4.18 to 5.97	174.0 to 248.6	C
H70	2.00 to 4.00	49.7 to 99.4	A
H70	4.00 to 7.00	99.4 to 174.0	B
H70	7.00 to 10.00	174.0 to 248.6	C
H70	>10.00	>248.6	D

9.3 Pressure Requirements

9.3.1 Initial Pressure

The initial pressure shall be used as $P_{initial}$ in applying the MC Formula-based protocol. If the initial pressure is less than 0.5 MPa or greater than the pressure class nominal working pressure (35 MPa or 70 MPa), then the station shall terminate the fueling procedure as soon as possible but within 5 seconds.

NOTE: The initial pressure is measured by the station (see definition in 3.11.3). A communicated pressure from the vehicle <0.5 MPa prior to the connection pulse is acceptable provided the initial pressure measured after the connection pulse exceeds 0.5 MPa.

9.3.2 Station Pressure Corridor

9.3.2.1 Station Pressure Tolerance

During the main fueling time, the MC Formula-based protocol calculates a pressure ramp rate PRR and ramp pressure P_{ramp}, at a frequency of once every second (see J.2.6). The ramp pressure is utilized to calculate an upper and lower pressure limit which form the boundaries of a pressure corridor. An upper pressure tolerance ΔP_{tol_high} is added to the ramp pressure P_{ramp} to calculate the upper pressure limit P_{limit_high}, and for CHSS Capacity Categories A, B, and C, a lower pressure tolerance ΔP_{tol_low} is subtracted from the ramp pressure P_{ramp} to calculate the lower pressure limit P_{limit_low}. For CHSS Capacity Category D, a lower pressure tolerance ΔP_{tol_low} is subtracted from a pressure based on a pressure ramp rate of 1 MPa/min (0.0167 MPa/s). The upper pressure tolerance is 7 MPa, and the lower pressure tolerance is 2.5 MPa.

During the main fueling time, with an exception of the first 15 seconds, the station shall maintain the station pressure within the upper and lower pressure limits. If the station pressure exceeds the upper pressure limit by 5 MPa or less, it shall come back within the limit within 5 seconds of the initial excursion, or shall stop fueling within 5 seconds of the initial excursion. If the magnitude of the excursion is greater than 5 MPa, the station shall stop fueling within 5 seconds of the initial excursion. If the station pressure falls below the lower pressure limit, it shall come back within the limit within a total of 15 seconds of the initial excursion, not counting intended non-fueling time, and if it does not, the station shall stop fueling within a total of 15 seconds of the initial excursion.

Upper pressure limit (CHSS Capacity Categories A, B, C, D):

$P_{station} \leq P_{limit\_high}$ where $P_{limit\_high} = P_{ramp} + \Delta P_{tol\_high}$, where $\Delta P_{tol\_high} = 7.0$ MPa

Lower pressure limit (CHSS Capacity Categories A, B, C):

$P_{station} \geq P_{limit\_low}$ where $P_{limit\_low} = Max[P_{startup}, P_{ramp} - \Delta P_{tol\_low}]$, where $\Delta P_{tol\_low} = 2.5$ MPa

Lower pressure limit (CHSS Capacity Category D)

$P_{station} \geq P_{limit\_low}$ where $P_{limit\_low} = Max[P_{startup}, P_{startup} + 0.0167 \times t - \Delta P_{tol\_low}]$, where $\Delta P_{tol\_low} = 2.5$ MPa

An illustration of the pressure corridor for CHSS Capacity Categories A, B, and C is shown in Figure 9 for a fueling without intended non-fueling time, and in Figure 10 for a fueling with intended non-fueling time. An illustration of the pressure corridor for CHSS Capacity Category D is shown in Figure 11 for a fueling without intended non-fueling time. Note that, although the ramp pressure and upper and lower pressure limits are illustrated as straight lines in Figures 9, 10, and 11, due to the variable pressure ramp rate of the MC Formula-based protocol, in practice, the slope of the ramp pressure and upper and lower pressure limits will change with the change in the pressure ramp rate on a continuous basis. The width of the pressure corridor, however, always remains constant.

In the MC Formula-based protocol, intended non-fueling time (e.g., for bank switch or leak check) is included in the main fueling period elapsed time t (i.e., t continues to advance during intended non-fueling time). During the intended non-fueling time, the ramp pressure is held constant, but the pressure ramp rate continues to be calculated. Once the intended non-fueling time has passed, the fill resumes at the most recently calculated pressure ramp rate. This is depicted in Figure 10 by an increase in the slope of the ramp pressure and upper and lower pressure limits.

H.2.6.2 provides a more detailed explanation of the pressure corridor and its derivation.

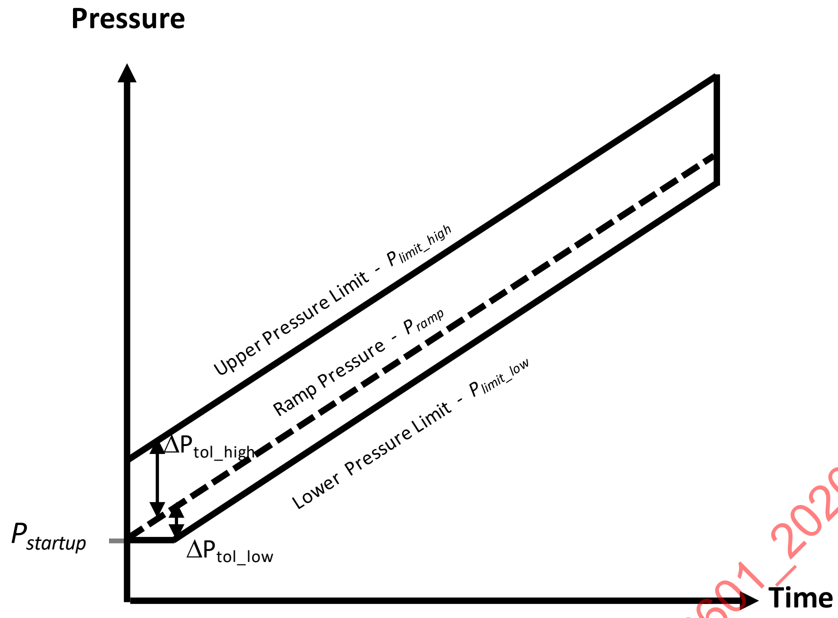

Figure 9 - Illustration of pressure corridor limits for CHSS Capacity Categories A, B, C

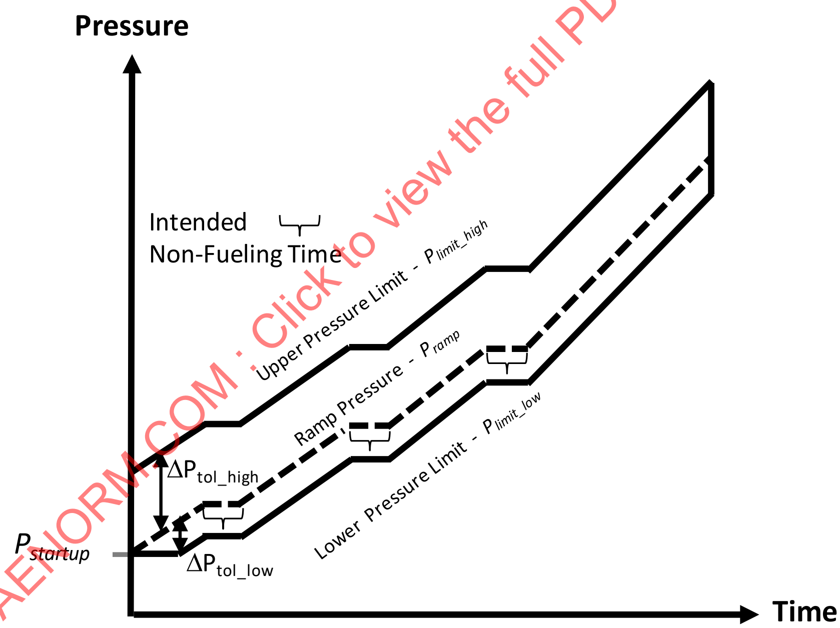

Figure 10 - Illustration of pressure corridor limits with non-fueling time for CHSS Capacity Categories, A, B, C

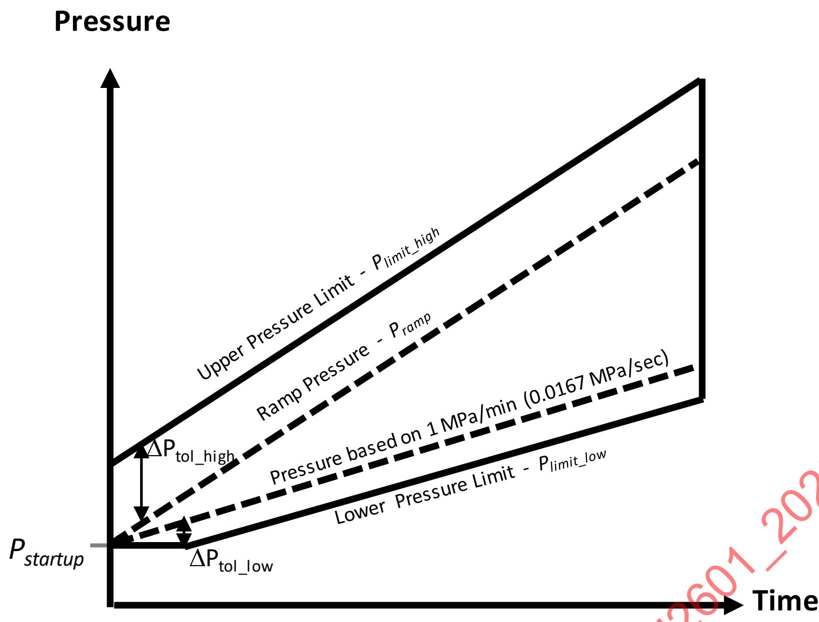

Figure 11 - Illustration of pressure corridor limits for CHSS Capacity Category D

9.3.2.2 Control Pressure

The pressure corridor defined in 9.3.2.1 and illustrated in Figures 9 and 10 is intended to give allowance for variability in the dispenser's ability to control the station pressure. Depending on the control method and precision of the components used for pressure control, the dispenser should target a specific region of the pressure corridor to account for inherent fluctuations in the station pressure. The control pressure is utilized as a target pressure that the dispenser is aiming for at any point in time during the fill.

In the MC Formula-based protocol, the ramp pressure is utilized as the input to the variable pressure ramp rate equation and as a means for defining the upper and lower pressure limits of the pressure corridor. The control pressure is set as an offset from the ramp pressure. This offset may be a constant, or may be a variable parameter which changes based on the dispenser's pressure control characteristics. To minimize the overall fueling time, the offset value should be set as high as possible, while at the same time, enabling sufficient control margin. H.2.7 provides a more comprehensive description of the control pressure.

9.4 Cycle Control

The dispenser shall not control hydrogen flow in a cyclic manner by repeatedly starting and stopping the fueling. The station shall not decrease the flow of gas below 1% of the maximum flow rate more than ten times during the main fueling period. This requirement includes the non-fueling events (leak checks, bank switching, etc.) during the main fueling period.

9.5 Abort Signal from Vehicle

If the dispenser is capable of communications, whether the fueling procedure is using communications or not, the station shall continue to monitor the communications interface and shall terminate fueling upon detection of an "abort" signal from the vehicle as soon as possible but within 5 seconds. The vehicle may use the abort signal to stop the fueling for any reason. This allows the vehicle to monitor the fueling process and complement the station operation with a secondary layer of control.

9.6 Tolerances

The station shall account for its tolerances in applying this fueling protocol. Tolerances shall be applied to ensure that the station pressure and fuel delivery temperature remain within their specified boundaries or limits.

9.7 MC Formula-Based Fueling Flow Chart

Figure 12 illustrates a general flow chart for communications and non-communications, MC Formula-based, fueling. More detailed flow charts with subroutines are contained within Appendix I, and complete descriptions of these subroutines with all required formulas are contained within Appendix J.

All shall statements in Appendix J are mandatory requirements for implementing the MC Formula-based protocol.

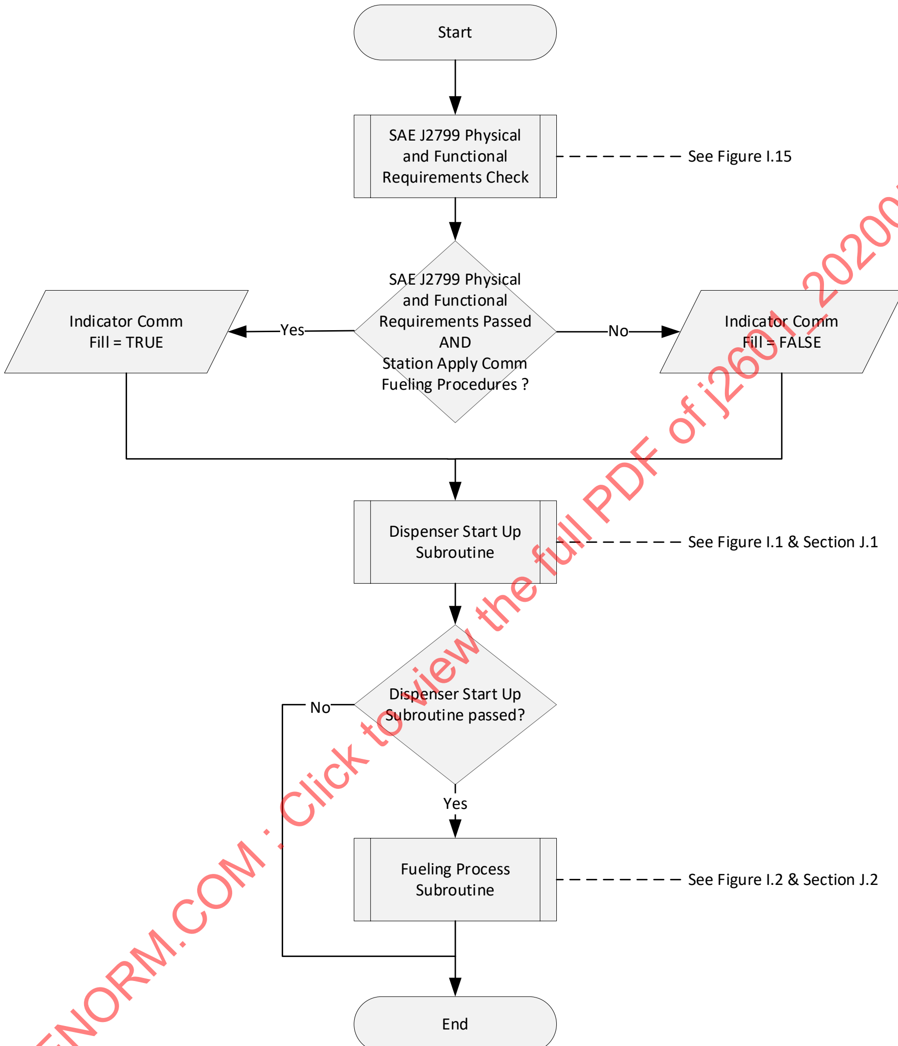

Figure 12 - General flow chart for MC Formula-based fueling

9.7.1 Dispenser Startup

The dispenser startup process is illustrated by a flow chart found in Figure I1, and the formulas utilized are detailed in the dispenser startup subroutine, found in J.1. The station shall pass the dispenser startup subroutine, or if it fails, shall end the fueling.

At the start of fueling, the station shall monitor the communications interface for SAE J2799 signals. If no signal is present or if signals received do not pass the physical and functional requirements, as defined in SAE J2799 (and Figure I15), then the station shall apply the non-communications fueling procedure as described in 9.8. If a signal is present and passes the physical and functional requirements, then the station should apply the communications fueling procedure as described in 9.9.

NOTE: In Figure 12, the station dispenser startup routine may begin before the SAE J2799 physical and functional requirements check, based on the station dispenser fueling methodology.

9.7.2 Fueling Process

Once the station has passed the dispenser startup subroutine, it has all the information (ambient temperature, initial CHSS pressure, determined CHSS capacity category, expected MAT, etc.) it requires and shall then execute the fueling process as described in the fueling process subroutine. The fueling process subroutine flow chart is illustrated in Figure I2 and the formulas utilized in the fueling process subroutine are detailed in J.2.

9.8 Non-Communications Fueling

All stations using the MC Formula-based fueling protocol shall have the ability to fuel without communications from the vehicle.

The non-communications MC Formula-based fueling protocol assumes that no data is being passed from the vehicle to the station. For a given CHSS volume category and ambient temperature, the t_{final} and resulting PRR is the same as in the communications fueling procedure. The primary difference is the end of fueling is defined by a separate target pressure.

9.8.1 Fueling Procedure

The non-communications fueling process uses the general description discussed in 9.7. The station shall use the fueling process flow chart as represented in Figures I0 and I2. For a non-communications fueling the flag variable “Indicator Comm Fill” shall be set to FALSE. This indicates to the dispenser that the non-communication pressure target shall be used to end the fill.

9.8.2 End of Fueling

All non-communications fuelings shall end the non-communications fueling when the station pressure equals the non-communication target pressure $P_{target\_non\_comm}$. The station pressure shall be compared to the non-communication target pressure at least once every 100 ms, as prescribed in the evaluate end of fill criteria subroutine, J.2.8. The station may apply a methodology to measure or calculate the pressure loss between $P_{station}$ and $P_{vehicle}$ and adjust the station pressure by this value. If this approach is used, the station shall take appropriate measures to ensure that under all conditions, $P_{vehicle}$ does not exceed the target pressure (P_{target}).

The MC Formula-based protocol allows two options for ending pressure control: (a) the MC Method, or (b) ending pressure tables. See H.3 for a detailed explanation of these two ending pressure control options. Regardless of the ending pressure control option utilized, a non-communication pressure target $P_{target\_non\_comm}$ shall be calculated at least once every second, as prescribed in the determination of pressure targets and limits subroutine, J.2.7.

9.9 Communications Fueling

The communications MC Formula-based fueling protocol shall use the IrDA signals as defined in SAE J2799 to provide information from the vehicle to the station. For the communications fueling procedure and for a given CHSS volume and ambient temperature, the t_{final} and resulting PRR is the same as the non-communications fueling procedure.

If applicable, the use of communications should consider 3.6.1.1, as well as local codes.

9.9.1 Fueling Procedure

The communications fueling process uses the general description discussed in 9.7. The station shall use the fueling process flow chart as represented in Figures I0 and I2. For communications fuelings, the flag variable “Indicator Comm Fill” shall be set to TRUE.

9.9.2 Establishing Communications

The dispenser shall attempt to receive communications from the vehicle, based on SAE J2799, throughout the fueling process. To prevent communications faults while the user is connecting the fueling nozzle, the dispenser shall not consider communications as having been fully established until the nozzle is in place and the fueling startup procedure has begun. Once communications are established, the dispenser shall proceed to fuel using the communications fueling process for as long as valid signals continue to be received.

9.9.3 Loss of Communications

If the data signal from the vehicle is lost or fails the physical and functional requirements as defined in SAE J2799 (see Figure I15), then the dispenser shall terminate the fueling as soon as possible but within 5 seconds or shall optionally set the flag variable "Indicator Comm Fill" to FALSE and continue fueling the vehicle using the non-communication target pressure $P_{target\_non\_comm}$, assuming the station determines it is appropriate to continue with fueling after the loss of the fuel command signal.

9.9.4 Communications Overfueling Density Limit

A pressure limit is determined for communication fueling, P_{limit_comm}. This pressure limit value is used as a secondary means of protection to limit the over fueling density in the event of a fault in the CHSS measured temperature MT, which causes the communication pressure target to be incorrect. The determination of P_{limit_comm} depends on the ending pressure control option utilized. For the ending pressure tables option, P_{limit_comm} is looked up from a set of pressure limit tables. For the MC Method ending pressure control option, P_{limit_comm} is calculated based on a cold case gas temperature T_{cold} and a maximum density corresponding to 115% SOC, or P_{final}, whichever is lower. See H.3.1.4 for the rationale and further detail. See J.2.7 for the formulas used to calculate P_{limit_comm}.

9.9.5 End of Fueling

The station may use vehicle data, including the communicated CHSS temperature, to calculate the communication target pressure and should end the fueling at a pressure corresponding to an SOC of 95 to 100%. All communications fuelings shall end when the station pressure or vehicle pressure equals the calculated communication target pressure P_{target_comm} or limit pressure P_{limit_comm}, whichever is reached first.

9.9.6 Communications Data Fields Definition

SAE J2799 defines the IrDA communications data fields. This section defines their values and use for the MC Formula-based fueling protocols. The data fields to be sent from the vehicle to the station are listed below and described in the following sections. They should be placed in the order as follows:

ID: Protocol Identifier

VN: Version Number

TV: Tank Volume

RT: Receptacle Type

FC: Fueling Command

MP: Measured Pressure

MT: Measured Temperature

OD: Optional Data

9.9.6.1 Protocol Identifier

|ID=SAE␣J2799|

The vehicle shall transmit the Protocol Identifier ID=SAE J2799. The "␣" symbol is to denote a space and used after SAE in the identifier. The dispenser shall not fuel the vehicle if the Protocol Identifier from the vehicle does not match.

9.9.6.2 Data Communications Software Version Number

For the MC Formula-based fueling protocol, the following are the communication version numbers

VN=01.00 or 01.10 are valid communications protocol as defined in SAE J2799-2014.

The data field definitions are found in 9.9.6.

The dispenser shall not fuel the vehicle if the Version Number from the vehicle does not match VN=01.00 or VN=01.10.

VN=01.00 applicable stations shall be able to receive and use VN=01.00 data communications.

VN=01.10 applicable stations shall be able to receive and use both VN=01.00 and VN=01.10 data communications.

9.9.6.3 Tank Volume

Range: 0000.0 to 5000.0

The vehicle shall transmit the storage volume of the vehicle CHSS in liters (water volume at the nominal working pressure) to the dispenser.

9.9.6.4 Receptacle Type

|RT=H35| or |RT=H70|

The vehicle shall transmit the SAE J2600 pressure class for the vehicle's original fuel receptacle which shall also correspond to the CHSS NWP. The dispenser shall not dispense fuel if the RT is less than the pressure class of the station dispenser.

9.9.6.5 Fueling Command

The vehicle shall use the following fueling commands

|FC = Dyna|

When the vehicle transmits |FC = Dyna|, the dispenser shall dispense fuel based on the MC Formula-based communications fueling protocol defined in 9.9.

|FC = Stat|

|FC = Stat| shall not be used. If this command is received by the station, then the station shall consider communications to have failed the physical and functional requirements.

|FC = Halt|

|FC = Halt| is optional for vehicles. If a station does not implement the |FC = Halt|, then the station shall respond to this command by terminating the fueling process.

If the station uses this fueling command |FC = Halt|, then it shall pause the fueling. The elapsed time during an |FC = Halt| is included in the main fueling period elapsed time t. During |FC = Halt|, the ramp pressure and control pressure are held constant, but the pressure ramp rate continues to be calculated. If the fueling command |FC = Dyna| is received for at least 2 seconds, the station shall re-start the fueling process and resume the fill at the most recently calculated PRR. The station shall end the fueling process if the fueling command |FC = Halt| is received for over 60 seconds.

|FC = Abort|

When the vehicle transmits |FC = Abort|, the dispenser shall terminate the fueling process as soon as possible but within 5 seconds.

9.9.6.6 Measured Pressure

Range: 000.0 to 100.0

The vehicle shall transmit the measured CHSS gas pressure in MPa. If the dispenser monitors the measured pressure, it should terminate the fueling as soon as possible but within 5 seconds if the measured pressure exceeds the MOP as defined in 3.11.7.

9.9.6.7 Measured Temperature

Range: 16.0 to 425.0

The vehicle shall transmit its CHSS measured gas temperature in Kelvin. The measured temperature should be representative of the average CHSS gas temperature. If the dispenser monitors the measured temperature, it shall terminate the fueling as soon as possible but within 5 seconds if the measured temperature exceeds the maximum operating vehicle CHSS gas temperature as defined in 6.3.2.

9.9.6.8 Optional Data

For the SAE MC Formula-based fueling protocol, the optional data command is ignored.

9.10 Cold Dispenser Fueling

For communications fueling only and for CHSS Capacity Categories A, B and C only, stations may optionally use the cold dispenser (CD) fueling procedure, which utilizes a separate set of t_{final} coefficients, when all of the dispenser components are at sufficiently cold temperature. This results in smaller t_{final} values and thus a higher PRR, facilitating shorter fueling times. The CD fueling procedure can use smaller t_{final} values because when the dispenser components begin the fueling at a lower temperature, less heat is generated within the CHSS. Colder dispenser components can occur when two or more vehicles are fueled consecutively with minimal time in between.

The CD fueling procedure shall only be used for the H70 pressure class. The CD fueling procedure shall only be used when the temperature of the dispenser components and T_{fuel} at the start of fueling are colder than 0 °C following the guidance below. The CD fueling procedure shall only be used with communications. The CD t_{final} coefficient tables are listed in Tables J9 through J16.

As this is a safety-relevant, information-based (station temperature sensors, etc.) decision made by the dispenser, IEC 61508/61511 or equivalent shall be adhered to which includes safety integrity levels (SIL), as well as requirements for the specification, design, installation, operation and maintenance of a safety instrumented system. Lastly, correct operation should be field tested in accordance with CSA HGV 4.3 or equivalent.

Station manufacturers and operators should be aware that accurate temperature measurement on the station side is critical to ensuring that the CHSS temperature does not exceed its maximum operating temperature. Furthermore, environmental conditions, such as sunlight, may affect the accurate temperature measurement of the station.

The dispenser component temperature measurement(s) shall consider the effects of dispenser component temperature on fuel cooldown. The dispenser component measurement(s) should be in a location(s) where the hydrogen is expected to be warmest, which will generally be closest to the vehicle and downstream of the T_{fuel} measurement. The measurement location should consider the mass of the component, its heat transfer properties, and environmental factors. An example is a temperature measurement of the nozzle component or an in-stream hydrogen temperature measurement in the nozzle flow path. The dispenser component temperature measurement shall be used in accordance with the MC-Formula-Based dispenser startup subroutine, Figure I1.

The CD fueling procedure t_{final} coefficient tables were generated using the same modeling approach as the standard fueling tables. However, the CD t_{final} coefficient tables were not tested and verified to the same level as the standard t_{final} coefficient tables. Therefore, station manufacturers should perform these tests prior to using the procedure in the field.

10. NON-STANDARD, DEVELOPMENT HYDROGEN FUELING PROTOCOLS

All dispensers which are certified to SAE J2601 shall have the capability to fuel vehicles using one or more of the standard fueling protocols defined herein. Public dispensers may fuel vehicles using development fueling protocols as means for field validation after engineering due diligence is performed. However, they shall not use them as the primary fueling protocol and shall have a method of ensuring an unattended public user cannot access them without authorization from the station provider and vehicle OEM. The use of authorization systems, such as access codes or authorization cards, which can be accessed by public users, have been problematic in the past. The use of development fueling protocols should be done responsibly and it is ultimately the responsibility of the station provider to ensure that a development fueling protocol is only utilized for the intended vehicle(s) and user(s).

The purpose of utilizing a non-standard fueling protocol in a demonstration or in a development capacity is to bring data and real world experience (to verify the protocol's capability to operate within the constraints of Section 6), back to the SAE Fuel Cell Standards Interface Task Force for future incorporation into the SAE J2601 standard.

11. NOTES

11.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

NOTE: One or more patents may apply to one or more aspects of the standards or the entire standard. By publication of this standard, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. The patent holder(s) has, however, filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license for the purpose of complying with the standard. Details may be obtained from SAE International at: http://www.sae.org/standardsdev/patents.htm.

PREPARED BY THE SAE FUEL CELL COMMITTEE

APPENDIX A - FUELING PROTOCOL RATIONALE AND DEVELOPMENT PROCESS

For the table-based fueling protocol described in Section 8, the SAE J2601 team used thermodynamic modeling and simulation to develop the tables listed in Appendices D and E. The simulations used the boundary conditions and process requirements listed in Sections 5, 6, and 8 to determine the appropriate average pressure ramp rate (APRR) and target pressure (end pressure) which met the goals discussed in 5.1. This appendix describes the modeling approach for the table-based fueling protocol. This protocol was developed for the fueling of Type III/IV CHSSs on road today. If other storage systems on vehicles are utilized, it is recommended that they be evaluated before implementing this protocol.

A.1 SIMULATION MODEL

A numerical simulation model was employed to evaluate the evolution of gas pressure and temperature inside the CHSS. The components of this model are depicted in Figure A1. The fuel gas is delivered by the station with a given pressure P_{fs} (corresponding to $P_{station}$ in Section 3) and a given fuel temperature T_{fs} (corresponding to T_{fuel} in Section 3). Both fuel pressure and temperature vary as the simulation proceeds, the pressure is ramped up with a linear dependence with respect to time, while the temperature may ramp down from ambient to a value in the respective fuel delivery temperature categories (see Section 8). The pressure drop between fuel station and vehicle CHSS is used in combination with a pressure drop coefficient to calculate the mass flow rate $\dot{m}_{fs}$ delivered by the dispenser. The specific enthalpy h_{fs} is computed from its stationary contribution $h(P_{fu}, T_{fu})$ plus its dynamic contribution $w_{fu}^2/2$ with the gas velocity w_{fu}. The fresh fuel from the station enters a control volume "gas in fuel line" where it exchanges heat with the thermal masses constituted by the fueling hose, pipes, and components. The thermal masses belonging to the station and to the vehicle are separate. Each thermal mass is characterized by its mass, specific heat capacity, and thermal conductivity. For each thermal mass, a set of ordinary differential equations is solved for their temperature. The thermal mass representing the station's components was discretized in radial direction in order to allow for a one-dimensional temperature profile T_{ls}. The vehicle side was modeled with a lumped mass that has a homogeneous temperature T_{fs}. Both thermal masses exchange heat with the environment at ambient temperature T_{am}, the respective heat fluxes are $\dot{Q}_{as}$ and $\dot{Q}_{av}$. They also exchange heat with the fuel gas in the control volume. A heat transfer coefficient based on a Nusselt equation for forced convection inside a pipe is used to compute the two heat fluxes $\dot{Q}_{sf}$ and $\dot{Q}_{vf}$. They affect the enthalpy H_{fu} of the gas in the fuel line, this is reflected in the fuel temperature T_{fu}. The fuel gas then enters the CHSS with a specific enthalpy h_{fu}. The mass flow rate $\dot{m}_{io}$ through the inlet/outlet port of each vehicle vessel equals the flow rate $\dot{m}_{fs}$ from the station divided by the number of identical vessels in the CHSS. In the case of multi-vessel systems, only one vessel is simulated as a representative. For this vessel, mass and energy balance are solved in order to obtain the gas mass m and internal energy U at any time. It is assumed that the gas inside the CHSS is perfectly mixed at all times, i.e., there are no spatial gradients. In the case of fueling the CHSS, the flow rate $\dot{m}_{io}$ is positive and the inflowing gas carries the specific enthalpy $h_{io} = h_{fu}$. For a defueling/extraction simulation, $\dot{m}_{io}$ is negative and the outflowing gas has the specific enthalpy of the gas inside the vessel, $h_{io} = h$. All properties of the gas inside the vessel (e.g., P, T, h) are computed from the gas equation of state with the given density computed from the gas mass divided by the vessel volume, $\rho = m/V$ and the given specific internal energy from the total internal energy divided by the gas mass, $u = U/m$. A highly accurate equation of state was used that describes all relevant real gas behavior (e.g., compressibility, Joule-Thomson effect). (See footnote under 3.12.) The heat transfer rate $\dot{Q}_{li}$ between gas and vessel internal surface (liner) is computed from a set of Nusselt equations for various geometries and for forced and free convection. The vessel wall is discretized in radial direction and the transient heat conduction equation is solved in one dimension. This yields the temperature profile T_{vw}inside the vessel wall at any given time. On the outer surface, the vessel wall exchanges heat with the environment, the heat transfer coefficient is again based on a set of Nusselt equations for various geometries and for free convection.

The hydrogen gas temperature in the CHSS increases during fueling due to the heat transferred from the station, vehicle thermal masses, the Joule-Thomson heating of the fuel as it is throttled through the fuel line orifices, and the heat of compression inside the CHSS. Different materials and designs of CHSSs will lead to different degrees of compressive heating during fueling due to differences in heat transfer characteristics, the heat capacity, and storage volume. The fueling protocol in this Standard is based on input from automotive OEMs and CHSS manufacturers on extreme-case heating in a CHSS that reflects the range of configurations of current storage technology. These extreme cases are described in the following sections. They influence fixed model parameters (e.g., masses, surface areas, volumes), initial conditions of all states for which ordinary differential equations are solved (e.g., T_{ls}, T_{vw}, m, U), and boundary conditions (e.g., T_{am}, T_{fs}, $\dot{m}_{ex}$).

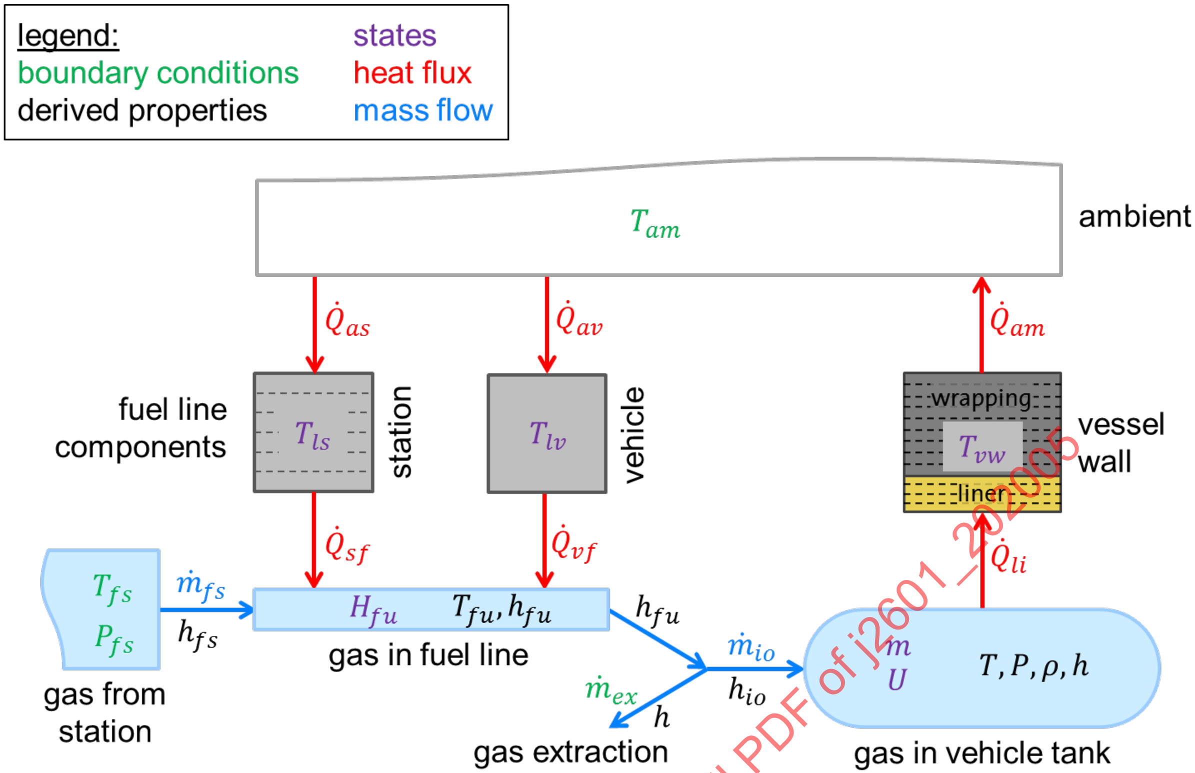

Figure A1 - Simulation model

A.2 GENERAL ASSUMPTIONS

As described in 5.2, there are two primary operating limits that shall not be violated during fueling: an upper temperature limit of 85 °C that is mainly imposed by the integrity of plastic liner materials, and an upper pressure limit originating from the structural strength of the vessel composite overwrap. The density limit that may lead to overfueling is only an indirect constraint because it does not directly lead to vessel damage, although overfueling in extreme cold weather or cold soaked CHSSs may lead to exceeding the upper pressure limit as a consequence of a subsequent gas temperature increase. The procedure in developing the look-up tables in Appendices D and E is split into two steps. Each step basically addresses the observation of one of the two limits:

The first step is to determine an average pressure ramp rate APRR such that the temperature limit will not be violated in any conceivable operating condition. This is achieved by setting all model parameters, initial conditions, and boundary conditions such that the highest conceivable gas temperature is obtained at the end of the fueling process. This set of conditions is referred to as "hot case" assumptions in the following sections.

The second step is to define the fueling end pressures (target pressures) such that the pressure limit will not be violated in any conceivable operating condition. This is achieved by setting all model parameters, initial conditions, and boundary conditions such that the lowest conceivable gas temperature is obtained at the end of the fueling process. This set of conditions is referred to as "cold case" assumptions in the following. Certain tradeoffs were made in Step 1 in order to allow for faster fueling under default conditions. These tradeoffs require that the target pressure be constrained in Step 2 in order not to violate the upper temperature limit by means of hot case simulation runs.

A.3 HOT CASE AND COLD CASE ASSUMPTIONS

In the case of non-communications fueling, there is very little information about the condition of the CHSS available to the fueling station. The only information the fueling station can rely on is the local ambient temperature at the station and the rated fuel delivery temperature of its dispensed fuel. The station is also required to determine an estimate of the initial pressure inside the CHSS by pressurizing the fuel line for a short time in order to open all check valves in the line. Similarly, the station shall estimate the CHSS internal gas volume.

There are a large number of indeterminates to the fueling station. In the course of developing the pressure ramp rates and the fueling target pressures, two combinations of all worst-case assumptions have been made for all indeterminates. This way it can be ensured that the values in the tables are conservative. Table A1 lists all conditions that lead to the highest ("hot case") and the lowest ("cold case") CHSS gas temperatures at the end of the fueling process.

Table A1 - Assumptions for "hot soak" and "cold soak" zones

Parameter/Initial Cond./Boundary Cond.	Hot Case	Cold Case
Station fuel delivery temperature	Upper bound	Lower bound
Station pipe diameter	Small: 5 mm	Large: infinite
Dispenser components thermal mass	High thermal mass: S2	Low thermal mass: S1
Dispenser components initial temperature	Ambient	Ambient
Vehicle components thermal mass	Common representative thermal mass	
Vehicle components initial temperature	Ambient	Ambient
Pressure drop in fuel line from dispenser to vehicle	Large: 35 MPa	Small: 17 MPa
Pressure ramp rate type	HPRR	APRR
Intermediate pressure leak checks	None	Every 3000 psi pressure increase
Vehicle vessel geometry	Large/small vessel	Small vessels
Vehicle vessel count	Single vessel	Multiple identical vessels
Vehicle vessel liner material	Plastic (Type IV)	Aluminum (Type III)
Vehicle vessel soak state	Hot soak	Cold soak
Vehicle history	None	Driving from initially full

A.3.1 Station Fuel Delivery Temperature

The fuel delivery temperature at the station is defined to stay within given bounds (see 8.1.2).

The set of hot case assumptions always uses the upper bound for simulation, which is the warmest possible gas allowed for a given dispenser type throughout the fueling. It is assumed that the first slug of gas is at ambient temperature if ambient is warmer than the fuel delivery temperature bound. This warm slug gradually cools down to the actual fuel delivery temperature at a linear ramp and within a maximum cool-down time of 30 seconds (see Figure A2). In the few cases when ambient temperature is lower than the upper fuel delivery temperature bound, the fuel delivery temperature immediately starts at the upper bound (see Figure A3).

In the cold case fueling simulations, the fuel delivery temperature at the break-away-coupling immediately starts at the lower bound, independent of the ambient temperature (see Figures A2 and A3). Even in the few cases when ambient temperature is lower than the lower fuel delivery temperature bound, the fuel delivery temperature is held constant at the lower bound (not illustrated).

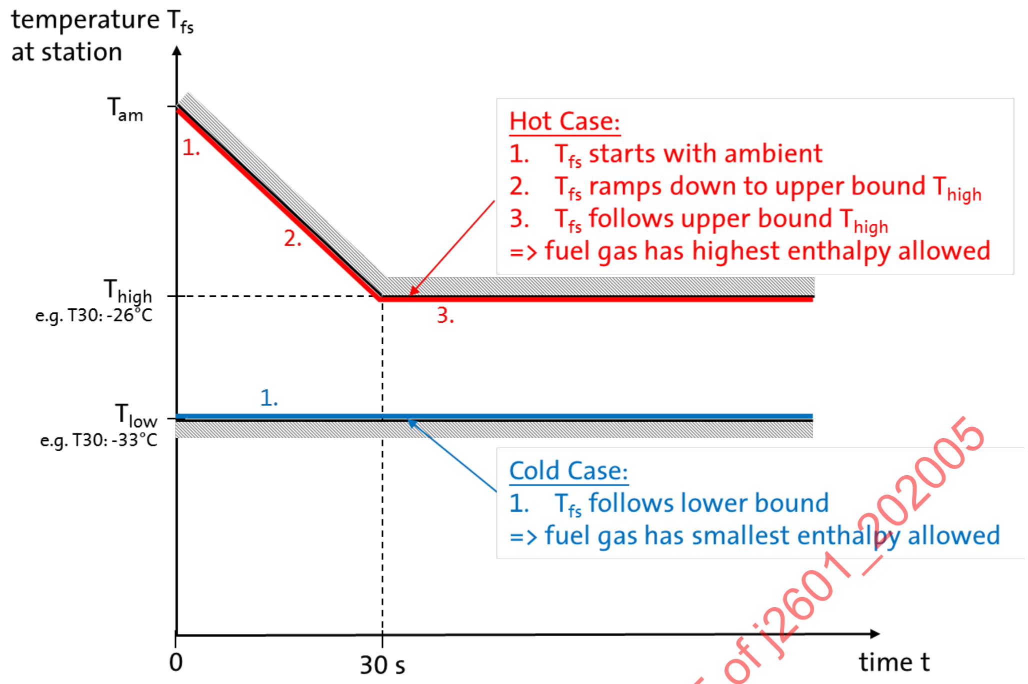

Figure A2 - Station fuel temperature if ambient is warmer than upper fuel delivery temperature bound

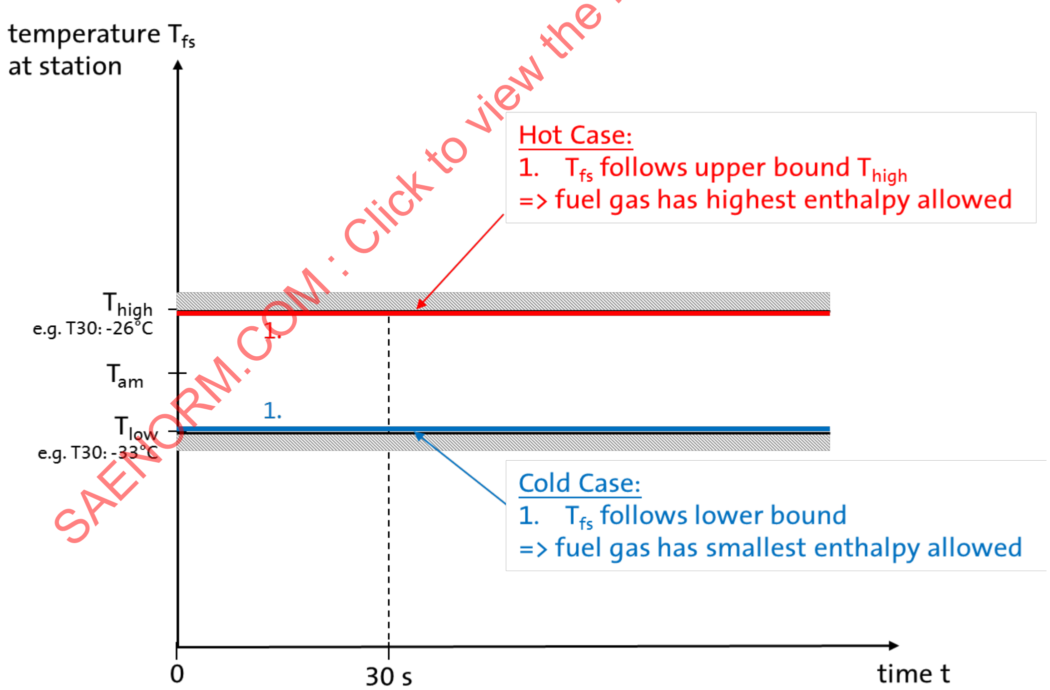

Figure A3 - Station fuel temperature if ambient is colder than upper fuel delivery temperature bound

A.3.2 Station Pipe Diameter

The internal pipe diameter at the fuel delivery location inside the dispenser (i.e., where the temperature and pressure sensor are located) determines the fuel gas velocity inside the pipe which in turn affects the dynamic contribution to the fuel gas enthalpy. A feasible range of pipe diameters has been taken into consideration in the modeling assumptions.

The hot case uses the smallest assumed internal pipe diameter 5 mm which leads to the highest fuel gas velocity and thus to the highest total enthalpy for a given fuel temperature and pressure.

The cold case assumes the largest possible internal pipe diameter which is assumed “infinite” in the model. In this case, there is no dynamic contribution to the total energy corresponding to zero gas velocity.

A.3.3 Station and Vehicle Fuel Line Components

As the fueling process parameters “fuel delivery temperature” and “station pressure” are both measured near the break-away-coupling (see 6.2), it is important to consider the thermal mass of dispenser components (pipe, break-away-coupling, hose, and nozzle) and of vehicle components (receptacle, pipes, valves, etc.). These thermal masses transfer heat to the hydrogen fuel during fueling due to their specific heat capacity and heat transfer characteristics. All parameters are based on real station and vehicle designs and represent the variability in existing designs.

Hot case assumptions use station parameters S2 (see Table A2) with high heat capacity and large heat exchanging surface areas to ambient and to fuel gas. This represents a high thermal mass that needs to be cooled down by the fuel gas and which in turn introduces a large amount of heat into the fuel gas.

The cold case uses station parameters S1 with low heat capacity and small heat exchanging surface areas to ambient and to fuel gas.

Note that in Table A2, the inside diameters are only used to calculate the internal surface area for heat transfer. These diameters do not influence the pressure drop, which is calculated independently (see A.3.4).

The following assumptions are made for both hot and cold case: There is only one set of parameters for vehicle components. Both station and vehicle components are initially soaked at ambient temperature, as they are directly exposed to ambient conditions and essentially consist of stainless steel, which has a characteristic high thermal conductivity.

Table A2 - Station and vehicle fuel line components

Geometry	**Units**	**Station-S1**	**Station-S2**	**Vehicle**
Internal gas volume	liters	0.2	0.4	0.2
Total external length	mm	4937	4479	5538
External diameter	mm	17	30	10
Internal diameter	mm	7	10	1.3
Wall thickness	mm	5	10	5
mass (= effective thermal mass in simulation)	kg	6	10	4
Material Properties				
Density	kg/m^3	6328	3694	7900
Thermal conductivity	W/m/K	0.5	1.5	Inf
Specific heat capacity	J/kg/K	728	558	659

A.3.4 Pressure Drop in Fuel Line from Dispenser to Vehicle

The pressure drop coefficient used for calculating the mass flow rate is calibrated from the reference pressure drop situation defined in 7.2. The pressure drop under reference conditions determines the value of the coefficient. A high pressure drop leads to two effects that both yield a higher CHSS gas temperature at the end of fueling: First, the fueling is delayed (i.e., the peak mass flow occurs at a later time). This consequently delays the temperature rise inside the CHSS and gives the gas less time to exchange heat with the internal liner surface. Secondly, more Joule-Thomson heating is introduced into the CHSS because a higher station pressure is required to generate a given mass flow rate, and the enthalpy of hydrogen fuel gas increases with pressure.

The reference flow condition is a function of the CHSS size and is defined as follows:

- 1.5 times the average mass flow required to fuel the entire storage capacity in 3 minutes (e.g., for a capacity of 5 kg: mass flow = 5000 g/180 s * 1.5 = 41.67 g/s)
- Vehicle CHSS pressure = 10 MPa
- H2 temperature at break-away = -15 °C

Under this reference flow condition, the fueling model utilizes a pressure drop coefficient that calculates the pressure drop on the station side, from break-away to nozzle, to be 15 MPa, and the pressure drop on the vehicle side, from receptacle to CHSS, to be 20 MPa (for the hot case) or 2 MPa (for the cold case).

Hot case modeling assumes the highest reference pressure drop of 35 MPa from the station break-away to vehicle vessel inlet/outlet port: 15 MPa over dispenser components (pipe, break-away, hose, and nozzle) plus 20 MPa over vehicle components (receptacle, pipes, valves, etc.).

Cold case modeling assumes a low reference pressure drop of 17 MPa from the station break-away to vehicle vessel inlet/outlet port: 15 MPa over dispenser components plus 2 MPa over vehicle components.

A.3.5 Pressure Ramp Rate Type

Section 8 defines upper and lower tolerances on the pressure at the station. The tolerances are constant offsets that are applied to the linear pressure rise. Its slope is referred to as average pressure ramp rate (APRR). The corridor defined by the upper and lower tolerances allows for some deviation in the station's pressure rise.

Figure A4 illustrates a fueling event where the station delays fueling by the time t_{Lower} and then ramps up its pressure at an increased ramp referred to as hot pressure ramp rate (HPRR). This pressure ramp will lead to a higher final CHSS gas temperature because the greater slope reduces the time for heat transfer from gas in the CHSS to the inside liner surface. It is therefore used for all hot case simulation runs. There is a constant conversion factor between APRR and HPRR that is derived from simple geometrical considerations and that uses the pressure corridor bandwidth parameters (see Figure A4):

$$APRR = HPRR * (1- (\Delta P_{lower} + \Delta P_{upper})/(MOP - P_0))$$

For the H70 protocols, MOP is 87.5 MPa, the lowest initial pressure P_0 is 2 MPa, and the pressure bounds are defined in Section 8, so this equation simplifies to:

$$APRR = 0.889 * HPRR$$

This conversion is used for all simulation runs, including H70 and H35 protocols and top-off simulation runs. H35 protocols do not use their individual MOP of 43.8 MPa to compute the conversion factor. They use a common conversion with H70 protocols in order to ensure protocol interaction compatibility. This means if a partial or complete H35 fueling is succeeded by a H70 fueling, then both protocols must use the same ramp rates to avoid overheating.

There is no equivalent consideration for cold case simulations; they always use APRR and follow the dashed line in Figure A4. Note that the final look-up tables in Appendices D and E report the value of APRR; the value of HPRR is not reported.

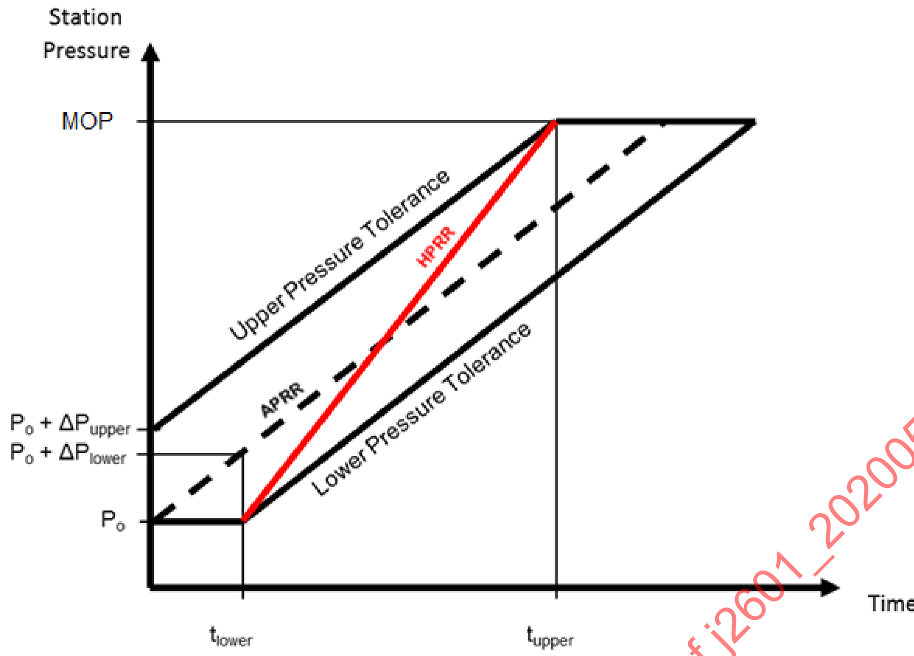

Figure A4 - Hot pressure ramp rate (HPRR) and average pressure ramp rate (APRR)

A.3.6 Intermediate Pressure Leak Checks

There are region specific additional leak checks during fueling that force the mass flow to stop at given pressure levels during the fueling process. During these pauses, there is no heat introduced into the CHSS while the hot gas inside the CHSS continues to transfer heat to the inner liner surface. Therefore, intermediate leak check pauses reduce the final gas temperature inside the CHSS and are consequently part of the cold case set of assumptions. Modeling assumes leak checks during the fueling every 3000 psi (20.7 MPa) pressure increase at the dispenser. For the H70 simulations, this equates to three leak checks. For the modeling assumptions, the following leak checks were simulated: a 10 second, 20 second, 30 second pause for the first, second, and third leak check, respectively.

There is no equivalent in the hot case assumptions, the pressure ramps up without interruption.

A.3.7 Vehicle CHSS System: Vessel Geometry, Count, and Material

The final look-up tables are not derived from a single hydrogen vehicle storage system, but rather reflect the full scope of storage system characteristics across all OEM applications that were considered during table development. Table A3 lists the CHSSs used in the protocol development, along with some of their key parameters. It should be noted that not all of these are existing CHSS systems, but rather collections of parameters designed according to the concept of hot and cold case fueling conditions. Table A3 identifies which CHSSs were used for hot and cold case conditions.

The vehicle CHSS is one of the most important indeterminates to the fueling station in non-comm fueling. There are a large number of factors that can vary in a large range and that have a significant impact on final gas temperature. These factors can be divided into three main categories:

- The vessel geometry describes the general shape of the vessel(s) in the CHSS. The major parameters are internal gas volume, internal surface area, and wall thickness. Recall that the station and vehicle fuel line components introduce a given amount of heat into the fuel gas in order to cool down. A big vessel contains more gas to consume this given amount of heat; it will therefore have a lower final gas temperature than a smaller vessel. At the same time, large vessels tend to have a smaller surface-to-volume ratio, i.e., they have less heat exchanging area per unit volume and therefore will get hotter than a smaller vessel. In addition, the vessel parameters listed in Table A3 do consider that vessels with larger diameter require a larger composite wall thickness; this inhibits the heat flux to the environment. The geometry of the hot case vessels is generic and was created as follows: small vessels have an outer length of 800 mm; the diameter grows to increase internal gas volume. The outer diameter is limited to 600 mm; for large vessels the outer diameter is fixed to 600 mm and the outer length grows with internal volume.

- The number of vessels is an important parameter for cold case simulations. All hot case simulations are conducted with single vessels because they have the smallest surface-to-volume ratio. Multiple small vessels have a significantly higher surface area for the same volume and are therefore considered cold case relevant. All cold case CHSSs are constituted with repeated identical 1 kg vessels. For example, the 10 kg cold case HSS contains ten vessels. For the simulation of the heat exchange with the fuel line components, it is assumed that the complete flow passes the thermal masses before it splits up into the individual vessels. Note that repeated vessels are not simulated explicitly, only one representative is simulated.

- The liner material is another very important control factor. The Type IV plastic liners have an extremely low thermal conductivity and a large temperature gradient builds up across the liner thickness during the fueling process. For that reason, Type IV vessels result in a much higher final gas temperature after fueling when compared to Type III vessels. The aluminum's thermal conductivity on the other hand is so high that there is hardly a temperature gradient inside the liner during fueling. The liner temperature rises permanently during fueling and the aluminum liner serves as a heat sink.

Table A3 - CHSS vessels

		Cold Case Tanks		Hot Case Tanks			
General	**Units**	**1kg-35MPa-TypeIII**	**1kg-70MPa-TypeIII**	**2kg-70MPa-TypeIV**	**4kg-70MPa-TypeIV**	**7kg-70MPa-TypeIV**	**10kg-70MPa-TypeIV**
Nominal working pressure (NWP)	MPa	35	70	70	70	70	70
Storage capacity system	kg	2	2, 4, 7, 10	2	4	7	10
Storage capacity vessel	kg	1	1	2	4	7	10
Number of vessels in system	-	2 to 6	2, 4, 7, 10	1	1	1	1
Defueling rate system (max)	g/s	1.4	1.4	-	-	-	-
Defueling rate per vessel (max)	g/s	0.7 to 0.2	0.7 to 0.14	-	-	-	-
Vessel Geometry Specification							
Required internal gas volume	liters	42	25	50	99	174	249
Total external length, without necks	mm	800	835	800	800	938	1298
External diameter	mm	300	240	347	493	600	600
Internal diameter	mm	267	200	293	420	513	513
Wall thickness liner (cylindrical section)	mm	3.25	3.25	5	5	5	5
Wall thickness carbon wrapping (cylindrical section)	mm	13.4	16.7	22.2	31.6	38.3	38.3
Internal liner surface area	m^2	0.7	0.5	0.8	1.1	1.6	2.2
Liner mass (= effective thermal mass in simulation)	kg	6.0	4.7	3.6	5.1	7.4	10.1
Composite mass (= effective thermal mass in simulation)	kg	14.8	14.9	27.9	57.2	99.4	135.6
Vessel Wall Material Properties							
Composite Wrapping		composite		composite			
Density	kg/m^3	1494	1494	1494	1494	1494	1494
Thermal conductivity	W/m/K	0.74	0.74	0.5	0.5	0.5	0.5
Specific heat capacity	J/kg/K	1120	1120	1120	1120	1120	1120
Liner		aluminium		plastic			
Density	kg/m^3	2700	2700	945	945	945	945
Thermal conductivity	W/m/K	164	164	0.5	0.5	0.5	0.5
Specific heat capacity	J/kg/K	1106	1106	2100	2100	2100	2100

A.3.8 Vehicle Vessel Soak State: Initial CHSS Temperatures

The temperature of the vehicle storage system (gas and vessel wall) at the onset of fueling is not available to the dispenser and could potentially be warmer or colder than ambient temperatures because of transport, storage, parking, and other conditions (e.g., vehicle package location). The industry-wide consensus on the temperature deviation from ambient or so-called "soak" temperature is shown in Figure A5. The rationale for the specified "hot soak" and "cold soak" zones are listed in Table A4.

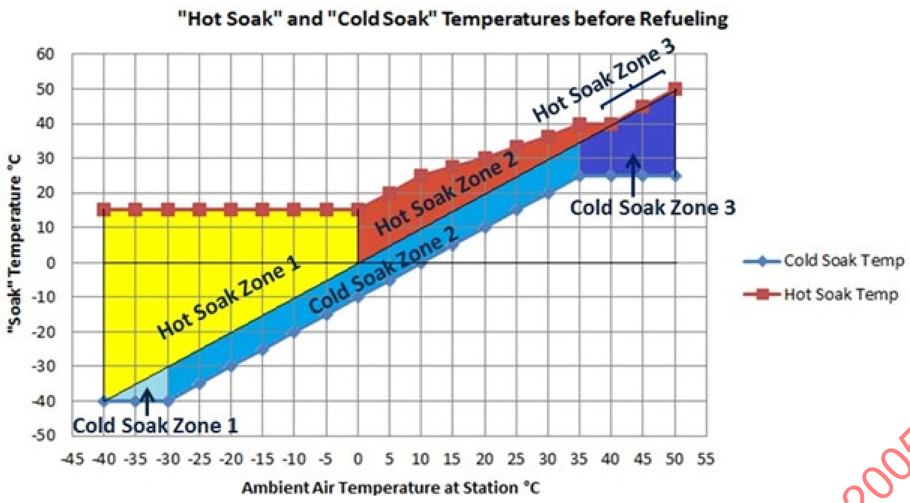

Figure A5 - "Cold soak" and "hot soak" CHSS temperatures compared to ambient temperature

Table A4 - Assumptions for "hot soak" and "cold soak" zones

Temperatures (°C)			Assumptions	
Ambient	Cold Soak	Hot Soak	Cold Soak	Hot Soak
-40	-40	15	Cold Soak Zone 1: Vehicle minimum ambient operating temperature of -40 °C	Hot Soak Zone 1: Vehicle stored in a climate controlled garage at 15 °C
-30	-40	15	Cold Soak Zone 2: CHSS is 10 °C colder than ambient due to local climate and storage variations.	
0	-10	15		Hot Soak Zone 2: CHSS is ≤ 15°C warmer than ambient due to diurnal effects, local climate, and storage variations.
10	0	25		
20	10	30		
35	25	40		
40	25	40	Cold Soak Zone 3: Vehicle stored in a climate controlled garage or underground parking at 25 °C.	Hot Soak Zone 3: CHSS is as warm as ambient
50	25	50		

A.3.9 Vehicle History

After soaking at a certain temperature and prior to fueling, the vehicle may be operated by means of gas addition (i.e., fueling) or extraction (e.g., driving the vehicle). This potential operation is another source for heating up or cooling down the gas inside the CHSS relative to ambient temperature.

For the hot case fueling simulations, a partial fueling history was assumed in order to initialize the CHSS with the highest conceivable gas and vessel wall temperatures at the given initial pressure P_0. However, the fueling tables do not use the CHSS initial pressure as a parameter for looking up the pressure ramp. Instead, hot case fueling simulations started with the lowest permissible initial pressure, independent of the actual CHSS pressure. This means, a fueling history followed by the actual fueling event was simulated as a single fueling event starting at the lowest pressure. Potential circumstances (roadside fueling, equipment malfunctions, service procedures, certain ambient temperature fill protocols, etc.) may arise which result in the initial start-of-fill temperature of the CHSS being hotter than assumed in the simulations. Future versions of SAE J2601 may incorporate additional development of methods to detect temperatures or verify starting temperature assumptions (see Appendix M).

For the cold case fueling simulations, a vehicle driving history was assumed in order to initialize the CHSS with the lowest conceivable gas and vessel wall temperatures. The gas temperature in the vehicle storage system decreases during vehicle operation due to depressurization. Different materials and designs of vehicle storage systems will lead to different degrees of cooling during vehicle operation. This is due to differences in heat transfer characteristics, heat capacity, and storage volume of on-board storage systems. The cooling effects of vehicle operation are specific to each vehicle. The modeling and testing of these effects were done according to OEM's worst-case CHSS specification. The driving history constrained the CHSS gas temperature and pressure to the existing CHSS certification temperature limit of -40 °C during defueling and a minimum system pressure of 0.5 MPa.

A.3.10 Step 1 - Pressure Ramp Rate

Pressure ramp rates are generally designed to avoid overheating a CHSS under worst-case conditions. These worst-case conditions for overheating are collected in the set of hot case assumptions. The simulation runs for determining the highest pressure ramp rate that will still not overheat the CHSS therefore use hot case parameters, initial and boundary conditions. The CHSS initial pressure is 2 MPa. Figure A6 illustrates a H70 fueling simulation in a pressure-temperature state diagram for an exemplary ambient temperature 0 °C. The CHSS temperature is initialized at the hot soak temperature 15 °C. During fueling, there is a rapid temperature increase inside the CHSS at the beginning; later the slope of the fueling curve becomes steeper because the pressure increase dominates over the temperature increase. The simulation stops whenever the CHSS is "full" (95% SOC) or reaches the upper temperature limit 85 °C. During the simulation, the pressure ramp rate at the station is held constant. The procedure of computing the optimal pressure ramp rate that fulfills both SOC and temperature conditions at the end is an iterative process. It requires a number of fueling simulations with different pressure ramp rates to find the optimal ramp rate. There is a third condition to be fulfilled by the optimal ramp rate: the peak flow rate which may occur at any time during the fueling simulation shall not exceed 60 g/s. This is illustrated in Figure A7. If it does, the pressure ramp rate must be decreased, which will automatically decrease the peak flow rate. Therefore, the resulting pressure ramp rate will generally satisfy only one of the conditions: (a) the final gas temperature reaches 85 °C (this typically occurs for high ambient temperatures and small CHSSs), or (b) the peak flow rate reaches 60 g/s (this typically occurs for cold ambient conditions and large CHSSs). The final SOC, however, is always 95%. Note that the SOC target 95% is a tradeoff to increase the resulting pressure ramp rate. In an earlier version of the protocol the SOC target 100% was used which resulted in smaller ramp rates. However the final SOC target 100% can never be reached in non-communications fueling because the target pressure (see A.5) limits final CHSS pressure such that hot case conditions typically resulted in SOC values below 90%.

A second tradeoff was made in order to generate higher pressure ramp rates: an alternative pressure ramp rate was computed in the same fashion as described before, but starting with an elevated initial CHSS pressure 5 MPa. The look-up tables in Appendices D and E report this alternative higher pressure ramp rate whenever the rate computed with 2 MPa initial CHSS pressure would fail to permit a 3-minute fueling. The cases in which the higher ramp rates are reported can be identified by the Top-Off option in the communications fueling tables. The higher pressure ramp rate could potentially lead to overheating the CHSS if the actual initial pressure is below 5 MPa. The precaution to avoid this is a reduced target pressure; this is described in A.5.

The pressure ramp rates were determined for the smallest and the largest CHSS in each size category because it cannot be said in advance which one will be limiting the ramp rate. The reasons for this are two opposing effects. On the one hand, the smaller CHSS has a higher surface-to-volume ratio; this leads to a lower final gas temperature because of better heat transfer to the liner. On the other hand, the smaller CHSS receives the same fixed amount of extra heat from the thermal fuel line masses which causes a higher gas temperature increase inside the vessel when compared to the larger CHSS.

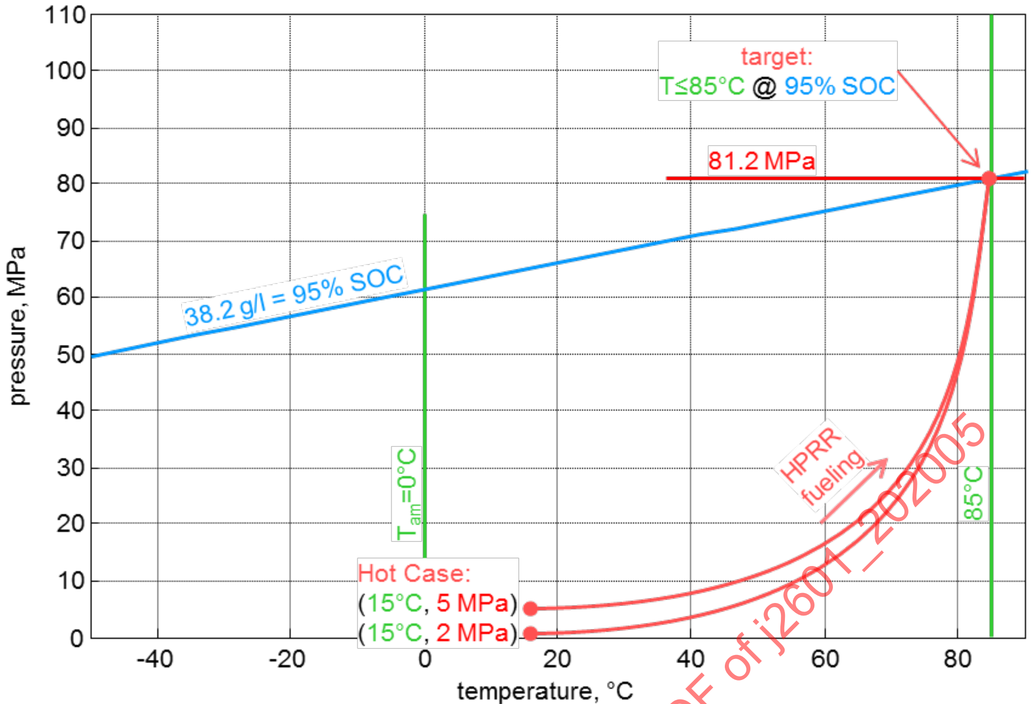

Figure A6 - Step 1 - pressure ramp rate simulation

The fastest pressure ramp rates reported in the look-up tables are additionally clipped at an upper value 28.5 MPa/min. This upper bound allows fueling a CHSS according to the H70 protocol from 2 MPa to 87.5 MPa in exactly 3 minutes. It is reached at cold ambient temperatures in most protocols for CHSS capacity categories A and B.

The peak mass flow limitation became active only in the CHSS Capacity Category C at low ambient temperatures. The resulting pressure ramp rate is 19.9 MPa/min for all low ambient temperatures. It permits fueling from 2 to 87.5 MPa in 4.3 minutes

The pressure ramp rates were designed for H70 CHSSs only. All H35 protocols use the same pressure ramp rates as the corresponding H70 protocols. Corresponding protocols used the same vessels during the simulations: H35 CHSS Capacity Category B (2.4 to 4.2 kg) uses the same vessels as H70 CHSS Capacity Category B (4 to 7 kg) and H35 CHSS Capacity Category C (4.2 to 6.0 kg) uses the same vessels as H70 CHSS Capacity Category C (7 to 10 kg). This procedure was chosen on purpose in order to ensure safe protocol interaction, i.e., a partial H35 fueling may be continued with a H70 fueling and vice versa.

For the same reason, the communications fueling protocols use the same pressure ramp rates as the non-comm protocols. This ensures safe protocol interaction between communications and non-communications fueling protocols, i.e., a partial communications fueling may be continued with a non-comm fueling and vice versa. The advantage of communications fueling over non-comm is a higher SOC at the end of fueling, but not a faster fueling event. In fact, communications fueling takes longer than non-comm fueling because the fueling stops later, i.e., at a higher target pressure.

In the creation of this document, the Interface Task Force of the SAE Fuel Cell Standards Committee assumed that a vehicle would fill from one dispensing system. The analysis, testing, simulation and development of the standard did not consider conditions under which the vehicle is fueled using multiple dispensers. The committee did align the pressure ramp rates for H35 and H70 fueling to minimize the potential for overheating under the scenario where a user fills first at H35 and then completes the fill at H70. Although this minimizes the potential for overheating, it does not completely eliminate it if both dispensers are warm at the beginning of each fill.

Examples of fueling scenarios not fully considered:

- Fueling under H35, then fueling under H70 non-communication fueling
- Fueling under H70 fueling with multiple re-starts at a unique dispenser each time

Under one of the above scenarios, gas temperatures within the CHSS could exceed the limit. While one of the fueling scenarios above could potentially occur, the probability of occurrence is small. For this reason, and due to the difficulty of bounding these scenarios, they were not considered.

It is recommended that stations utilize common fuel delivery temperature categories for all dispensers, as this reduces the risk of the CHSS gas temperature exceeding the limit under these unlikely scenarios.

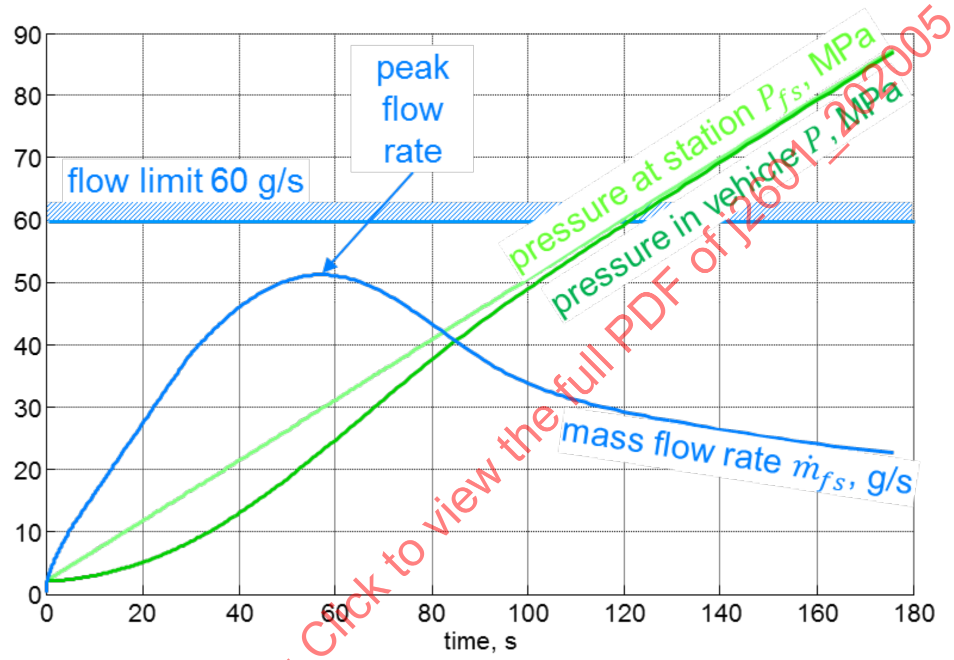

Figure A7 - Typical pressure and mass flow development

The pressure ramp rates obtained with the described procedure are hot pressure ramp rates (HPRR) by definition. They are scaled by the constant factor explained earlier in this appendix to obtain the tabulated average pressure ramp rate values APRR.

A.3.11 Step 2 - Target Pressure

The second step in defining the fueling process is to compute the target pressure (i.e., the pressure at the station at which the fueling process is stopped) to ensure that the CHSS stays within its operating boundaries under any conceivable condition. For this purpose, the cold case simulation assumptions were made. With the two tradeoff modifications made to the calculation of the pressure ramp rates in Step 1 (i.e., targeting at 95% SOC instead of 100% and starting at 5 MPa in some cases) it is also required to simulate the fueling process under hot case conditions again to exclude the possibility of overheating.

A.3.12 Non-Communications Target Pressure

Figure A8 illustrates the cold case simulation for the H70 example at 0 °C ambient temperature and 0.5 MPa CHSS pressure prior to fueling. The cold case simulation starts with full CHSS (100% SOC) soaked at the cold soak temperature -10 °C. The system is drained from hydrogen in the driving history simulation indicated with a dotted line. When the CHSS gas temperature reaches the lower operating limit -40 °C, the extraction mass flow rate is reduced in order to maintain the lower operating temperature while the pressure continues to drop. The history simulation is stopped when the CHSS pressure reaches the initial fueling CHSS pressure P_0. In the example, a value of 0.5 MPa was chosen. Note that the initial CHSS pressure is the second dimension in the look-up tables (ambient temperature is the first). The final values of the CHSS states (i.e., gas mass, internal energy, and wall temperatures T_{vw}) are used to initialize the fueling simulation. The cold case fueling simulation stops when the SOC has reached a value 100%, and the corresponding CHSS pressure P_{CC} is stored as a result. There is no cold case simulation that ever reaches the upper temperature limit 85 °C. The cold case simulations were only conducted for the larger CHSS in each size category because the two opposing effects described for the hot case simulations in Step 1 do not exist in the same way. The CHSS size varies in the cold case assumptions only by the number of identical vessels in the system (H70: 2, 4, 7, or 10), the geometry of the vessels is always the same. Therefore, all CHSSs have the same surface-to-volume ratio. The extra amount of heat coming from the fuel line thermal masses however is evenly distributed to all vessels in the system. Therefore, the largest system with the highest vessel count will have the lowest gas temperature.

No hot case simulations were performed in Step 2. Instead, the hot case pressure limit P_{HC} is set to the value from the Step 1 fueling target at 95% SOC and 85 °C; this is 81.2 MPa and 41.1 MPa for the for the H70 and H35 protocols, respectively. The fact that some hot case fuelings starting at pressures lower than 2 or 5 MPa (depending on the simulation chosen to deliver the ramp in Step 1) will overheat when fueled to P_{HC} was not taken into consideration.

For each ambient temperature and initial CHSS pressure, there are two CHSS gas pressure limitations, P_{CC} from the cold case simulation and P_{HC} for the hot case consideration. The lower of the two values is used as the limit for the final CHSS pressure. The target pressures reported in the look-up tables in Appendices D and E are final simulation pressure at the station if the cold case is limiting, 81.2 MPa otherwise. It is expected that the final fuel pressure inside the CHSS will be smaller than the fueling pressure target due to the pressure drop from dispenser to CHSS. Inspection of the H70 look-up tables shows that the hot case pressure limit P_{HC} is never active because all cold case simulation end pressures are lower.

After determining the fueling target pressures, hot case simulations for all initial pressures (especially the low pressures smaller than 5 MPa) were conducted, stopping at the target pressure in order to check the final gas temperatures. It turned out that no hot case simulation leads to overheating. The reason for this is the fact that the target pressures are all determined by the cold case simulations and the fueling always stops earlier than 81.2/41.1 MPa.

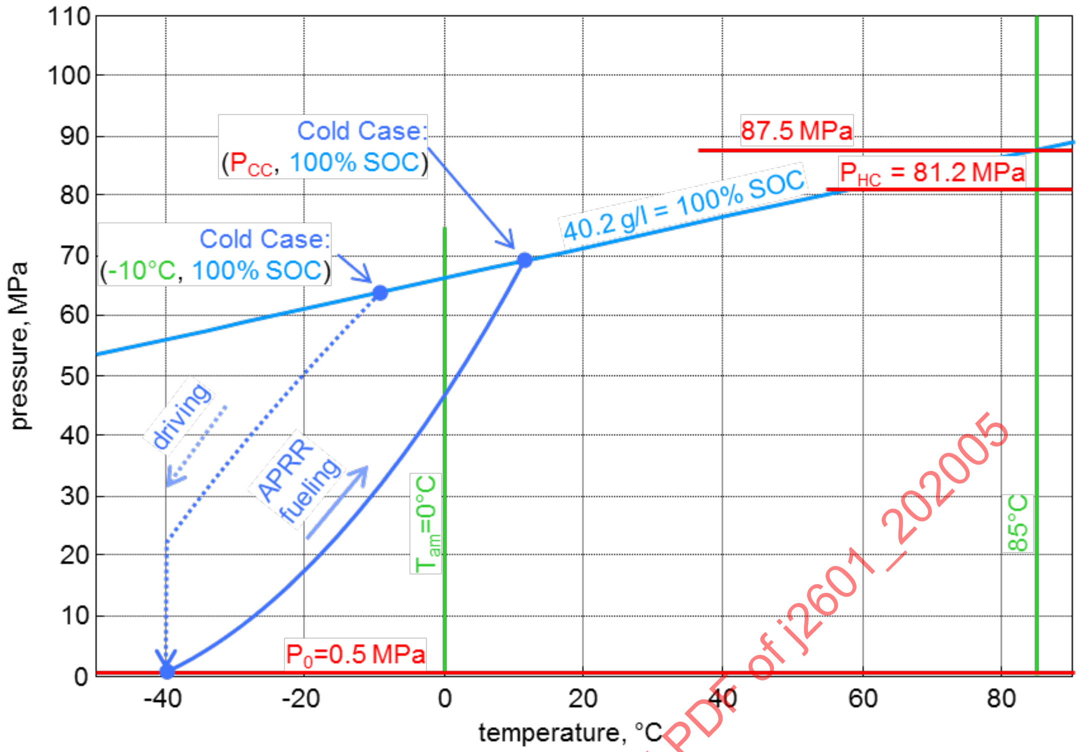

Figure A8 - Step 2 - non-communications target pressure simulation

A.3.13 Communications Target Pressure

Communications between the fueling station and the vehicle according to SAE J2799 is used to increase the final SOC. This means the fueling station relies on the signal received from the vehicle in order to raise the target pressure. Recall that the pressure ramp rate is the same as in non-communications fuelings to ensure safe protocol interaction (e.g., switching from a partial communications fueling to non-comm or vice versa). As stated in 3.6.1.1, it was taken into consideration that the information received from the vehicle is not ASIL/SIL classified to any standard. This means that the CHSS must stay within its certification limits even if communications delivers invalid data. The key to raising the target pressure is the assumption that all concerned pressure vessels are tested according to the United Nations Global Technical Regulation (GTR) on Hydrogen and Fuel Cell Vehicles or to SAE J2579. Both require a hydraulic test with ten cycles to 150% NWP in order to address a possible fueling station over-pressurization. For 70 MPa CHSSs, this is a pressure of 105 MPa. This means in case of communications failure, the CHSS pressure may reach a value of 105 MPa once. This is not a normal operating pressure; it must be treated as an exception that occurs only in the case of communications failure.

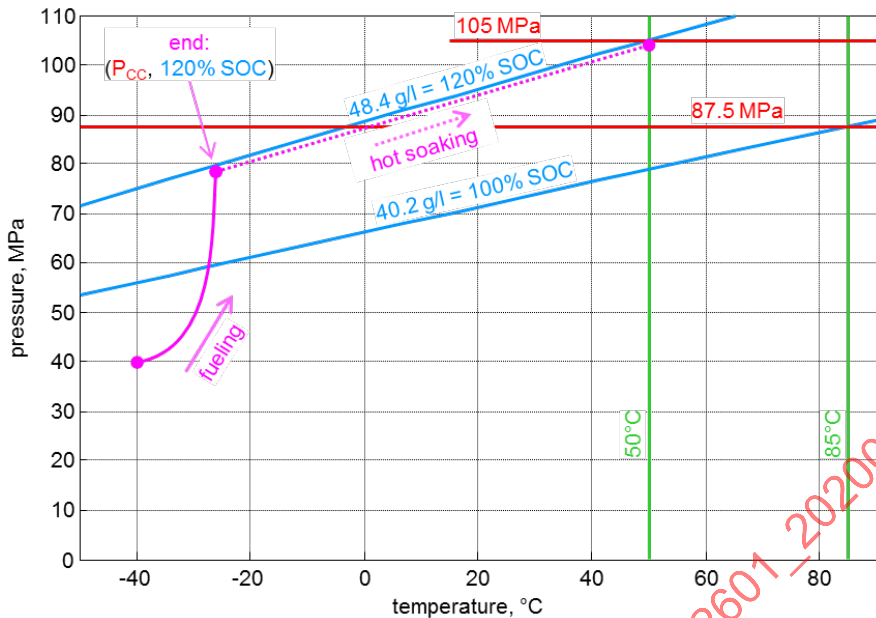

Figure A9 - Step 2 - communications fueling: rationale for 120% SOC limitation

Figure A9 illustrates the rationale for raising the fueling target pressure for the communications protocols. As explained before, the upper pressure limit that may occur once and only in the case of communications failure is 105 MPa. This pressure limit may be reached by the following course of events, even if the communications target pressure is below 87.5 MPa: consider a cold case fueling at low ambient temperature and medium initial CHSS pressure. This fueling is stopped at 120% SOC at a still very cold CHSS gas temperature below 0 °C. The final pressure P_{CC} inside the CHSS is well below 87.5 MPa. Subsequently, the CHSS is exposed to different ambient conditions (e.g., shipped to a different warmer location or the vehicle is parked for half a year from starting in winter and ending in summer). Eventually, the CHSS may be hot soaked at 50 °C ambient temperature. The corresponding hot soak temperature is 50 °C; see Table A4. At this temperature, the CHSS gas pressure will reach exactly 105 MPa. Hence, 120% SOC is chosen as the target SOC for computing the cold case final pressures P_{CC}.

Figure A10 illustrates the cold case simulation for the H70 example at 0 °C ambient temperature and 0.5 MPa CHSS pressure prior to fueling. As in the non-comm simulation, the cold case simulation starts with full CHSS (100% SOC) soaked at the cold soak temperature -10 °C. The system is drained from hydrogen in the driving history simulation, obeying the lower temperature limit and stopping at the initial fueling pressure P_0; this is indicated with a dotted line. Again, the final values of the CHSS states are used to initialize the fueling simulation. The cold case simulation stops as the SOC reaches the value 120%, and the corresponding final CHSS pressure P_{CC} is stored as a result. As before, the cold case simulations were only conducted for the larger CHSS size in each size category because the smaller size will always end at a higher pressure.

The hot case simulation starts with the measured initial CHSS pressure P_0 (a possible fueling history is ignored) and the hot soak temperature +15 °C. The system is fueled with the HPRR, and the simulation stops when the upper temperature limit 85 °C is reached. The corresponding pressure P_{HC} is stored as a result. As in Step 1, both the smallest and the largest vessel size for each size category were simulated.

For each ambient temperature and initial CHSS pressure, there are three final CHSS gas pressures (one cold case P_{CC} and two hot case P_{HC} results). The limiting case is the simulation run with the lowest final CHSS pressure. The look-up tables in Appendices D and E report final simulation pressure at the station for the limiting case as target pressure. It is expected that the final fuel pressure inside the CHSS will be smaller than the fueling pressure target due to the pressure drop from dispenser to CHSS. As a result, now all hot case simulations determine the target pressure. This is because the 120% limitation for the cold case simulations results in very high pressures, typically above 87.5 MPa.

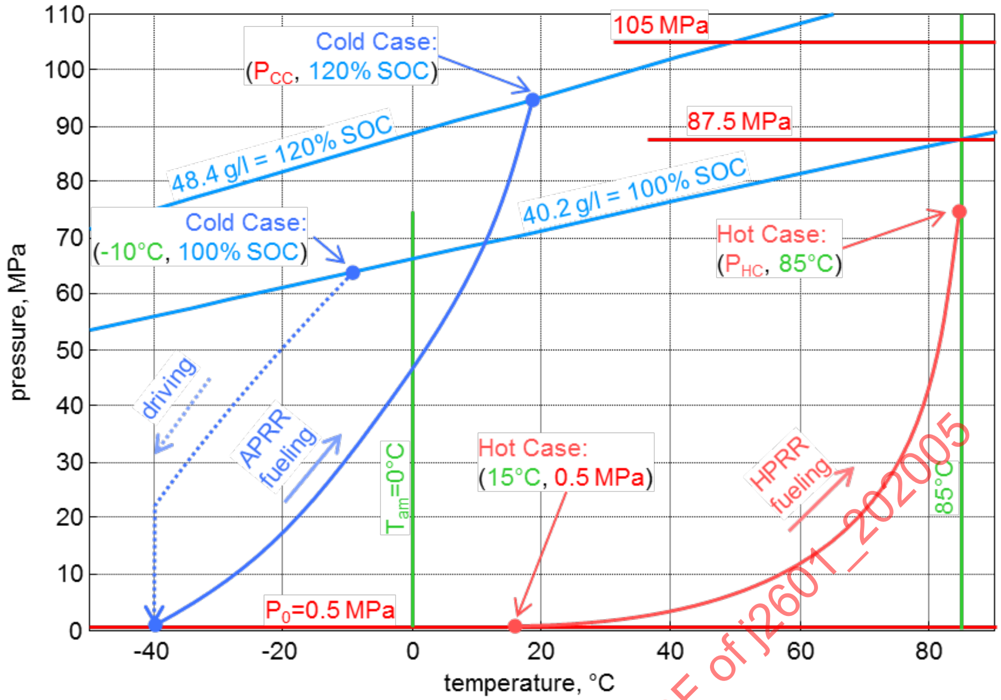

Figure A10 - Step 2 - communications target pressure simulation

A.3.14 Communications Top-Off Fueling

To increase the APRR for standard fuelings described before, the initial CHSS pressure for Step 1 (standard fueling) simulations has been increased from 2 to 5 MPa, if the simulation with 2 MPa yielded a poor fueling time longer than 3 minutes. Having advantages for fuelings at all ambient temperatures and for initial pressures equal to or higher than 5 MPa, this methodology decreased the maximum possible SOC for fuelings starting at initial CHSS pressures less than 5 MPa at each ambient temperature for which the faster ramp rate is applied. The countermeasure to avoid these very low SOC is the so-called top-off fueling, applicable for communications fuelings following SAE J2799.

Top-off fueling is a continued fueling at a reduced pressure ramp rate that starts immediately after a standard fueling. It allows the station to do a follow-up fueling without interruption of the fill, but with a reduced top-off APRR and a new top-off target pressure. Figure A11 shows a standard fueling succeeded with a follow-up top-off fueling.

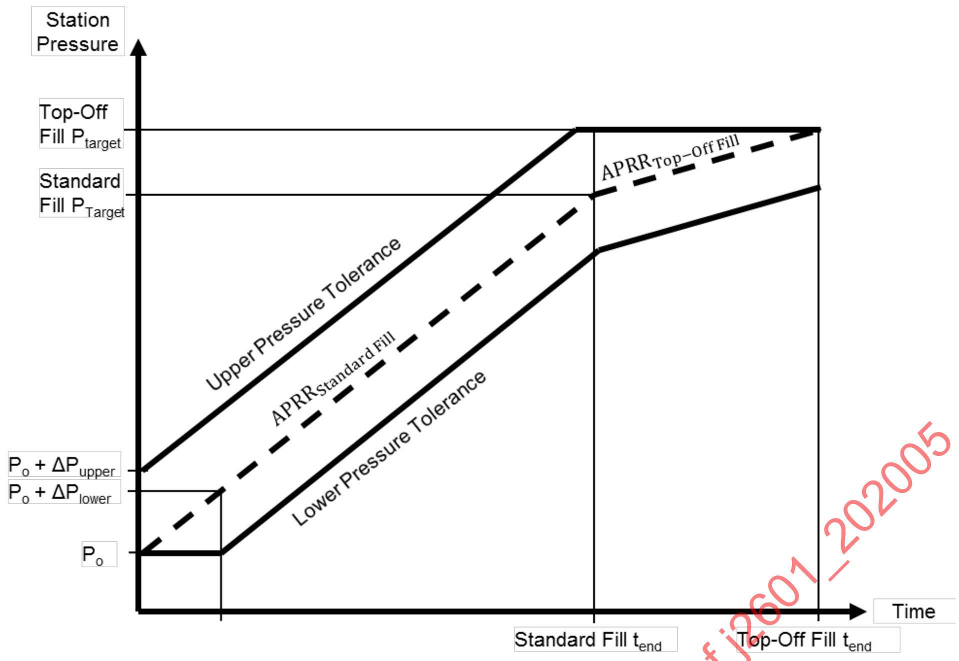

Figure A11 - Station pressure bounds for standard and top-off fueling

The design of top-off pressure ramp rate and top-off target pressure follows the same two step procedure as the design of the standard fueling pressure ramp rate and target pressure.

A.4 STEP T1 - TOP-OFF PRESSURE RAMP RATE

The top-off pressure ramp rates were designed iteratively in the same fashion as the standard pressure ramp rates by finding the ramp rate value that ends a hot case top-off fueling at 100% SOC without violating the 85 °C temperature limit. A fueling history simulation is run in order to initialize the CHSS states at the end of the standard fueling. This standard fueling history uses hot case assumptions; it starts at 0.5 MPa initial pressure, fuels at the HPRR, and ends at the tabulated communications target pressure. This is depicted in Figure A12. The dispenser will hold the temperature at the break-away-coupling, continuing the standard fueling fuel delivery temperature without any additional cool-down time. The final CHSS pressure p_{hc} was recorded for later use in determining the top-off target pressure. The resulting HPRR was then converted to an APRR using the same conversion factor as in Step 1. It is applied to all top-off fuelings that succeed standard fuelings starting between 0.5 MPa and 5 MPa. Only the CHSS size that limited the standard fueling target pressure was simulated.

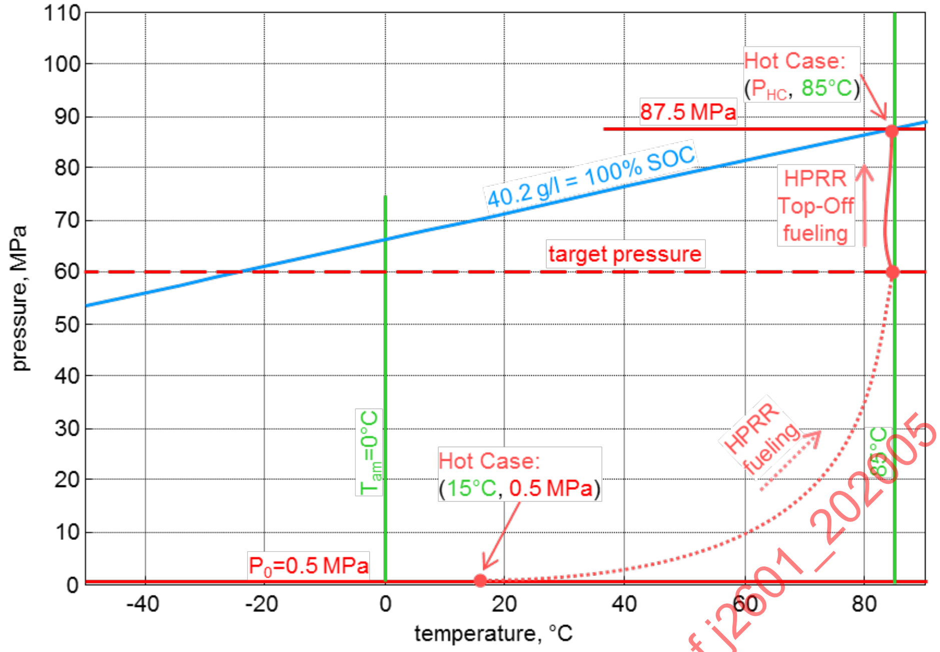

Figure A12 - Step T1 - top-off pressure ramp rate simulation

A.4.1 Step T2 - Top-Off Target Pressure

A cold case top-off fueling simulation was employed to determine the maximum final pressure to prevent overfueling. As in Step 2 for communications fueling, the 120% SOC limitation was used. See Figure A13 for an illustration of the simulation procedure. The actual top-off simulation was initialized by two subsequent history simulations: First, the driving history as described before; second, the standard fueling process that is initialized with the final states from the driving history simulation, fuels with the APRR, and ends at the tabulated communications target pressure. The final CHSS states are then used to initialize the top-off simulation. The simulation ends at 120% SOC and the final pressure P_{CC} is recorded.

The smaller of the two simulation end pressures P_{CC} and P_{HT} limits the top-off target pressure. The final pressure at the fueling station from the limiting simulation is used in the look-up tables.

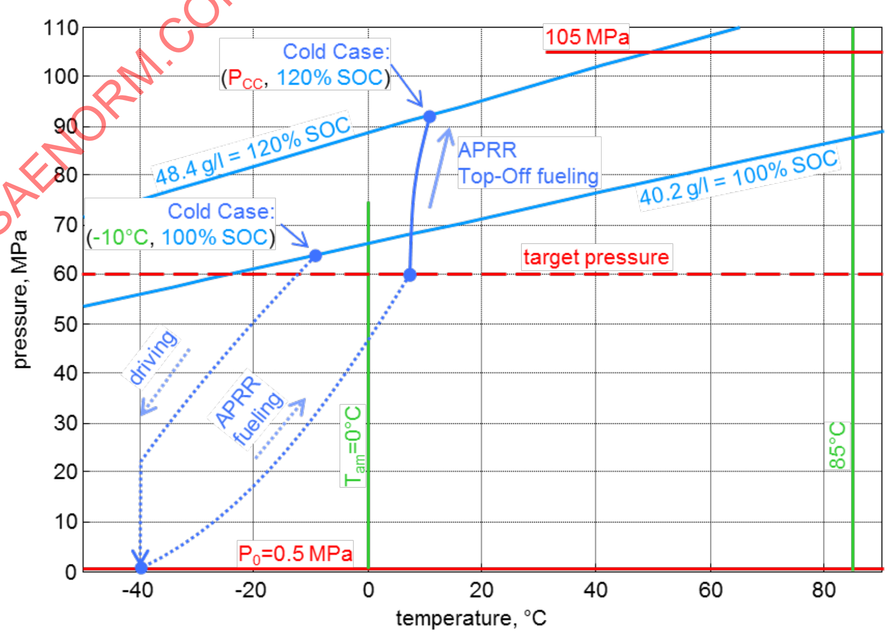

Figure A13 - Step T2 - top-off target pressure simulation

A.5 STEP 3 - PERFORMANCE CHECK

Step 2 to 3: The modeling performed under hot case conditions stops at 85 °C, 60 g/s, or 100% SOC, whichever is reached first. This makes sure that the resulting End Pressure results also in CHSS average gas temperatures below 85 °C.

A.6 COLD DISPENSER

Additional look-up tables were created to improve the fueling speed for the case of pre-cooled station equipment. The simulations performed to create these tables are identical to the ones described before, with the following two modifications to the hot case assumptions: First, the initial station temperature does not equal ambient but a given tabulated temperature (0 °C or -10 °C), but only if the given temperature is colder than ambient. The station then ramps down from its initial temperature to the upper temperature tolerance in 30 seconds. This procedure can be visualized in Figure A2 by replacing ambient temperature with the given initial station temperature. Secondly, the temperature T_{ls} of the station fuel line components is initialized with the same given temperature rather than ambient.

All pressure ramp rates are then computed as described above. Due to the reduced initial station and fuel line temperature compared to the default tables, a higher pressure ramp rate is obtained, especially for high ambient temperatures.

All subsequent steps for computing target pressure (non-communications and communications), as well as communications top-off ramp rate and target pressure, were recalculated following the same procedure as described before, but using the modified Hot-Case assumption and the new pressure ramp rates.

A.7 LABORATORY FIELD VALIDATION AND SENSITIVITY STUDIES

Experimental tests were conducted to validate the standard SAE J2601 fueling protocol for the correlation of models, and validation of tables in the lab and in the field. Additionally, field experience of SAE J2601 has been gained with real fuel cell electric vehicles at real hydrogen stations. These trials and the sensitivity studies were documented in the external report SAE Technical Paper in 2014, SAE Paper 2014-01-1833, “Validation and Sensitivity Studies of SAE J2601, the Light Duty Vehicle Hydrogen Fueling Standard.”

APPENDIX B - SAE J2601 SUBROUTINE FLOW CHARTS

As per 8.7, this appendix details the subroutines flow charts for table-based fueling. The following subroutines are examples of control logic for SAE J2601, table-based fueling. An overview to the subroutines flow charts is as follows:

Figure B0	SAE J2601 table-based fueling overview
Figure B1	General dispenser start up subroutine
Figure B2	Start fueling process non-communications subroutine
Figure B3	Fueling start subroutine: communications fueling page 1 of 2
Figure B4	Fueling start subroutine: communications fueling page 2 of 2
Figure B5	Fueling process check subroutine
Figure B6	Determine fueling table subroutine
Figure B7	Fuel delivery temperature fallback fueling subroutine
Figure B8	Fuel delivery temperature check subroutine
Figure B9	Physical and functional (P&F) requirements subroutine

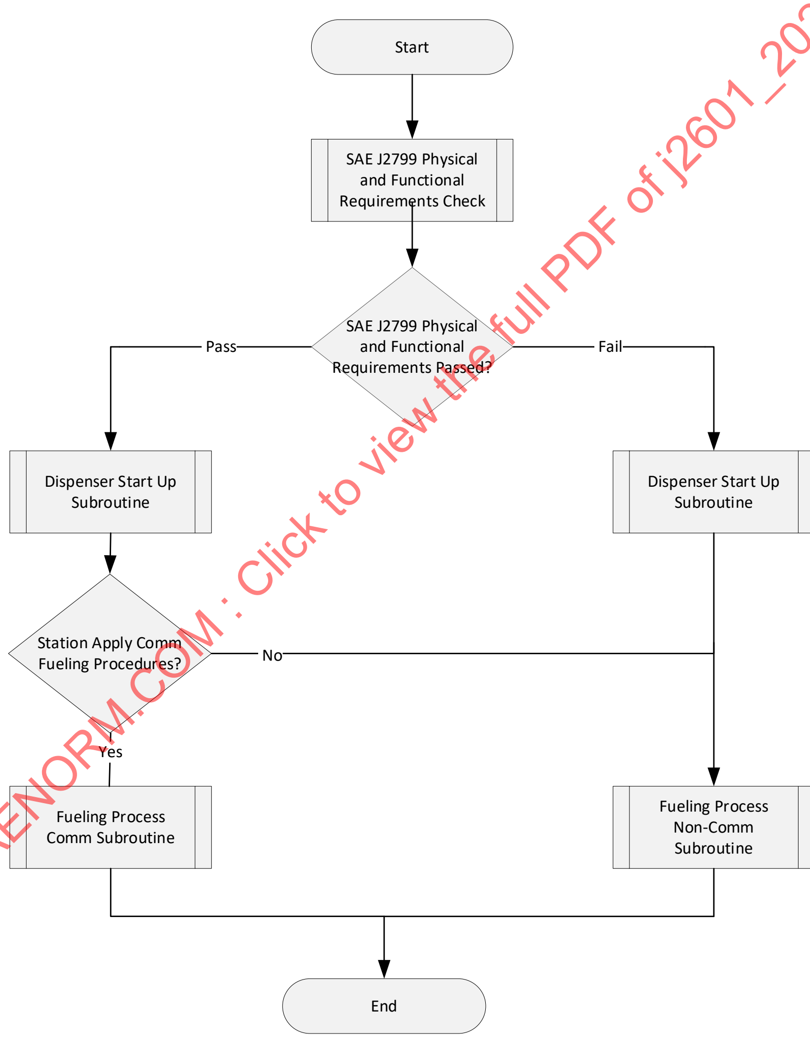

Figure B0 - SAE J2601 table-based fueling overview

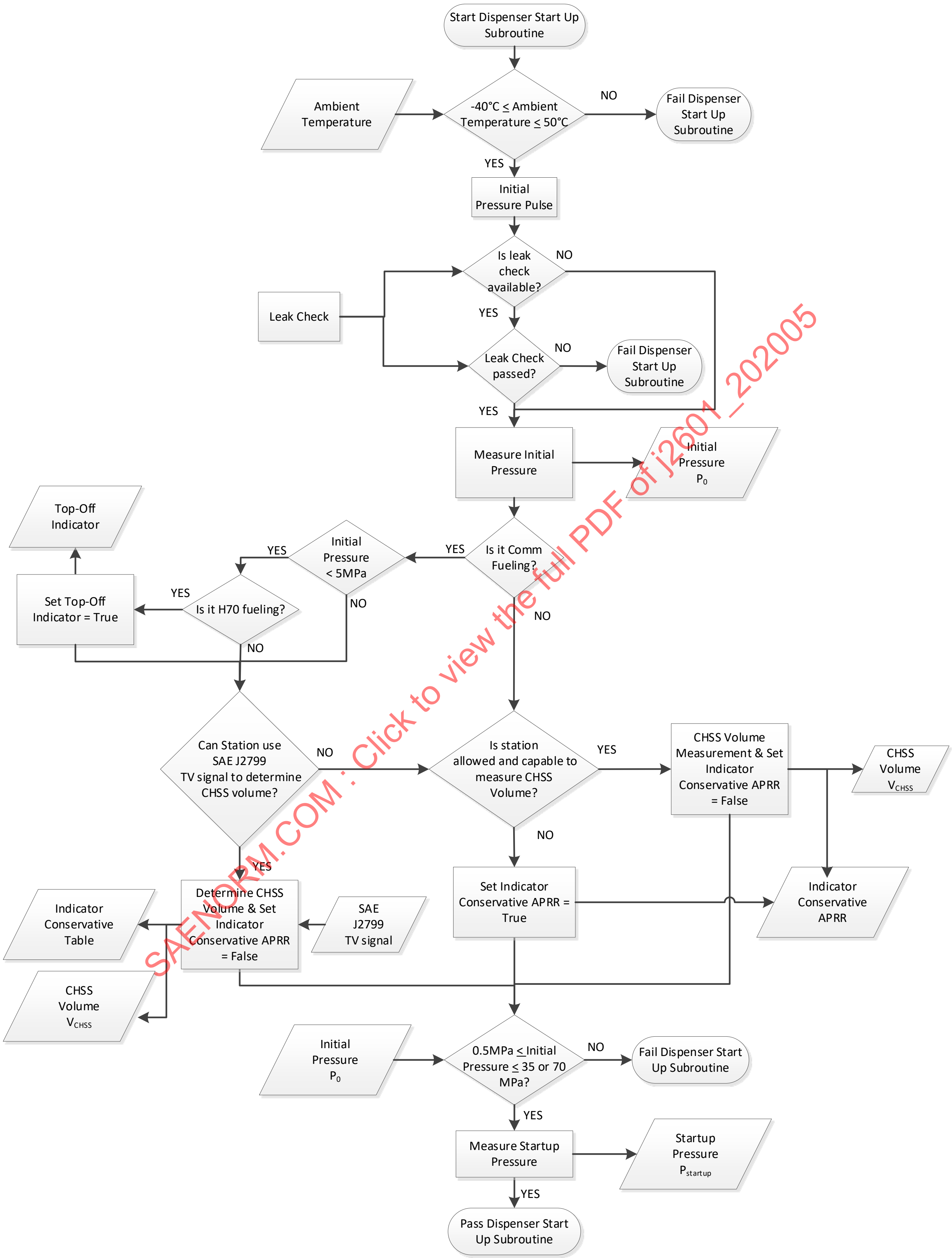

Figure B1 - General dispenser start up subroutine

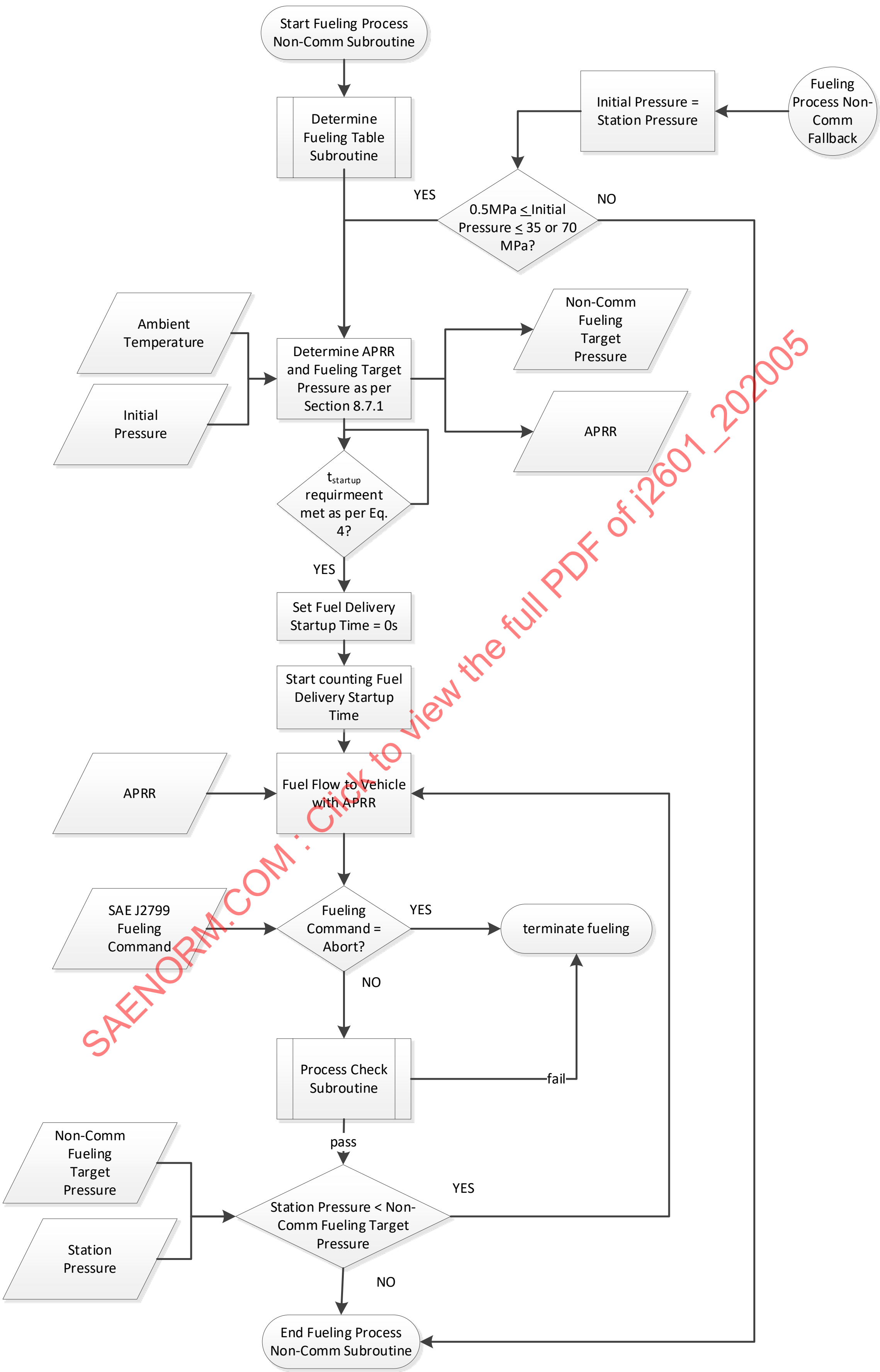

Figure B2 - Start fueling process non-communications subroutine

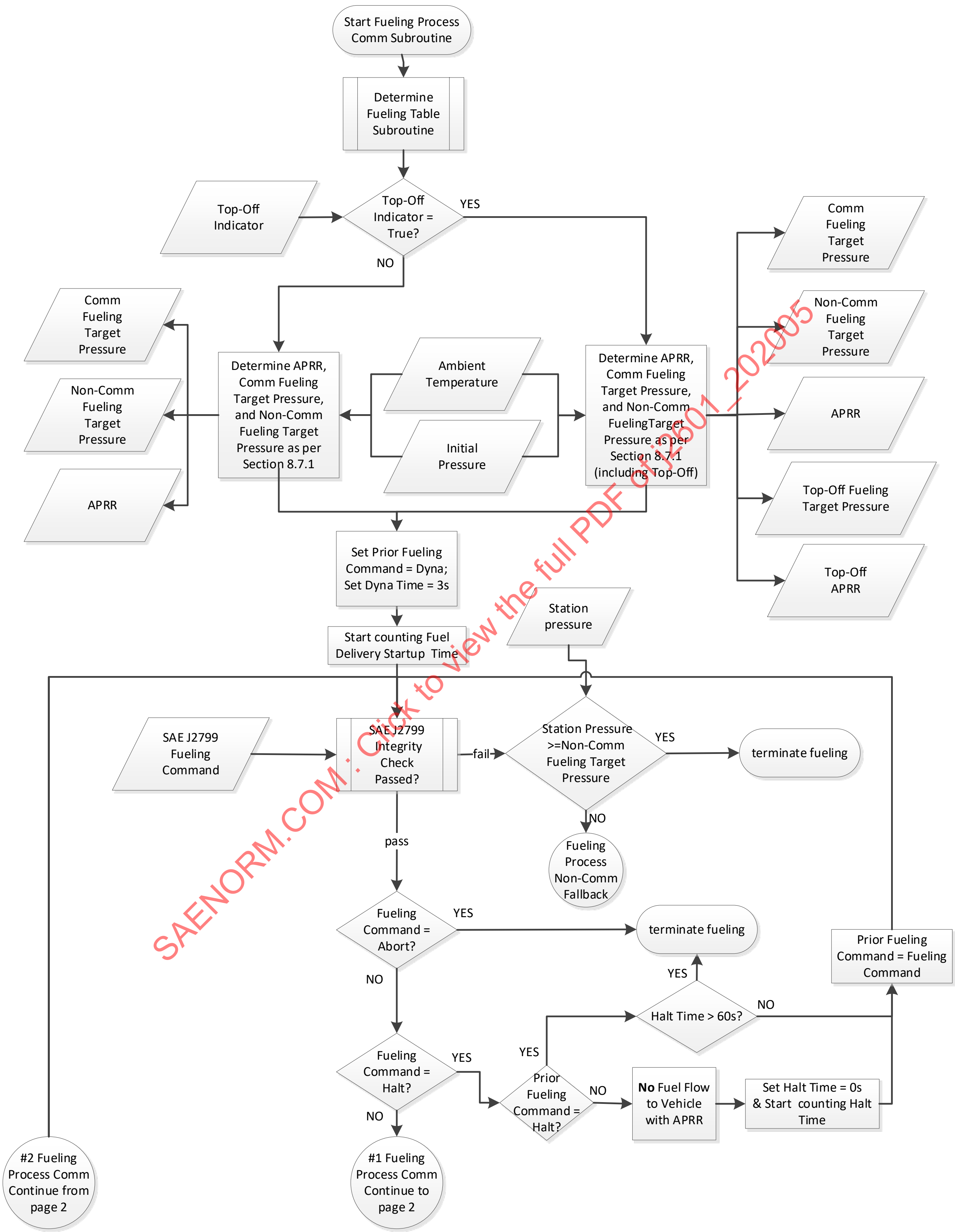

Figure B3 - Fueling start subroutine: communications fueling page 1 of 2

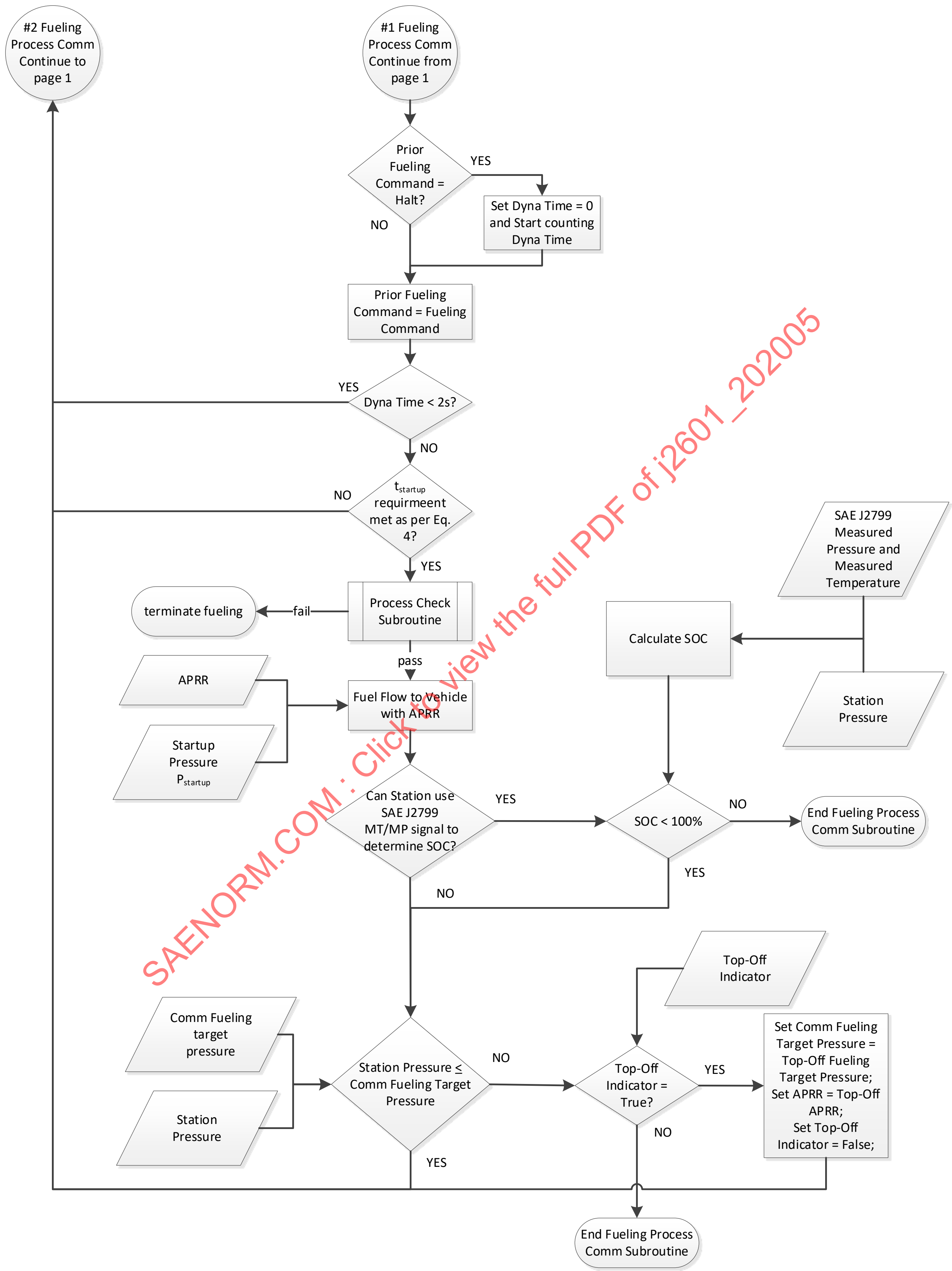

Figure B4 - Fueling start subroutine: communications fueling page 2 of 2

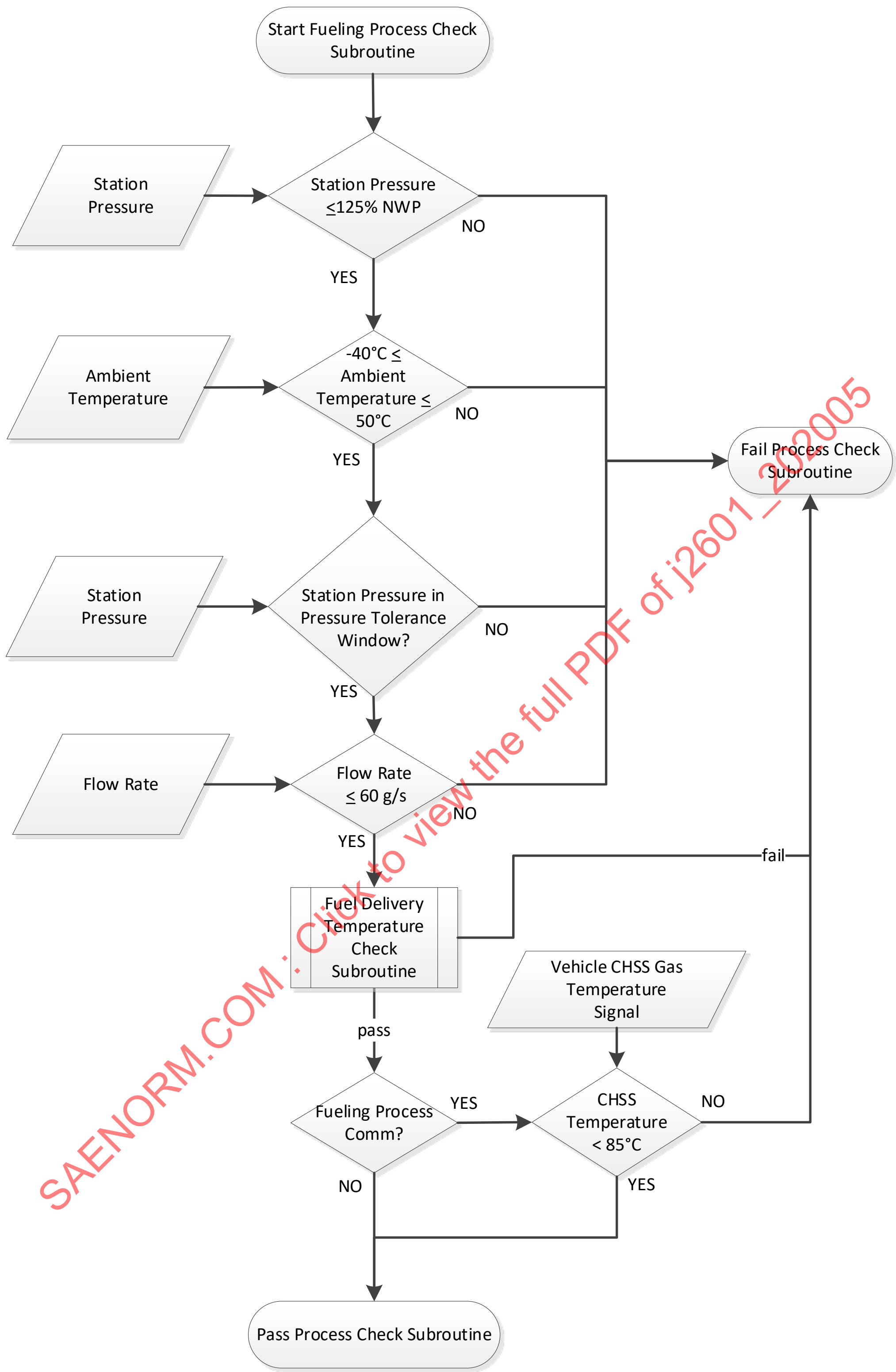

Figure B5 - Fueling process check subroutine

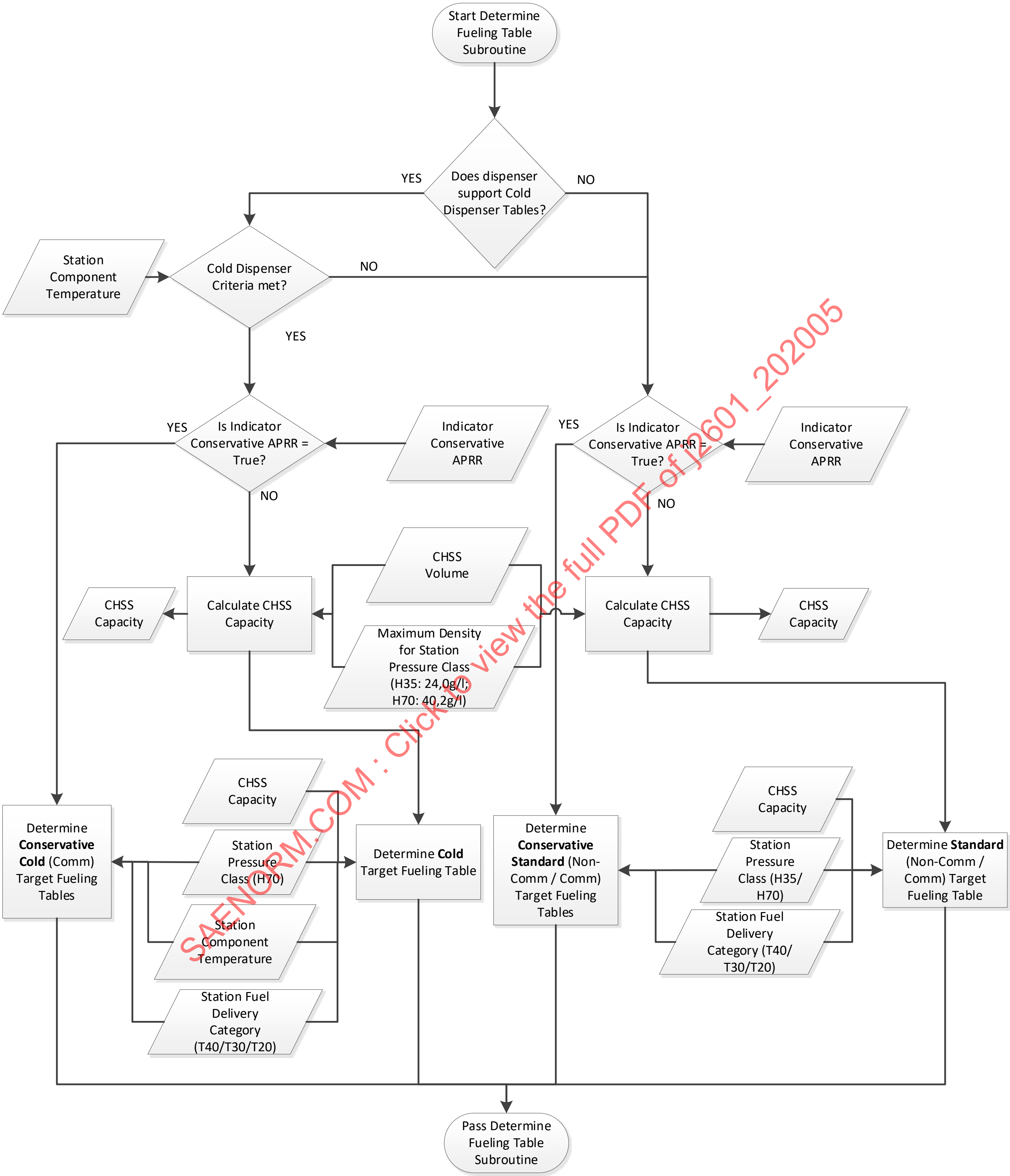

Figure B6 - Determine fueling table subroutine

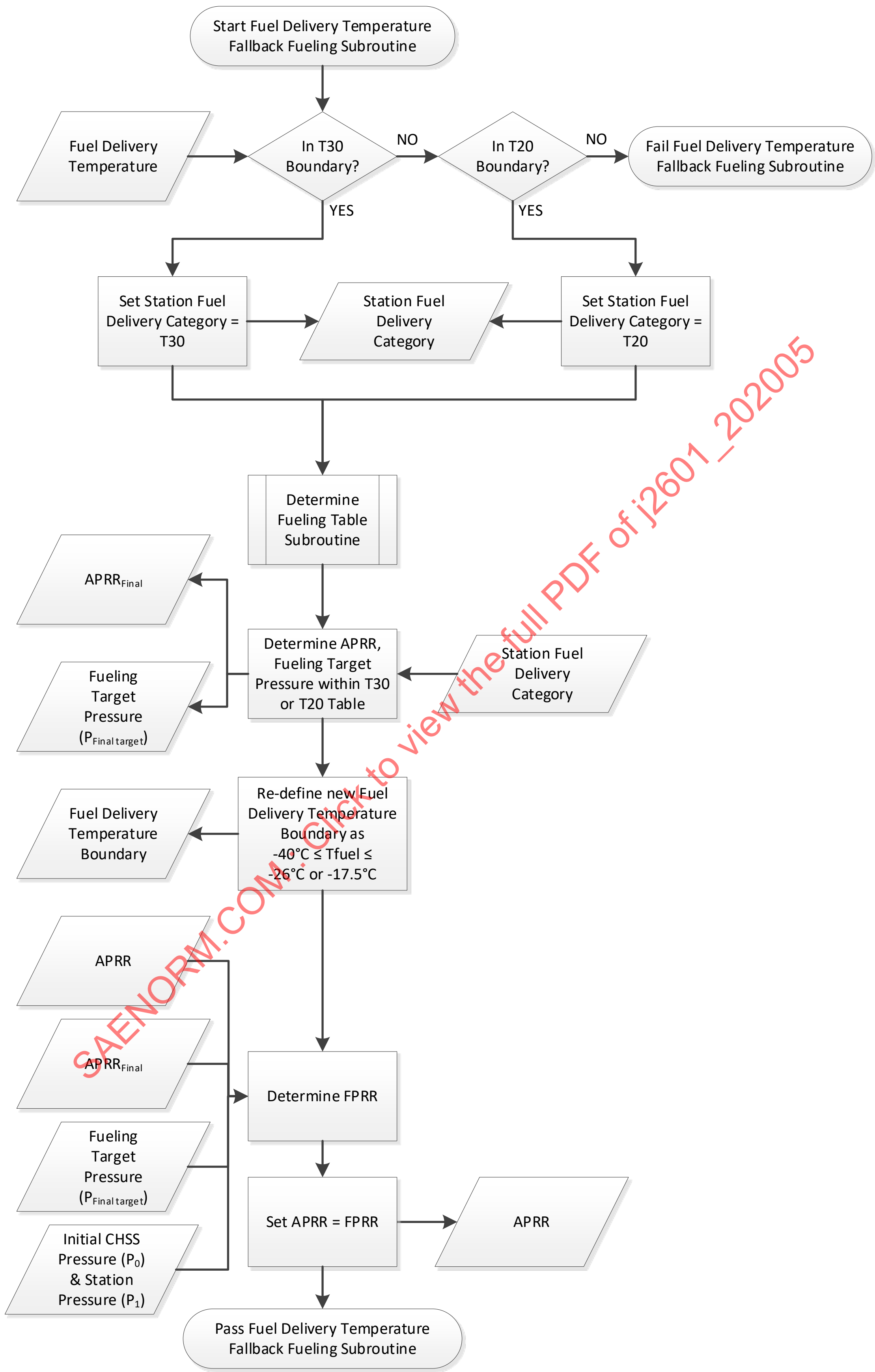

Figure B7 - Fuel delivery temperature fallback fueling subroutine

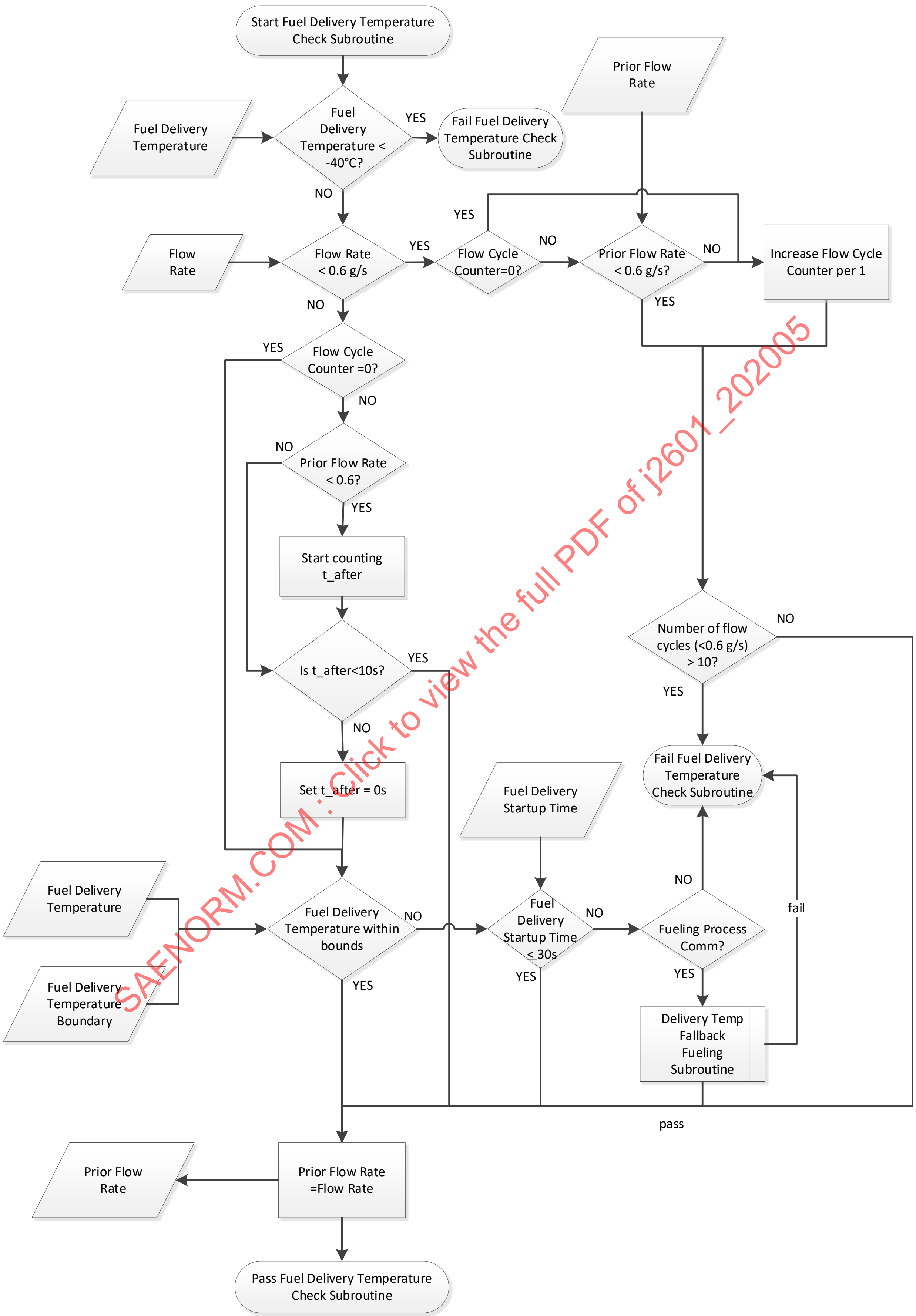

Figure B8 - Fuel delivery temperature check subroutine

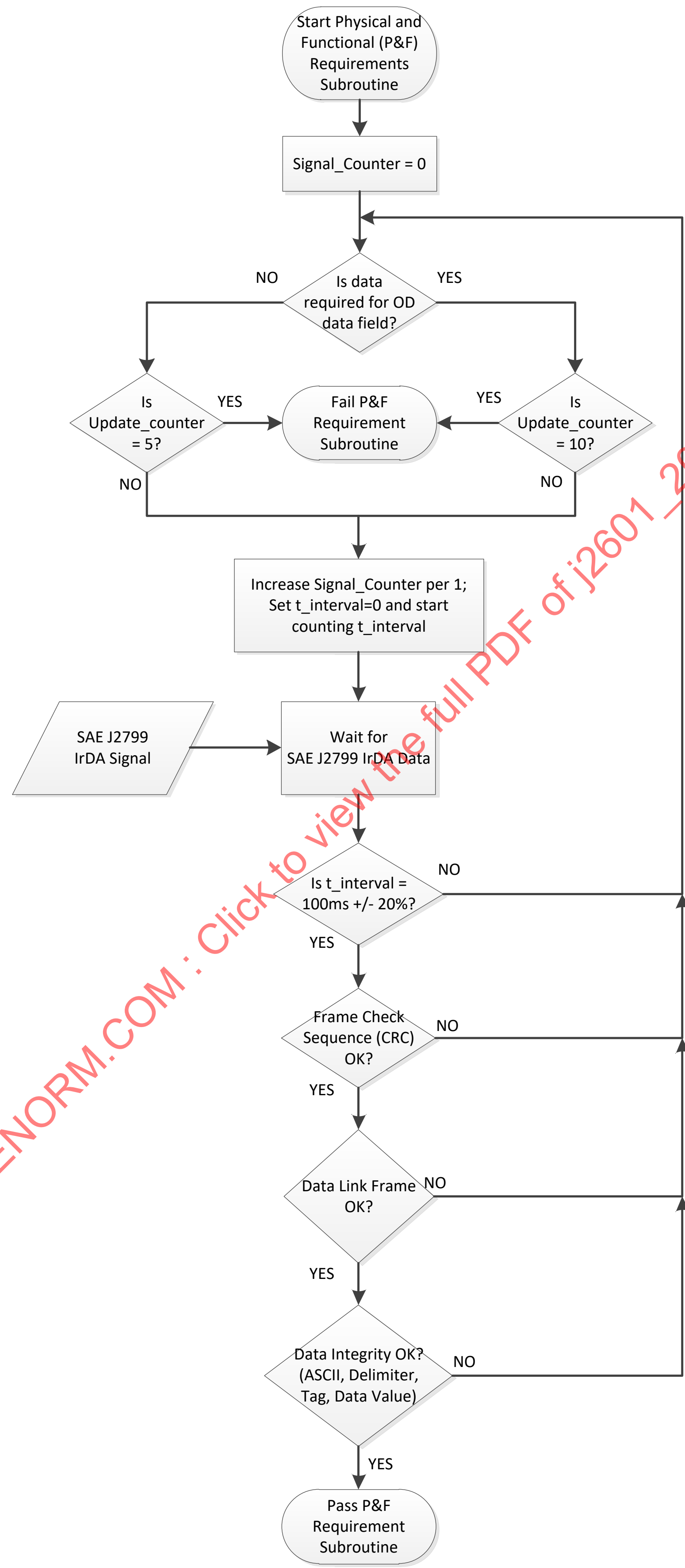

Figure B9 - Physical and functional (P&F) requirements subroutine

APPENDIX C - ACCEPTANCE CRITERIA FOR SAE J2601 PERFORMANCE TESTS

The adherence of a fueling dispenser to the fueling protocols specified in this standard should be verified by a hydrogen station test apparatus and procedure such as CSA HGV 4.3 (or equivalent). The performance tests are designed to demonstrate that the protocol meets the minimum criteria as per SAE J2601. Specifically, they are designed to demonstrate that fuel is delivered within the specified temperature range, at the specified ramp rate and up to the specified pressure target.

The dispenser should demonstrate capability to meet the general process limits in Section 6, and the specific fueling process requirements, as described in Section 8 for the table-based approach, or Section 9 for the MC Formula-based protocol.

The dispenser shall demonstrate that it can fuel hydrogen within these limits while meeting the stop criteria of the fueling protocol. It is essential that a dispenser can demonstrate under every fueling that it is within the limits described in SAE J2601 with the designation of “shall.”

The station provider should do due diligence to meet the other criteria which are designated as “should” or “optional.”

APPENDIX D - SAE J2601 STANDARD TABLES

The tables found in this appendix are the standard "look-up table" for communications and non-communications hydrogen fueling in SAE J2601. See Appendix G for table value interpolation guideline

Note that the SAE J2601 tables are in European/International format for commas and periods (this is opposite to the convention used for the U.S.).

Below is the key to the tables found in Appendix D:

Table D1	H35-T40: CHSS Capacity Category A non-communications
Table D2	H35-T30: CHSS Capacity Category A non-communications
Table D3	H35-T20: CHSS Capacity Category A non-communications
Table D4	H35-T40: CHSS Capacity Category A communications
Table D5	H35-T30: CHSS Capacity Category A communications
Table D6	H35-T20: CHSS Capacity Category A communications
Table D7	H35-T40: CHSS Capacity Category B non-communications
Table D8	H35-T30: CHSS Capacity Category B non-communications
Table D9	H35-T20: CHSS Capacity Category B non-communications
Table D10	H35-T40: CHSS Capacity Category B communications
Table D11	H35-T30: CHSS Capacity Category B communications
Table D12	H35-T20: CHSS Capacity Category B communications
Table D13	H35-T40: CHSS Capacity Category C non-communications
Table D14	H35-T30: CHSS Capacity Category C non-communications
Table D15	H35-T20: CHSS Capacity Category C non-communications
Table D16	H35-T40: CHSS Capacity Category C communications
Table D17	H35-T30: CHSS Capacity Category C communications
Table D18	H35-T20: CHSS Capacity Category C communications
Table D19	H70-T40: CHSS Capacity Category A non-communications
Table D20	H70-T30: CHSS Capacity Category A non-communications
Table D21	H70-T20: CHSS Capacity Category A non-communications
Table D22	H70-T40: CHSS Capacity Category A communications
Table D23	H70-T30: CHSS Capacity Category A communications
Table D24	H70-T20: CHSS Capacity Category A communications
Table D25	H70-T40: CHSS Capacity Category B non-communications
Table D26	H70-T30: CHSS Capacity Category B non-communications
Table D27	H70-T20: CHSS Capacity Category B non-communications
Table D28	H70-T40: CHSS Capacity Category B communications
Table D29	H70-T30: CHSS Capacity Category B communications
Table D30	H70-T20: CHSS Capacity Category B communications
Table D31	H70-T40: CHSS Capacity Category C non-communications
Table D32	H70-T30: CHSS Capacity Category C non-communications
Table D33	H70-T20: CHSS Capacity Category C non-communications
Table D34	H70-T40: CHSS Capacity Category C communications
Table D35	H70-T30: CHSS Capacity Category C communications
Table D36	H70-T20: CHSS Capacity Category C communications
Table D37	H70-T40D: CHSS Capacity Category D non-communications
Table D38	H70-T30D: CHSS Capacity Category D non-communications
Table D39	H70-T20D: CHSS Capacity Category D non-communications
Table D40	H70-T40D: CHSS Capacity Category D communications
Table D41	H70-T30D: CHSS Capacity Category D communications
Table D41	H70-T20D: CHSS Capacity Category D communications

Table D1 - H35-T40: CHSS Capacity Category A non-communications

H35-T40 CHSS Capacity Category A Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	3,2	40,1	40,0	39,9	39,5	39,1	38,7	37,7	36,7	no fueling
	45	5,8	40,2	40,1	40,0	39,7	39,4	39,0	37,8	36,7	no fueling
	40	8,6	40,4	40,3	40,2	39,9	39,6	39,2	37,9	36,7	no fueling
	35	9,7	40,4	40,4	40,2	40,0	39,6	39,2	37,9	36,7	no fueling
	30	12,5	40,2	40,1	39,9	39,6	39,2	38,7	37,2	35,9	no fueling
	25	15,7	40,0	39,9	39,7	39,3	38,8	38,2	36,5	no fueling	no fueling
	20	19,3	39,8	39,7	39,4	38,9	38,4	37,7	35,8	no fueling	no fueling
	10	27,0	39,3	39,2	38,8	38,2	37,5	36,6	34,2	no fueling	no fueling
	0	28,5	38,6	38,4	38,0	37,2	36,3	35,3	32,5	no fueling	no fueling
	-10	28,5	37,8	37,6	37,1	36,2	35,1	33,9	30,8	no fueling	no fueling
	-20	28,5	37,0	36,8	36,2	35,1	33,9	32,5	no fueling	no fueling	no fueling
	-30	28,5	36,3	35,9	35,2	34,0	32,6	31,1	no fueling	no fueling	no fueling
	-40	28,5	36,3	35,9	35,2	34,0	32,6	31,1	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D2 - H35-T30: CHSS Capacity Category A non-communications

H35-T30 CHSS Capacity Category A Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
		Initial Tank Pressure, P_0 [MPa]								
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	35	>35
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	1,7	40,5	40,3	40,1	39,6	39,2	38,7	37,5	36,7	no fueling
45	3,9	40,4	40,3	40,1	39,7	39,3	38,9	37,7	36,7	no fueling
40	6,0	40,5	40,4	40,2	39,9	39,5	39,1	37,9	36,7	no fueling
35	6,7	40,5	40,4	40,3	39,9	39,6	39,1	37,9	36,7	no fueling
30	8,7	40,2	40,1	39,9	39,6	39,2	38,7	37,2	35,9	no fueling
25	10,9	40,0	39,9	39,7	39,2	38,7	38,2	36,5	no fueling	no fueling
20	13,2	39,7	39,6	39,4	38,9	38,3	37,7	35,8	no fueling	no fueling
10	17,4	39,3	39,1	38,7	38,1	37,4	36,5	34,2	no fueling	no fueling
0	25,3	39,0	38,8	38,3	37,4	36,5	35,4	32,5	no fueling	no fueling
-10	28,1	38,3	38,1	37,5	36,5	35,3	34,1	30,8	no fueling	no fueling
-20	28,5	37,6	37,3	36,6	35,4	34,1	32,7	no fueling	no fueling	no fueling
-30	28,5	36,8	36,4	35,7	34,3	32,8	31,2	no fueling	no fueling	no fueling
-40	28,5	36,8	36,4	35,7	34,3	32,8	31,2	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D3 - H35-T20: CHSS Capacity Category A non-communications

H35-T20 CHSS Capacity Category A Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	<1	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	45	2,3	40,6	40,4	40,2	39,7	39,3	38,8	37,6	36,7	no fueling
	40	3,6	40,6	40,4	40,2	39,8	39,4	38,9	37,8	36,7	no fueling
	35	3,9	40,5	40,4	40,2	39,8	39,4	39,0	37,8	36,7	no fueling
	30	5,0	40,1	40,0	39,8	39,4	38,9	38,5	37,1	35,9	no fueling
	25	6,2	39,8	39,7	39,4	39,0	38,5	38,0	36,4	no fueling	no fueling
	20	7,6	39,5	39,4	39,1	38,6	38,1	37,4	35,7	no fueling	no fueling
	10	10,2	38,9	38,7	38,4	37,8	37,1	36,4	34,2	no fueling	no fueling
	0	15,3	38,6	38,4	38,0	37,2	36,3	35,3	32,5	no fueling	no fueling
	-10	16,9	38,0	37,7	37,2	36,2	35,2	34,0	30,8	no fueling	no fueling
	-20	18,6	37,3	37,0	36,4	35,2	34,0	32,6	no fueling	no fueling	no fueling
	-30	20,3	36,7	36,3	35,6	34,2	32,8	31,2	no fueling	no fueling	no fueling
	-40	22,1	36,9	36,5	35,7	34,3	32,8	31,2	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D4 - H35-T40: CHSS Capacity Category A communications

H35-T40 CHSS Capacity Category A Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	3,2	43,0	43,0	42,9	42,8	42,7	42,4	41,5	40,7	no fueling
	45	5,8	43,0	43,0	42,9	42,8	42,5	42,1	41,0	40,0	no fueling
	40	8,6	43,0	43,0	42,9	42,6	42,2	41,7	40,3	39,2	no fueling
	35	9,7	43,1	43,1	42,9	42,6	42,2	41,8	40,3	39,2	no fueling
	30	12,5	43,1	43,1	42,9	42,5	42,0	41,5	39,9	38,7	no fueling
	25	15,7	43,1	43,0	42,8	42,3	41,8	41,1	39,5	no fueling	no fueling
	20	19,3	43,1	43,0	42,7	42,2	41,5	40,8	39,0	no fueling	no fueling
	10	27,0	43,2	43,1	42,7	42,0	41,2	40,3	38,3	no fueling	no fueling
	0	28,5	42,7	42,5	42,0	41,1	40,2	39,1	36,7	no fueling	no fueling
	-10	28,5	42,7	42,5	42,0	41,1	40,1	39,1	36,7	no fueling	no fueling
	-20	28,5	42,7	42,4	41,9	41,0	40,0	39,0	no fueling	no fueling	no fueling
	-30	28,5	42,6	42,4	41,9	40,9	40,0	38,9	no fueling	no fueling	no fueling
	-40	28,5	42,6	42,4	41,8	40,9	39,9	38,9	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D5 - H35-T30: CHSS Capacity Category A communications

H35-T30 CHSS Capacity Category A Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,7	42,9	42,9	42,8	42,7	42,5	42,2	41,4	40,6	no fueling
	45	3,9	43,2	43,2	43,1	42,8	42,5	42,2	41,0	40,0	no fueling
	40	6,0	43,3	43,2	43,1	42,7	42,3	41,8	40,3	39,2	no fueling
	35	6,7	43,4	43,3	43,1	42,8	42,4	41,8	40,4	39,2	no fueling
	30	8,7	43,4	43,3	43,1	42,7	42,2	41,6	39,9	38,7	no fueling
	25	10,9	43,4	43,3	43,1	42,6	42,0	41,3	39,5	no fueling	no fueling
	20	13,2	43,4	43,3	43,0	42,4	41,7	40,9	39,0	no fueling	no fueling
	10	17,4	43,4	43,3	42,9	42,1	41,3	40,4	38,3	no fueling	no fueling
	0	25,3	43,3	43,1	42,5	41,5	40,4	39,3	36,7	no fueling	no fueling
	-10	28,1	43,4	43,2	42,6	41,5	40,4	39,3	36,7	no fueling	no fueling
	-20	28,5	43,4	43,1	42,5	41,5	40,4	39,2	no fueling	no fueling	no fueling
	-30	28,5	43,4	43,1	42,5	41,5	40,4	39,2	no fueling	no fueling	no fueling
	-40	28,5	43,4	43,1	42,5	41,5	40,3	39,2	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D6 - H35-T20: CHSS Capacity Category A communications

H35-T20 CHSS Capacity Category A Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	<1	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	45	2,3	43,2	43,2	43,0	42,8	42,5	42,1	40,9	39,9	no fueling
	40	3,6	43,3	43,2	43,0	42,7	42,3	41,8	40,3	39,2	no fueling
	35	3,9	43,4	43,3	43,1	42,8	42,3	41,8	40,3	39,2	no fueling
	30	5,0	43,4	43,3	43,1	42,7	42,2	41,6	39,9	38,7	no fueling
	25	6,2	43,5	43,3	43,1	42,6	42,0	41,3	39,5	no fueling	no fueling
	20	7,6	43,5	43,4	43,1	42,5	41,8	41,0	39,0	no fueling	no fueling
	10	10,2	43,6	43,4	43,0	42,3	41,4	40,5	38,3	no fueling	no fueling
	0	15,3	43,5	43,3	42,7	41,7	40,6	39,4	36,8	no fueling	no fueling
	-10	16,9	43,6	43,4	42,8	41,7	40,6	39,4	36,7	no fueling	no fueling
	-20	18,6	43,7	43,4	42,8	41,8	40,6	39,4	no fueling	no fueling	no fueling
	-30	20,3	30,3	43,5	42,9	41,8	40,7	39,4	no fueling	no fueling	no fueling
	-40	22,1	27,7	43,6	43,0	41,9	40,7	39,5	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D7 - H35-T40: CHSS Capacity Category B non-communications

H35-T40 CHSS Capacity Category B Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
		Initial Tank Pressure, P_0 [MPa]								
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	35	>35
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	5,1	38,7	38,6	38,4	38,2	38,0	37,9	37,2	36,4	no fueling
45	8,1	38,7	38,6	38,5	38,3	38,0	37,9	37,2	36,4	no fueling
40	11,5	38,8	38,7	38,5	38,3	38,1	38,0	37,1	36,4	no fueling
35	12,4	38,7	38,6	38,4	38,2	37,9	37,8	37,1	36,3	no fueling
30	15,3	38,5	38,4	38,2	37,8	37,5	37,4	36,4	35,7	no fueling
25	18,5	38,4	38,2	38,0	37,5	37,1	36,9	35,7	no fueling	no fueling
20	21,8	38,2	38,1	37,7	37,2	36,6	36,4	35,0	no fueling	no fueling
10	28,0	37,1	36,7	37,2	36,4	35,7	35,2	33,5	no fueling	no fueling
0	28,5	36,7	36,1	36,4	35,4	34,5	34,0	32,0	no fueling	no fueling
-10	28,5	36,3	36,8	36,0	34,7	33,3	32,7	30,6	no fueling	no fueling
-20	28,5	36,0	36,5	35,7	34,4	32,8	31,6	no fueling	no fueling	no fueling
-30	28,5	35,5	36,1	35,4	34,0	32,5	31,2	no fueling	no fueling	no fueling
-40	28,5	35,3	35,9	35,1	33,8	32,3	31,1	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D8 - H35-T30: CHSS Capacity Category B non-communications

H35-T30 CHSS Capacity Category B Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
		Initial Tank Pressure, P_0 [MPa]								
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	35	>35
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	2,5	38,8	38,7	38,4	38,1	37,8	37,7	37,1	36,4	no fueling
45	4,4	38,6	38,5	38,3	38,1	37,9	37,7	37,1	36,4	no fueling
40	6,4	38,6	38,5	38,3	38,1	37,9	37,8	37,1	36,4	no fueling
35	7,0	38,4	38,3	38,1	37,9	37,7	37,7	37,0	36,3	no fueling
30	8,8	38,2	38,1	37,9	37,6	37,3	37,2	36,4	35,7	no fueling
25	10,9	38,0	37,9	37,7	37,3	36,9	36,7	35,7	no fueling	no fueling
20	13,2	37,9	37,7	37,4	37,0	36,5	36,3	35,0	no fueling	no fueling
10	16,9	37,6	37,3	36,9	36,2	35,5	35,2	33,5	no fueling	no fueling
0	23,6	36,8	37,3	36,6	35,5	34,6	34,1	32,0	no fueling	no fueling
-10	25,4	36,6	37,1	36,3	34,8	33,4	32,8	30,6	no fueling	no fueling
-20	27,3	36,4	36,9	36,1	34,6	32,9	31,7	no fueling	no fueling	no fueling
-30	28,5	36,0	36,6	35,8	34,3	32,7	31,4	no fueling	no fueling	no fueling
-40	28,5	35,8	36,3	35,5	34,1	32,5	31,2	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D9 - H35-T20: CHSS Capacity Category B non-communications

H35-T20 CHSS Capacity Category B Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,0	39,4	39,2	38,9	38,4	38,0	37,6	37,0	36,4	no fueling
	45	2,2	38,7	38,6	38,3	38,0	37,7	37,5	37,0	36,4	no fueling
	40	3,3	38,5	38,3	38,1	37,9	37,6	37,5	37,0	36,4	no fueling
	35	3,5	38,2	38,1	37,9	37,7	37,5	37,4	37,0	36,4	no fueling
	30	4,5	37,9	37,7	37,5	37,3	37,0	36,9	36,3	35,7	no fueling
	25	5,5	37,6	37,4	37,2	36,9	36,6	36,5	35,7	no fueling	no fueling
	20	6,7	37,3	37,2	36,9	36,5	36,2	36,0	35,0	no fueling	no fueling
	10	8,8	36,9	36,6	36,3	35,7	35,2	34,9	33,5	no fueling	no fueling
	0	13,2	37,1	36,7	36,0	35,2	34,3	33,9	32,0	no fueling	no fueling
	-10	14,2	36,9	36,5	35,7	34,4	33,5	32,7	30,6	no fueling	no fueling
	-20	15,2	36,7	36,3	35,5	34,2	33,0	31,5	no fueling	no fueling	no fueling
	-30	16,1	36,3	36,0	35,3	33,9	32,8	31,2	no fueling	no fueling	no fueling
	-40	17,1	36,3	35,9	35,2	33,8	32,6	31,1	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D10 - H35-T40: CHSS Capacity Category B communications

H35-T40 CHSS Capacity Category B Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	5,1	42,6	42,6	42,5	42,4	42,2	42,0	41,2	40,5	no fueling
	45	8,1	42,6	42,6	42,5	42,3	42,0	41,6	40,6	39,9	no fueling
	40	11,5	42,7	42,6	42,4	42,1	41,7	41,2	40,0	39,2	no fueling
	35	12,4	42,7	42,6	42,4	42,1	41,6	41,2	40,0	39,1	no fueling
	30	15,3	42,7	42,6	42,4	41,9	41,4	40,9	39,6	38,6	no fueling
	25	18,5	42,8	42,6	42,4	41,8	41,2	40,6	39,2	no fueling	no fueling
	20	21,8	42,8	42,7	42,3	41,7	41,0	40,3	38,7	no fueling	no fueling
	10	28,0	42,9	42,7	42,2	41,5	40,6	39,8	38,0	no fueling	no fueling
	0	28,5	42,5	42,2	41,7	40,7	39,7	38,7	36,5	no fueling	no fueling
	-10	28,5	42,3	42,0	41,5	40,6	39,6	38,5	36,4	no fueling	no fueling
	-20	28,5	42,0	41,8	41,3	40,4	39,4	38,4	no fueling	no fueling	no fueling
	-30	28,5	41,8	41,6	41,0	40,1	39,1	38,2	no fueling	no fueling	no fueling
	-40	28,5	41,6	41,4	40,8	39,9	38,9	38,0	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D11 - H35-T30: CHSS Capacity Category B communications

H35-T30 CHSS Capacity Category B Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
		Initial Tank Pressure, P_0 [MPa]								
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	35	>35
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	2,5	42,8	42,8	42,7	42,5	42,3	42,0	41,2	40,5	no fueling
45	4,4	42,9	42,8	42,7	42,4	42,1	41,7	40,6	39,8	no fueling
40	6,4	42,9	42,8	42,6	42,3	41,8	41,3	40,0	39,1	no fueling
35	7,0	42,9	42,8	42,6	42,3	41,8	41,3	40,0	39,1	no fueling
30	8,8	43,0	42,9	42,6	42,1	41,6	41,0	39,6	38,6	no fueling
25	10,9	43,0	42,9	42,6	42,0	41,4	40,7	39,1	no fueling	no fueling
20	13,2	43,0	42,9	42,5	41,9	41,2	40,4	38,7	no fueling	no fueling
10	16,9	43,1	42,9	42,4	41,6	40,8	39,9	38,0	no fueling	no fueling
0	23,6	43,0	42,7	42,2	41,1	40,0	38,9	36,5	no fueling	no fueling
-10	25,4	42,8	42,6	42,0	41,0	39,9	38,8	36,4	no fueling	no fueling
-20	27,3	42,7	42,4	41,8	40,8	39,7	38,6	no fueling	no fueling	no fueling
-30	28,5	42,6	42,3	41,7	40,6	39,5	38,4	no fueling	no fueling	no fueling
-40	28,5	42,4	42,1	41,5	40,4	39,3	38,2	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D12 - H35-T20: CHSS Capacity Category B communications

H35-T20 CHSS Capacity Category B Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,0	42,8	42,7	42,6	42,4	42,1	41,9	41,1	40,5	no fueling
	45	2,2	43,0	43,0	42,8	42,5	42,1	41,7	40,7	39,8	no fueling
	40	3,3	43,1	43,0	42,8	42,4	41,9	41,4	40,1	39,1	no fueling
	35	3,5	43,1	43,0	42,8	42,4	41,9	41,4	40,0	39,1	no fueling
	30	4,5	43,1	43,0	42,7	42,3	41,7	41,1	39,6	38,6	no fueling
	25	5,5	43,1	43,0	42,7	42,1	41,5	40,8	39,2	no fueling	no fueling
	20	6,7	43,2	43,0	42,6	42,0	41,3	40,5	38,7	no fueling	no fueling
	10	8,8	43,1	42,9	42,6	41,8	40,9	40,0	38,0	no fueling	no fueling
	0	13,2	43,0	42,8	42,3	41,3	40,2	39,0	36,5	no fueling	no fueling
	-10	14,2	42,9	42,7	42,1	41,1	40,1	38,9	36,4	no fueling	no fueling
	-20	15,2	42,8	42,6	42,0	40,9	39,9	38,7	no fueling	no fueling	no fueling
	-30	16,1	42,7	42,4	41,8	40,8	39,7	38,6	no fueling	no fueling	no fueling
	-40	17,1	42,6	42,3	41,7	40,6	39,5	38,4	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D13 - H35-T40: CHSS Capacity Category C non-communications

H35-T40 CHSS Capacity Category C Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	7,6	38,9	38,8	38,7	38,4	38,2	38,1	37,2	36,4	no fueling
	45	11,0	39,0	38,9	38,7	38,5	38,2	38,1	37,2	36,4	no fueling
	40	14,5	39,1	39,0	38,8	38,5	38,2	38,1	37,1	36,4	no fueling
	35	15,3	38,9	38,8	38,6	38,3	38,0	37,9	37,1	36,3	no fueling
	30	17,9	38,7	38,6	38,4	38,0	37,6	37,4	36,4	35,7	no fueling
	25	19,9	38,5	38,3	38,0	37,6	37,1	36,9	35,7	no fueling	no fueling
	20	19,9	38,1	37,9	37,6	37,1	36,6	36,3	35,0	no fueling	no fueling
	10	19,9	37,4	37,2	36,7	36,1	35,4	35,1	33,5	no fueling	no fueling
	0	19,9	36,9	36,6	35,9	35,1	34,3	33,9	32,0	no fueling	no fueling
	-10	19,9	36,6	36,3	35,5	34,3	33,1	32,6	30,6	no fueling	no fueling
	-20	19,9	36,3	35,9	35,3	34,0	32,5	31,5	no fueling	no fueling	no fueling
	-30	19,9	35,9	35,5	34,9	33,6	32,6	31,1	no fueling	no fueling	no fueling
	-40	19,9	35,6	35,3	34,7	33,4	32,4	31,0	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D14 - H35-T30: CHSS Capacity Category C non-communications

H35-T30 CHSS Capacity Category C Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
		Initial Tank Pressure, P_0 [MPa]								
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	35	>35
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	3,1	38,8	38,7	38,5	38,2	37,9	37,7	37,1	36,4	no fueling
45	4,9	38,6	38,5	38,4	38,1	37,9	37,8	37,1	36,4	no fueling
40	7,1	38,7	38,5	38,4	38,2	37,9	37,8	37,1	36,4	no fueling
35	7,5	38,5	38,4	38,2	38,0	37,8	37,7	37,0	36,3	no fueling
30	9,3	38,3	38,1	37,9	37,7	37,4	37,2	36,4	35,7	no fueling
25	11,2	38,1	37,9	37,7	37,3	36,9	36,8	35,7	no fueling	no fueling
20	13,3	37,9	37,7	37,4	37,0	36,5	36,3	35,0	no fueling	no fueling
10	17,0	37,6	37,3	36,9	36,2	35,5	35,2	33,5	no fueling	no fueling
0	19,9	37,4	37,0	36,3	35,4	34,5	34,0	32,0	no fueling	no fueling
-10	19,9	37,1	36,7	35,9	34,6	33,2	32,7	30,6	no fueling	no fueling
-20	19,9	36,8	36,4	35,6	34,3	32,7	31,6	no fueling	no fueling	no fueling
-30	19,9	36,3	36,0	35,3	33,9	32,3	31,2	no fueling	no fueling	no fueling
-40	19,9	36,1	35,8	35,0	33,7	32,6	31,1	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D15 - H35-T20: CHSS Capacity Category C non-communications

H35-T20 CHSS Capacity Category C Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,2	39,3	39,1	38,8	38,3	37,9	37,6	37,0	36,4	no fueling
	45	2,2	38,7	38,6	38,3	38,0	37,7	37,5	37,0	36,4	no fueling
	40	3,3	38,5	38,3	38,1	37,9	37,6	37,5	37,0	36,4	no fueling
	35	3,5	38,2	38,1	37,9	37,7	37,5	37,4	37,0	36,4	no fueling
	30	4,5	37,9	37,7	37,5	37,3	37,0	36,9	36,3	35,7	no fueling
	25	5,5	37,6	37,4	37,2	36,9	36,6	36,5	35,7	no fueling	no fueling
	20	6,6	37,3	37,1	36,9	36,5	36,1	36,0	35,0	no fueling	no fueling
	10	8,7	36,8	36,6	36,3	35,7	35,2	34,9	33,5	no fueling	no fueling
	0	12,9	37,0	36,6	36,0	35,1	34,6	33,9	32,0	no fueling	no fueling
	-10	13,6	36,8	36,4	35,7	34,4	33,5	32,6	30,6	no fueling	no fueling
	-20	14,4	36,6	36,2	35,4	34,1	33,0	31,5	no fueling	no fueling	no fueling
	-30	15,0	36,2	35,9	35,1	33,8	32,7	31,2	no fueling	no fueling	no fueling
	-40	15,7	36,1	35,7	35,0	33,7	32,6	31,1	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D16 - H35-T40: CHSS Capacity Category C communications

H35-T40 CHSS Capacity Category C Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	7,6	42,9	42,8	42,8	42,6	42,4	42,1	41,2	40,6	no fueling
	45	11,0	42,9	42,8	42,7	42,4	42,1	41,7	40,7	39,9	no fueling
	40	14,5	42,9	42,8	42,6	42,2	41,8	41,3	40,1	39,2	no fueling
	35	15,3	42,9	42,8	42,6	42,2	41,8	41,2	40,0	39,2	no fueling
	30	17,9	42,9	42,8	42,5	42,1	41,5	40,9	39,6	38,6	no fueling
	25	19,9	42,9	42,7	42,4	41,9	41,3	40,6	39,2	no fueling	no fueling
	20	19,9	42,7	42,6	42,2	41,6	40,9	40,2	38,7	no fueling	no fueling
	10	19,9	42,4	42,3	41,9	41,2	40,4	39,6	37,9	no fueling	no fueling
	0	19,9	42,0	41,8	41,3	40,4	39,5	38,5	36,5	no fueling	no fueling
	-10	19,9	41,9	41,6	41,1	40,3	39,3	38,4	36,3	no fueling	no fueling
	-20	19,9	41,7	41,5	41,0	40,1	39,2	38,3	no fueling	no fueling	no fueling
	-30	19,9	41,6	41,4	40,9	40,0	39,1	38,1	no fueling	no fueling	no fueling
	-40	19,9	41,5	41,2	40,7	39,8	38,9	38,0	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D17 - H35-T30: CHSS Capacity Category C communications

H35-T30 CHSS Capacity Category C Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	3,1	42,9	42,9	42,8	42,6	42,4	42,1	41,2	40,5	no fueling
	45	4,9	43,0	42,9	42,8	42,5	42,2	41,7	40,7	39,9	no fueling
	40	7,1	43,0	42,9	42,7	42,3	41,9	41,4	40,1	39,1	no fueling
	35	7,5	43,0	42,9	42,7	42,3	41,8	41,3	40,0	39,1	no fueling
	30	9,3	43,0	42,9	42,7	42,2	41,6	41,0	39,6	38,6	no fueling
	25	11,2	43,0	42,9	42,6	42,0	41,4	40,7	39,1	no fueling	no fueling
	20	13,3	43,0	42,9	42,5	41,9	41,2	40,4	38,7	no fueling	no fueling
	10	17,0	43,1	42,9	42,4	41,6	40,8	39,9	38,0	no fueling	no fueling
	0	19,9	43,1	42,8	42,2	41,1	40,0	38,9	36,5	no fueling	no fueling
	-10	19,9	42,9	42,6	42,0	41,0	39,9	38,8	36,4	no fueling	no fueling
	-20	19,9	42,8	42,5	41,9	40,8	39,7	38,6	no fueling	no fueling	no fueling
	-30	19,9	42,7	42,4	41,7	40,7	39,6	38,5	no fueling	no fueling	no fueling
	-40	19,9	42,5	42,2	41,6	40,5	39,5	38,3	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D18 - H35-T20: CHSS Capacity Category C communications

H35-T20 CHSS Capacity Category C Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]								
			Initial Tank Pressure, P_0 [MPa]								
			0,5	2	5	10	15	20	30	35	>35
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,2	43,0	42,9	42,8	42,5	42,3	42,0	41,2	40,5	no fueling
	45	2,2	43,0	43,0	42,8	42,5	42,1	41,7	40,7	39,8	no fueling
	40	3,3	43,1	43,0	42,8	42,4	41,9	41,4	40,1	39,1	no fueling
	35	3,5	43,1	43,0	42,8	42,4	41,9	41,4	40,0	39,1	no fueling
	30	4,5	43,1	43,0	42,7	42,3	41,7	41,1	39,6	38,6	no fueling
	25	5,5	43,1	43,0	42,7	42,1	41,5	40,8	39,2	no fueling	no fueling
	20	6,6	43,2	43,0	42,6	42,0	41,3	40,5	38,7	no fueling	no fueling
	10	8,7	43,2	43,0	42,6	41,8	40,9	40,0	38,0	no fueling	no fueling
	0	12,9	43,2	42,9	42,3	41,3	40,2	39,0	36,5	no fueling	no fueling
	-10	13,6	43,1	42,9	42,3	41,2	40,1	38,9	36,4	no fueling	no fueling
	-20	14,4	43,1	42,8	42,2	41,1	40,0	38,8	no fueling	no fueling	no fueling
	-30	15,0	43,0	42,7	42,1	41,0	39,9	38,7	no fueling	no fueling	no fueling
	-40	15,7	43,0	42,7	42,0	40,9	39,8	38,6	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D19 - H70-T40: CHSS Capacity Category A non-communications

H70-T40 CHSS Capacity Category A Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa] — Initial Tank Pressure, P_0 [MPa]: 0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	3,2	no fueling	77,2	76,8	76,4	76,1	75,7	75,2	74,8	74,3	73,7	72,7	no fueling
	45	5,8	75,3	76,5	76,2	75,8	75,8	75,5	75,1	74,9	74,3	73,7	72,7	no fueling
	40	8,6	72,2	74,9	76,0	75,7	75,7	75,5	75,1	74,9	74,3	73,6	72,6	no fueling
	35	9,7	71,3	74,2	75,8	75,4	75,5	75,4	74,9	74,7	74,1	73,5	72,6	no fueling
	30	12,5	69,1	73,2	75,1	74,6	74,8	74,6	73,9	73,7	72,9	72,2	71,3	no fueling
	25	15,7	66,4	71,2	74,5	73,9	74,2	73,8	72,9	72,6	71,6	70,9	no fueling	no fueling
	20	19,3	66,2	70,9	74,0	73,1	73,4	73,0	71,8	71,5	70,3	69,5	no fueling	no fueling
	10	27,0	66,1	70,9	73,1	71,7	72,0	71,2	70,4	69,2	68,0	66,7	no fueling	no fueling
	0	28,5	73,8	73,3	72,3	70,4	70,5	69,4	68,1	66,6	65,3	63,9	no fueling	no fueling
	-10	28,5	73,1	72,6	71,6	71,2	69,7	68,2	66,2	63,9	62,5	61,2	no fueling	no fueling
	-20	28,5	72,4	71,9	70,9	70,6	69,1	67,6	65,4	62,2	59,7	no fueling	no fueling	no fueling
	-30	28,5	71,4	71,0	70,1	69,8	68,4	67,0	64,8	61,7	58,6	no fueling	no fueling	no fueling
	-40	28,5	70,9	70,5	69,6	69,4	68,0	66,5	64,4	61,4	58,4	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D20 - H70-T30: CHSS Capacity Category A non-communications

H70-T30 CHSS Capacity Category A Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]											
		0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	1,7	74,5	76,6	77,9	77,3	76,8	76,3	75,5	74,8	74,2	73,6	72,8	no fueling
45	3,9	74,1	76,4	76,6	76,1	75,9	75,6	75,1	74,7	74,3	73,6	72,7	no fueling
40	6,0	71,0	74,3	76,2	75,8	75,7	75,5	75,0	74,8	74,2	73,6	72,7	no fueling
35	6,7	70,1	73,6	75,9	75,5	75,5	75,3	74,8	74,6	74,1	73,5	72,6	no fueling
30	8,7	67,7	72,1	75,2	74,7	74,7	74,5	73,9	73,6	72,9	72,2	71,3	no fueling
25	10,9	65,6	71,1	74,5	73,9	74,0	73,7	72,9	72,5	71,6	70,9	no fueling	no fueling
20	13,2	66,1	71,3	73,9	73,1	73,3	72,8	71,8	71,4	70,6	69,5	no fueling	no fueling
10	17,4	64,4	69,8	72,8	71,6	71,7	71,0	70,2	69,1	68,0	66,7	no fueling	no fueling
0	25,3	62,4	68,5	72,7	70,9	70,8	69,6	68,3	66,7	65,4	63,9	no fueling	no fueling
-10	28,1	62,7	68,7	72,3	70,3	70,2	68,6	66,5	64,1	62,6	61,2	no fueling	no fueling
-20	28,5	66,8	72,7	71,6	71,2	69,7	68,1	65,7	62,3	59,7	no fueling	no fueling	no fueling
-30	28,5	71,3	71,8	70,8	70,5	69,0	67,4	65,1	61,8	58,7	no fueling	no fueling	no fueling
-40	28,5	71,7	71,3	70,3	70,0	68,5	67,0	64,7	61,5	58,5	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D21 - H70-T20: CHSS Capacity Category A non-communications

H70-T20 CHSS Capacity Category A Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]											
			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	<1	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	45	2,3	74,0	76,5	77,3	76,7	76,2	75,8	75,1	74,6	74,1	73,6	72,7	no fueling
	40	3,6	71,0	74,2	76,5	76,0	75,7	75,4	74,9	74,6	74,1	73,6	72,7	no fueling
	35	3,9	71,3	74,5	76,0	75,6	75,4	75,1	74,6	74,4	74,0	73,5	72,7	no fueling
	30	5,0	69,8	73,6	75,1	74,6	74,4	74,1	73,6	73,3	72,8	72,2	71,3	no fueling
	25	6,2	67,7	72,2	74,2	73,7	73,6	73,2	72,6	72,3	71,6	70,9	no fueling	no fueling
	20	7,6	66,3	71,4	73,5	72,8	72,8	72,4	71,5	71,2	70,4	69,5	no fueling	no fueling
	10	10,2	63,1	69,4	72,3	71,8	71,1	70,6	69,8	68,9	67,9	66,8	no fueling	no fueling
	0	15,3	59,2	66,4	72,2	71,4	70,2	69,2	67,9	66,5	65,3	63,9	no fueling	no fueling
	-10	16,9	59,8	66,7	71,7	71,0	69,6	68,1	66,0	63,9	62,6	61,2	no fueling	no fueling
	-20	18,6	60,3	67,1	71,3	70,6	69,2	67,7	65,3	62,2	59,7	no fueling	no fueling	no fueling
	-30	20,3	60,9	67,5	70,6	70,1	68,7	67,2	64,9	61,7	58,6	no fueling	no fueling	no fueling
	-40	22,1	61,5	67,9	70,4	69,9	68,4	66,9	64,6	61,5	58,5	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D22 - H70-T40: CHSS Capacity Category A communications

H70-T40 CHSS Capacity Category A Comm		APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	3,2	no fueling	no fueling	no fueling	no fueling	77,8	81,0	86,9	86,7	86,5	85,9	85,1	84,2	82,9	81,2	no fueling
	45	5,8	75,3	87,5	3,8	see Top-Off	see Top-Off	80,9	86,9	86,6	86,3	85,5	84,5	83,3	81,8	79,8	no fueling
	40	8,6	72,2	87,5	5,7	see Top-Off	see Top-Off	81,3	86,8	86,4	86,0	85,0	83,8	82,3	80,6	78,3	no fueling
	35	9,7	71,3	87,5	6,3	see Top-Off	see Top-Off	80,8	86,8	86,4	86,0	84,9	83,7	82,2	80,5	78,3	no fueling
	30	12,5	69,1	87,5	7,8	see Top-Off	see Top-Off	81,5	86,8	86,3	85,7	84,5	83,1	81,5	79,6	77,2	no fueling
	25	15,7	66,4	87,5	9,4	see Top-Off	see Top-Off	81,0	86,8	86,1	85,5	84,0	82,4	80,7	78,7	76,2	no fueling
	20	19,3	66,2	87,5	10,6	see Top-Off	see Top-Off	81,3	86,7	86,0	85,2	83,6	81,8	79,8	77,7	75,1	no fueling
	10	27,0	66,1	87,4	11,7	see Top-Off	see Top-Off	81,2	86,7	85,8	84,8	82,8	80,7	78,5	76,2	73,4	no fueling
	0	28,5	no Top-Off	no Top-Off	no Top-Off	81,5	87,2	86,5	85,5	84,3	83,2	80,7	78,3	75,8	73,2	no fueling	no fueling
	-10	28,5	no Top-Off	no Top-Off	no Top-Off	86,9	86,6	86,0	84,9	83,8	82,6	80,3	77,9	75,5	72,9	no fueling	no fueling
	-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,4	84,3	83,2	82,1	79,8	77,5	75,2	72,7	no fueling	no fueling
	-30	28,5	no Top-Off	no Top-Off	no Top-Off	85,9	85,6	84,9	83,8	82,7	81,5	79,3	77,0	74,8	72,4	no fueling	no fueling
	-40	28,5	no Top-Off	no Top-Off	no Top-Off	85,4	85,1	84,4	83,3	82,1	81,0	78,8	76,6	74,4	72,2	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D23 - H70-T30: CHSS Capacity Category A communications

H70-T30 CHSS Capacity Category A Comm	APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	1,7	74,5	87,5	0,8	see Top-Off	see Top-Off	81,0	87,0	86,7	86,4	85,7	84,9	83,9	82,7	81,1	no fueling
45	3,9	74,1	87,5	2,4	see Top-Off	see Top-Off	81,4	87,2	86,9	86,5	85,6	84,6	83,3	81,8	79,8	no fueling
40	6,0	71,0	87,5	3,9	see Top-Off	see Top-Off	81,2	87,2	86,7	86,3	85,2	83,9	82,4	80,6	78,3	no fueling
35	6,7	70,1	87,5	4,4	see Top-Off	see Top-Off	80,7	87,2	86,8	86,3	85,1	83,8	82,3	80,5	78,2	no fueling
30	8,7	67,7	87,5	5,6	see Top-Off	see Top-Off	80,9	87,2	86,6	86,1	84,7	83,3	81,6	79,6	77,2	no fueling
25	10,9	65,6	87,5	6,9	see Top-Off	see Top-Off	81,0	87,1	86,5	85,8	84,3	82,6	80,8	78,7	76,2	no fueling
20	13,2	66,1	87,5	8,2	see Top-Off	see Top-Off	81,3	87,0	86,3	85,5	83,8	81,9	79,9	77,7	75,1	no fueling
10	17,4	64,4	87,4	7,3	see Top-Off	see Top-Off	81,2	86,6	85,8	84,9	82,9	80,8	78,6	76,2	73,4	no fueling
0	25,3	62,4	87,4	8,7	see Top-Off	see Top-Off	81,1	86,2	85,0	83,7	81,3	78,7	76,0	73,2	no fueling	no fueling
-10	28,1	62,7	87,4	9,0	see Top-Off	see Top-Off	81,2	85,9	84,7	83,4	80,9	78,3	75,7	73,0	no fueling	no fueling
-20	28,5	66,8	87,3	8,9	see Top-Off	see Top-Off	85,7	85,4	84,2	82,9	80,4	77,9	75,3	72,8	no fueling	no fueling
-30	28,5	71,3	87,3	8,7	see Top-Off	see Top-Off	86,2	84,9	83,6	82,4	79,9	77,4	75,0	72,5	no fueling	no fueling
-40	28,5	no Top-Off	no Top-Off	no Top-Off	75,5	81,9	85,7	84,4	83,2	81,9	79,4	77,0	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D24 - H70-T20: CHSS Capacity Category A communications

H70-T20 CHSS Capacity Category A Comm		APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	<1	no fueling	no fueling	no fueling	see Top-Off	see Top-Off	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	45	2,3	74,0	87,5	1,2	see Top-Off	see Top-Off	81,6	87,2	86,8	86,4	85,4	84,4	83,2	81,7	79,7	no fueling
	40	3,6	71,0	87,5	2,0	see Top-Off	see Top-Off	80,8	87,0	86,6	86,1	85,0	83,8	82,3	80,5	78,3	no fueling
	35	3,9	71,3	87,5	2,2	see Top-Off	see Top-Off	81,1	86,9	86,4	86,0	84,9	83,7	82,2	80,5	78,2	no fueling
	30	5,0	69,8	87,5	2,8	see Top-Off	see Top-Off	81,3	86,7	86,2	85,7	84,5	83,2	81,5	79,6	77,2	no fueling
	25	6,2	67,7	87,5	3,4	see Top-Off	see Top-Off	81,0	86,6	86,0	85,4	84,1	82,6	80,8	78,7	76,1	no fueling
	20	7,6	66,3	87,5	4,0	see Top-Off	see Top-Off	81,3	86,4	85,8	85,1	83,6	81,9	80,0	77,7	75,0	no fueling
	10	10,2	63,1	87,5	5,1	see Top-Off	see Top-Off	81,1	86,1	85,4	84,5	82,7	80,8	78,6	76,2	73,4	no fueling
	0	15,3	59,2	87,5	7,0	see Top-Off	see Top-Off	81,1	85,7	84,6	83,4	81,1	78,6	76,0	73,2	no fueling	no fueling
	-10	16,9	59,8	87,4	7,1	see Top-Off	see Top-Off	81,1	85,5	84,3	83,2	80,8	78,3	75,7	73,0	no fueling	no fueling
	-20	18,6	60,3	87,4	7,2	see Top-Off	see Top-Off	81,1	85,3	84,1	82,9	80,4	77,9	75,4	72,8	no fueling	no fueling
	-30	20,3	60,9	87,3	7,2	see Top-Off	see Top-Off	81,1	85,1	83,9	82,6	80,1	77,6	75,1	72,6	no fueling	no fueling
	-40	22,1	61,5	87,3	7,4	see Top-Off	see Top-Off	81,1	84,9	83,6	82,3	79,8	77,3	74,8	72,4	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D25 - H70-T40: Capacity Category B non-communications

H70-T40 Capacity Category B Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]											
			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	5,1	77,8	77,6	77,3	76,9	76,6	76,2	75,7	75,3	74,7	73,9	72,8	no fueling
	45	8,1	76,3	77,2	76,9	76,5	76,4	76,2	75,6	75,3	74,7	73,9	72,7	no fueling
	40	11,5	73,2	75,6	76,8	76,3	76,4	76,2	75,6	75,3	74,6	73,9	72,7	no fueling
	35	12,4	72,9	75,3	76,4	76,0	76,1	75,9	75,3	75,1	74,5	73,8	72,7	no fueling
	30	15,3	70,6	73,9	75,8	75,2	75,4	75,1	74,3	74,1	73,3	72,4	71,3	no fueling
	25	18,5	69,0	72,8	75,1	74,5	74,7	74,3	73,3	73,0	72,0	71,1	no fueling	no fueling
	20	21,8	67,9	72,1	74,5	73,7	74,0	73,4	72,2	71,9	70,7	69,7	no fueling	no fueling
	10	28,0	66,3	71,1	74,1	73,2	72,4	71,6	70,9	69,6	68,4	66,9	no fueling	no fueling
	0	28,5	74,0	73,4	72,4	70,6	70,7	69,6	68,6	67,1	65,7	64,0	no fueling	no fueling
	-10	28,5	73,4	72,9	71,9	70,0	70,0	68,4	66,5	64,4	62,9	61,2	no fueling	no fueling
	-20	28,5	72,9	72,3	71,3	71,0	69,5	68,0	65,7	62,4	60,0	no fueling	no fueling	no fueling
	-30	28,5	72,1	71,6	70,6	70,4	69,0	67,4	65,2	61,8	58,7	no fueling	no fueling	no fueling
	-40	28,5	71,6	71,1	70,2	70,0	68,5	66,9	64,8	61,5	58,5	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D26 - H70-T30: Capacity Category B non-communications

H70-T30 Capacity Category B Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]											
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	2,5	76,7	78,2	78,0	77,4	76,9	76,5	75,6	75,1	74,5	73,8	72,8	no fueling
45	4,4	74,9	76,9	77,1	76,6	76,3	76,0	75,4	75,0	74,5	73,8	72,7	no fueling
40	6,4	72,8	75,5	76,7	76,2	76,1	75,8	75,3	75,0	74,5	73,8	72,7	no fueling
35	7,0	72,5	75,3	76,2	75,8	75,7	75,5	75,0	74,8	74,3	73,7	72,7	no fueling
30	8,8	70,6	74,1	75,5	75,0	75,0	74,7	74,1	73,8	73,1	72,4	71,3	no fueling
25	10,9	68,0	72,3	74,8	74,2	74,3	73,9	73,1	72,8	71,9	71,1	no fueling	no fueling
20	13,2	66,4	71,3	74,2	73,4	73,6	73,1	72,1	71,7	70,6	69,7	no fueling	no fueling
10	16,9	64,7	70,0	72,9	71,7	71,9	71,3	70,5	69,4	68,3	66,9	no fueling	no fueling
0	23,6	61,9	68,2	72,6	70,8	70,7	69,6	68,6	67,1	65,7	64,0	no fueling	no fueling
-10	25,4	61,9	68,2	72,1	71,5	70,1	68,5	66,4	64,4	62,9	61,2	no fueling	no fueling
-20	27,3	61,9	68,2	71,6	71,1	69,6	68,0	65,6	62,4	60,0	no fueling	no fueling	no fueling
-30	28,5	62,1	68,4	70,8	70,5	69,0	67,4	65,1	61,8	58,7	no fueling	no fueling	no fueling
-40	28,5	62,0	68,4	70,3	70,0	68,5	67,0	64,7	61,5	58,5	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D27 - H70-T20: Capacity Category B non-communications

H70-T20 Capacity Category B Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]											
			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,0	74,2	76,4	79,6	78,9	78,1	77,5	76,4	75,4	74,5	73,7	72,8	no fueling
	45	2,2	74,0	76,4	77,8	77,1	76,6	76,2	75,4	74,8	74,2	73,7	72,7	no fueling
	40	3,3	71,3	74,5	76,9	76,4	76,0	75,6	75,0	74,6	74,2	73,7	72,7	no fueling
	35	3,5	71,4	74,6	76,3	75,8	75,5	75,2	74,7	74,4	74,0	73,6	72,7	no fueling
	30	4,5	70,5	74,1	75,4	74,8	74,6	74,2	73,6	73,4	72,9	72,3	71,3	no fueling
	25	5,5	68,6	72,8	74,5	73,8	73,7	73,3	72,6	72,3	71,7	71,0	no fueling	no fueling
	20	6,7	67,1	71,9	73,6	72,9	72,8	72,4	71,6	71,3	70,6	69,7	no fueling	no fueling
	10	8,8	64,8	70,4	72,2	71,7	71,1	70,6	69,9	69,0	68,1	66,9	no fueling	no fueling
	0	13,2	60,2	67,4	71,9	71,1	70,0	69,0	68,0	66,8	65,6	64,0	no fueling	no fueling
	-10	14,2	59,9	67,1	71,3	70,6	69,2	67,8	65,8	64,2	62,8	61,2	no fueling	no fueling
	-20	15,2	60,1	67,2	70,8	70,1	68,8	67,3	65,0	62,0	59,9	no fueling	no fueling	no fueling
	-30	16,1	60,2	67,1	70,0	69,5	68,1	66,7	64,5	61,5	58,6	no fueling	no fueling	no fueling
	-40	17,1	60,4	67,3	69,7	69,2	67,8	66,4	64,2	61,2	58,4	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D28 - H70-T40: Capacity Category B communications

H70-T40 Capacity Category B Comm / Ambient Temperature, T_{amb} [°C]	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	5,1	78,2	87,5	2,6	see Top-Off	see Top-Off	80,8	85,7	86,8	86,5	85,8	85,0	84,0	82,7	81,1	no fueling
45	8,1	76,3	87,5	4,0	see Top-Off	see Top-Off	81,1	86,9	86,6	86,2	85,3	84,3	83,0	81,6	79,7	no fueling
40	11,5	73,2	87,5	5,4	see Top-Off	see Top-Off	81,1	86,9	86,4	85,9	84,7	83,5	82,0	80,3	78,3	no fueling
35	12,4	72,9	87,5	5,6	see Top-Off	see Top-Off	81,2	86,9	86,4	85,9	84,7	83,4	81,9	80,2	78,2	no fueling
30	15,3	70,6	87,5	6,6	see Top-Off	see Top-Off	81,0	86,8	86,3	85,6	84,3	82,8	81,2	79,4	77,2	no fueling
25	18,5	69,0	87,4	7,2	see Top-Off	see Top-Off	81,0	86,8	86,1	85,4	83,8	82,2	80,4	78,5	76,1	no fueling
20	21,8	67,9	87,4	7,6	see Top-Off	see Top-Off	81,2	86,8	85,9	85,1	83,3	81,5	79,6	77,5	75,1	no fueling
10	28,0	66,3	87,4	9,0	see Top-Off	see Top-Off	81,2	86,8	85,7	84,7	82,6	80,5	78,3	76,1	73,4	no fueling
0	28,5	no Top-Off	no Top-Off	no Top-Off	78,4	84,6	86,8	85,6	84,4	83,1	80,6	78,1	75,6	73,1	no fueling	no fueling
-10	28,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,9	75,4	72,9	no fueling	no fueling
-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,6	75,1	72,7	no fueling	no fueling
-30	28,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,2	74,9	72,5	no fueling	no fueling
-40	28,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,0	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D29 - H70-T30: Capacity Category B communications

H70-T30 Capacity Category B Comm		APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	2,5	76,7	87,5	1,3	see Top-Off	see Top-Off	81,7	87,2	86,9	86,6	85,8	84,9	83,9	82,7	81,1	no fueling
	45	4,4	74,9	87,5	2,3	see Top-Off	see Top-Off	81,3	87,2	86,8	86,4	85,4	84,3	83,1	81,6	79,7	no fueling
	40	6,4	72,8	87,5	3,4	see Top-Off	see Top-Off	81,5	87,1	86,6	86,1	84,9	83,6	82,1	80,3	78,2	no fueling
	35	7,0	72,5	87,5	3,6	see Top-Off	see Top-Off	81,4	87,2	86,6	86,1	84,9	83,5	82,0	80,3	78,2	no fueling
	30	8,8	70,6	87,5	4,4	see Top-Off	see Top-Off	81,3	87,1	86,5	85,9	84,5	82,9	81,3	79,4	77,2	no fueling
	25	10,9	68,0	87,5	5,3	see Top-Off	see Top-Off	81,0	87,1	86,4	85,6	84,0	82,3	80,5	78,5	76,1	no fueling
	20	13,2	66,4	87,5	6,1	see Top-Off	see Top-Off	81,2	87,0	86,2	85,3	83,6	81,7	79,7	77,5	75,0	no fueling
	10	16,9	64,7	87,4	5,5	see Top-Off	see Top-Off	81,2	86,8	85,9	84,8	82,8	80,6	78,4	76,1	73,4	no fueling
	0	23,6	61,9	87,4	7,2	see Top-Off	see Top-Off	81,2	86,4	85,1	83,8	81,2	78,5	75,9	73,1	no fueling	no fueling
	-10	25,4	61,9	87,4	7,5	see Top-Off	see Top-Off	81,1	86,2	84,9	83,6	81,0	78,3	75,6	73,0	no fueling	no fueling
	-20	27,3	61,9	87,4	7,9	see Top-Off	see Top-Off	81,2	86,1	84,7	83,4	80,7	78,0	75,4	72,8	no fueling	no fueling
	-30	28,5	62,1	87,5	8,2	see Top-Off	see Top-Off	81,3	85,9	84,5	83,2	80,4	77,8	75,2	72,6	no fueling	no fueling
	-40	28,5	62,0	87,5	8,5	see Top-Off	see Top-Off	81,1	85,8	84,4	83,0	80,2	77,6	75,0	72,4	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D30 - H70-T20: Capacity Category B communications

H70-T20 Capacity Category B Comm	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	1,0	74,2	87,5	0,4	see Top-Off	see Top-Off	81,0	87,2	86,8	86,4	85,6	84,6	83,6	82,4	80,9	no fueling
45	2,2	74,0	87,5	1,1	see Top-Off	see Top-Off	81,6	87,3	86,9	86,4	85,4	84,3	83,0	81,5	79,7	no fueling
40	3,3	71,3	87,5	1,7	see Top-Off	see Top-Off	80,7	87,1	86,7	86,1	85,0	83,6	82,1	80,3	78,2	no fueling
35	3,5	71,4	87,5	1,8	see Top-Off	see Top-Off	80,9	87,1	86,6	86,1	84,9	83,5	82,0	80,3	78,1	no fueling
30	4,5	70,5	87,5	2,2	see Top-Off	see Top-Off	81,3	86,9	86,4	85,8	84,5	83,0	81,3	79,4	77,1	no fueling
25	5,5	68,6	87,5	2,6	see Top-Off	see Top-Off	81,0	86,8	86,2	85,5	84,1	82,4	80,5	78,5	76,1	no fueling
20	6,7	67,1	87,5	3,1	see Top-Off	see Top-Off	81,1	86,7	86,0	85,2	83,6	81,8	79,8	77,6	75,0	no fueling
10	8,8	64,8	87,5	3,8	see Top-Off	see Top-Off	81,2	86,5	85,6	84,7	82,8	80,8	78,5	76,1	73,4	no fueling
0	13,2	60,2	87,5	5,3	see Top-Off	see Top-Off	81,3	86,1	84,9	83,7	81,2	78,7	76,0	73,2	no fueling	no fueling
-10	14,2	59,9	87,4	5,4	see Top-Off	see Top-Off	81,1	86,0	84,8	83,5	81,0	78,4	75,7	73,0	no fueling	no fueling
-20	15,2	60,1	87,4	5,4	see Top-Off	see Top-Off	81,1	85,9	84,6	83,3	80,8	78,1	75,5	72,8	no fueling	no fueling
-30	16,1	60,2	87,3	5,4	see Top-Off	see Top-Off	81,0	85,7	84,5	83,2	80,6	77,9	75,3	72,7	no fueling	no fueling
-40	17,1	60,4	87,3	5,5	see Top-Off	see Top-Off	81,1	85,6	84,3	83,0	80,3	77,7	75,1	72,5	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D31 - H70-T40: Capacity Category C non-communications

H70-T40 Capacity Category C Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]											
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,6	77,9	78,8	78,4	77,9	77,3	77,3	76,5	76,0	75,2	74,3	72,8	no fueling
45	11,0	75,8	77,4	78,1	77,6	77,0	77,2	76,4	76,0	75,1	74,2	72,8	no fueling
40	14,5	72,8	75,3	77,9	77,3	76,7	77,0	76,2	75,9	75,0	74,2	72,7	no fueling
35	15,3	72,2	75,1	77,4	76,8	76,2	76,6	75,8	75,6	74,8	74,0	72,7	no fueling
30	17,9	70,5	73,9	76,7	76,0	76,2	75,7	74,8	74,5	73,6	72,7	71,3	no fueling
25	19,9	71,1	75,0	75,9	75,2	75,3	74,8	73,7	73,4	72,3	71,3	no fueling	no fueling
20	19,9	75,7	75,4	75,0	74,1	74,3	73,7	72,5	72,1	71,0	69,9	no fueling	no fueling
10	19,9	74,0	73,7	73,1	72,0	72,3	71,6	70,8	69,6	68,6	67,0	no fueling	no fueling
0	19,9	73,0	72,5	71,6	71,2	70,2	69,4	68,4	67,1	65,8	64,1	no fueling	no fueling
-10	19,9	72,3	71,8	70,9	70,4	69,1	67,7	66,0	64,4	63,0	61,2	no fueling	no fueling
-20	19,9	71,5	71,0	70,2	69,7	68,4	67,1	64,9	62,0	60,1	no fueling	no fueling	no fueling
-30	19,9	70,5	70,1	69,3	68,9	67,7	66,3	64,3	61,4	58,5	no fueling	no fueling	no fueling
-40	19,9	70,0	69,6	68,8	68,4	67,2	65,9	63,9	61,1	58,4	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D32 - H70-T30: Capacity Category C non-communications

H70-T30 Capacity Category C Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]											
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	3,1	76,1	77,5	78,8	78,1	77,5	77,1	76,2	75,5	74,8	74,0	72,8	no fueling
45	4,9	75,1	76,9	78,0	77,4	76,8	76,6	75,9	75,4	74,8	74,0	72,8	no fueling
40	7,1	72,8	75,5	77,5	77,0	76,8	76,4	75,8	75,4	74,7	74,0	72,7	no fueling
35	7,5	72,5	75,3	77,0	76,4	76,3	76,0	75,4	75,1	74,5	73,9	72,7	no fueling
30	9,3	70,8	74,2	76,2	75,6	75,6	75,2	74,4	74,1	73,4	72,6	71,3	no fueling
25	11,2	69,0	73,0	75,5	74,8	74,8	74,4	73,4	73,0	72,2	71,3	no fueling	no fueling
20	13,3	67,2	71,9	74,8	74,1	74,1	73,5	72,4	72,0	70,9	69,9	no fueling	no fueling
10	17,0	64,7	70,0	73,4	72,3	72,4	71,7	70,9	69,7	68,6	67,1	no fueling	no fueling
0	19,9	70,6	73,2	72,3	71,8	70,7	69,8	68,7	67,2	65,9	64,1	no fueling	no fueling
-10	19,9	73,0	72,5	71,5	71,0	69,6	68,1	66,3	64,6	63,1	61,2	no fueling	no fueling
-20	19,9	72,3	71,8	70,8	70,3	68,9	67,5	65,2	62,2	60,2	no fueling	no fueling	no fueling
-30	19,9	71,2	70,8	69,9	69,5	68,2	66,7	64,6	61,5	58,6	no fueling	no fueling	no fueling
-40	19,9	70,7	70,3	69,4	69,0	67,7	66,3	64,2	61,2	58,4	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D33 - H70-T20: Capacity Category C non-communications

H70-T20 Capacity Category C Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]											
			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,2	74,3	76,4	80,1	79,3	78,5	77,9	76,7	75,6	74,7	73,9	72,8	no fueling
	45	2,2	74,0	76,4	78,6	77,9	77,2	76,8	75,8	75,1	74,4	73,8	72,8	no fueling
	40	3,3	71,3	74,4	77,7	77,0	76,6	76,1	75,4	74,9	74,4	73,8	72,8	no fueling
	35	3,5	71,4	74,6	77,0	76,4	76,0	75,6	74,9	74,6	74,1	73,7	72,7	no fueling
	30	4,5	70,5	74,1	76,1	75,5	75,0	74,6	73,9	73,5	73,0	72,4	71,3	no fueling
	25	5,5	68,6	72,8	75,2	74,6	74,1	73,7	72,9	72,5	71,8	71,1	no fueling	no fueling
	20	6,6	67,1	71,9	74,5	73,8	73,3	72,8	71,9	71,4	70,6	69,8	no fueling	no fueling
	10	8,7	65,1	70,6	73,0	72,2	71,6	71,0	70,1	69,2	68,3	67,0	no fueling	no fueling
	0	12,9	60,4	67,5	72,4	71,2	70,2	69,4	68,3	67,0	65,8	64,1	no fueling	no fueling
	-10	13,6	60,4	67,5	71,3	70,5	69,2	67,8	66,0	64,4	63,0	61,2	no fueling	no fueling
	-20	14,4	60,0	67,2	70,7	70,0	68,7	67,3	64,9	62,0	60,1	no fueling	no fueling	no fueling
	-30	15,0	60,2	67,3	69,9	69,3	68,0	66,6	64,4	61,4	58,5	no fueling	no fueling	no fueling
	-40	15,7	60,2	67,2	69,5	68,9	67,6	66,2	64,0	61,2	58,4	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D34 - H70-T40: Capacity Category C communications

H70-T40 Capacity Category C Comm	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,6	77,9	87,5	2,8	see Top-Off	see Top-Off	81,1	86,2	86,9	86,6	85,8	84,9	83,8	82,6	81,0	no fueling
45	11,0	75,8	87,5	3,8	see Top-Off	see Top-Off	81,4	87,0	86,7	86,2	85,2	84,1	82,8	81,4	79,6	no fueling
40	14,5	72,8	87,4	4,5	see Top-Off	see Top-Off	81,2	87,0	86,4	85,9	84,6	83,3	81,8	80,2	78,2	no fueling
35	15,3	72,2	87,4	4,6	see Top-Off	see Top-Off	81,1	87,0	86,4	85,9	84,6	83,2	81,7	80,1	78,2	no fueling
30	17,9	70,5	87,4	5,0	see Top-Off	see Top-Off	81,1	86,9	86,3	85,6	84,2	82,6	81,0	79,2	77,2	no fueling
25	19,9	71,1	87,3	5,4	see Top-Off	see Top-Off	83,2	86,8	86,0	85,3	83,7	82,0	80,2	78,3	76,1	no fueling
20	19,9	77,4	87,3	5,6	see Top-Off	see Top-Off	87,1	86,4	85,5	84,7	83,0	81,2	79,3	77,4	75,0	no fueling
10	19,9	no Top-Off	no Top-Off	no Top-Off	87,3	87,1	86,6	85,7	84,8	83,9	82,0	80,0	78,0	75,9	73,4	no fueling
0	19,9	no Top-Off	no Top-Off	no Top-Off	86,6	86,3	85,7	84,6	83,4	82,3	80,0	77,7	75,4	72,9	no fueling	no fueling
-10	19,9	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,5	84,4	83,2	82,1	79,8	77,5	75,2	72,8	no fueling	no fueling
-20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	85,9	85,3	84,2	83,0	81,9	79,6	77,3	75,0	72,6	no fueling	no fueling
-30	19,9	no Top-Off	no Top-Off	no Top-Off	86,0	85,7	85,0	83,9	82,8	81,7	79,4	77,1	74,8	72,4	no fueling	no fueling
-40	19,9	no Top-Off	no Top-Off	no Top-Off	85,8	85,5	84,8	83,7	82,6	81,4	79,2	76,9	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D35 - H70-T30: Capacity Category C communications

H70-T30 Capacity Category C Comm	APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	3,1	76,1	87,5	1,4	see Top-Off	see Top-Off	80,8	87,1	86,9	86,5	85,7	84,8	83,7	82,5	81,0	no fueling
45	4,9	75,1	87,5	2,2	see Top-Off	see Top-Off	81,4	87,1	86,7	86,3	85,3	84,1	82,8	81,4	79,6	no fueling
40	7,1	72,8	87,5	3,0	see Top-Off	see Top-Off	81,3	87,0	86,5	86,0	84,7	83,4	81,8	80,2	78,1	no fueling
35	7,5	72,5	87,5	3,1	see Top-Off	see Top-Off	81,2	87,1	86,5	86,0	84,7	83,3	81,8	80,1	78,1	no fueling
30	9,3	70,8	87,5	3,7	see Top-Off	see Top-Off	81,3	87,0	86,4	85,7	84,3	82,7	81,1	79,2	77,1	no fueling
25	11,2	69,0	87,5	4,3	see Top-Off	see Top-Off	81,2	86,9	86,2	85,5	83,9	82,1	80,3	78,3	76,1	no fueling
20	13,3	67,2	87,5	4,9	see Top-Off	see Top-Off	81,3	86,8	86,0	85,2	83,4	81,5	79,5	77,4	75,0	no fueling
10	17,0	64,7	87,4	5,5	see Top-Off	see Top-Off	81,1	86,8	85,7	84,7	82,6	80,5	78,3	76,0	73,4	no fueling
0	19,9	70,6	87,3	5,8	see Top-Off	see Top-Off	87,3	86,0	84,7	83,5	80,9	78,3	75,7	73,1	no fueling	no fueling
-10	19,9	73,4	87,3	5,7	see Top-Off	see Top-Off	87,0	85,8	84,5	83,2	80,7	78,1	75,5	72,9	no fueling	no fueling
-20	19,9	76,3	87,3	5,6	see Top-Off	see Top-Off	86,8	85,6	84,3	83,0	80,4	77,9	75,3	72,7	no fueling	no fueling
-30	19,9	78,8	87,3	5,5	see Top-Off	see Top-Off	86,6	85,3	84,1	82,8	80,2	77,7	75,1	72,6	no fueling	no fueling
-40	19,9	81,1	87,3	5,5	see Top-Off	see Top-Off	86,4	85,2	83,9	82,6	80,0	77,5	75,0	72,5	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D36 - H70-T20: Capacity Category C communications

H70-T20 Capacity Category C Comm		APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,2	no Top-Off	no Top-Off	no Top-Off	74,3	76,4	80,7	87,2	86,8	86,4	85,6	84,6	83,6	82,4	80,9	no fueling
	45	2,2	74,0	87,5	1,1	see Top-Off	see Top-Off	81,6	87,2	86,7	86,3	85,2	84,1	82,8	81,3	79,6	no fueling
	40	3,3	71,3	87,5	1,7	see Top-Off	see Top-Off	80,7	87,2	86,6	86,0	84,8	83,4	81,9	80,2	78,1	no fueling
	35	3,5	71,4	87,5	1,8	see Top-Off	see Top-Off	80,9	87,2	86,6	86,0	84,8	83,4	81,8	80,1	78,1	no fueling
	30	4,4	70,5	87,5	2,2	see Top-Off	see Top-Off	81,4	87,1	86,5	85,8	84,4	82,8	81,1	79,3	77,1	no fueling
	25	5,5	68,6	87,5	2,6	see Top-Off	see Top-Off	81,0	87,1	86,4	85,6	84,0	82,3	80,4	78,4	76,0	no fueling
	20	6,6	67,1	87,5	3,1	see Top-Off	see Top-Off	81,1	87,0	86,2	85,3	83,6	81,7	79,6	77,5	75,0	no fueling
	10	8,7	65,1	87,5	3,6	see Top-Off	see Top-Off	81,2	86,9	85,9	84,9	82,8	80,7	78,4	76,0	73,4	no fueling
	0	12,8	60,4	87,4	4,8	see Top-Off	see Top-Off	81,2	86,5	85,3	84,0	81,3	78,6	75,9	73,1	no fueling	no fueling
	-10	13,6	60,4	87,4	4,8	see Top-Off	see Top-Off	81,3	86,4	85,1	83,8	81,2	78,5	75,8	73,0	no fueling	no fueling
	-20	14,3	60,0	87,4	4,9	see Top-Off	see Top-Off	81,1	86,4	85,0	83,7	81,0	78,3	75,6	72,8	no fueling	no fueling
	-30	15,0	60,2	87,3	4,9	see Top-Off	see Top-Off	81,2	86,3	84,9	83,6	80,9	78,2	75,5	72,7	no fueling	no fueling
	-40	15,7	60,2	87,3	5,0	see Top-Off	see Top-Off	81,2	86,2	84,9	83,5	80,8	78,0	75,3	72,6	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D37 - H70-T40D: Capacity Category D non-communications

H70-T40D Capacity Category D Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]												
		Initial Tank Pressure, P_0 [MPa]												
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,6	73,6	72,6	72,6	72,2	71,9	71,9	71,5	71,2	71,0	71,2	71,9	no fueling
45	11,0	73,1	72,2	72,6	71,8	71,6	71,5	71,2	71,0	70,9	71,1	71,9	no fueling
40	14,5	71,3	71,8	72,2	71,4	71,2	71,2	70,9	70,8	70,8	71,1	71,9	no fueling
35	15,3	71,4	71,3	71,3	71,1	70,9	70,8	70,6	70,6	70,7	71,0	71,9	no fueling
30	17,9	70,5	71,0	71,0	70,2	70,0	69,9	69,6	69,5	69,6	69,9	70,8	no fueling
25	19,9	68,6	69,7	69,6	69,3	69,0	68,9	68,6	68,4	68,5	68,8	no fueling	no fueling
20	19,9	67,1	68,9	68,8	68,4	68,1	67,9	67,5	67,4	67,4	67,7	no fueling	no fueling
10	19,9	64,7	67,8	67,3	66,3	65,9	65,6	65,1	64,7	64,5	64,6	no fueling	no fueling
0	19,9	60,4	67,3	66,8	65,9	64,9	64,0	63,4	63,0	62,9	63,2	no fueling	no fueling
-10	19,9	60,4	66,8	66,3	65,4	64,5	63,5	61,5	60,8	60,6	60,9	no fueling	no fueling
-20	19,9	60,0	66,3	65,8	65,0	64,1	63,0	61,2	59,4	57,5	no fueling	no fueling	no fueling
-30	19,9	60,2	65,8	65,3	64,5	63,7	62,7	61,0	59,3	57,5	no fueling	no fueling	no fueling
-40	19,9	60,2	65,3	64,8	64,1	63,3	62,4	60,7	59,1	57,5	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D38 - H70-T30D: Capacity Category D non-communications

H70-T30D Capacity Category D Non-Comm	APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]											
Ambient Temperature, T_{amb} [°C]		0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	3,1	73,6	72,6	72,6	72,2	71,9	71,9	71,5	71,2	71,0	71,2	71,9	no fueling
45	4,9	73,1	72,2	72,6	71,8	71,6	71,5	71,2	71,0	70,9	71,1	71,9	no fueling
40	7,1	71,3	71,8	72,2	71,4	71,2	71,2	70,9	70,8	70,8	71,1	71,9	no fueling
35	7,5	71,4	71,3	71,3	71,1	70,9	70,8	70,6	70,6	70,7	71,0	71,9	no fueling
30	9,3	70,5	71,0	71,0	70,2	70,0	69,9	69,6	69,5	69,6	69,9	70,8	no fueling
25	11,2	68,6	69,7	69,6	69,3	69,0	68,9	68,6	68,4	68,5	68,8	no fueling	no fueling
20	13,3	67,1	68,9	68,8	68,4	68,1	67,9	67,5	67,4	67,4	67,7	no fueling	no fueling
10	17,0	64,7	67,8	67,3	66,3	65,9	65,6	65,1	64,7	64,5	64,6	no fueling	no fueling
0	19,9	60,4	67,3	66,8	65,9	64,9	64,0	63,4	63,0	62,9	63,2	no fueling	no fueling
-10	19,9	60,4	66,8	66,3	65,4	64,5	63,5	61,5	60,8	60,6	60,9	no fueling	no fueling
-20	19,9	60,0	66,3	65,8	65,0	64,1	63,0	61,2	59,4	57,5	no fueling	no fueling	no fueling
-30	19,9	60,2	65,8	65,3	64,5	63,7	62,7	61,0	59,3	57,5	no fueling	no fueling	no fueling
-40	19,9	60,2	65,3	64,8	64,1	63,3	62,4	60,7	59,1	57,5	no fueling	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D39 - H70-T20D: Capacity Category D non-communications

H70-T20D Capacity Category D Non-Comm		APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]											
			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1,2	73,6	72,6	72,6	72,2	71,9	71,9	71,5	71,2	71,0	71,2	71,9	no fueling
	45	2,2	73,1	72,2	72,6	71,8	71,6	71,5	71,2	71,0	70,9	71,1	71,9	no fueling
	40	3,3	71,3	71,8	72,2	71,4	71,2	71,2	70,9	70,8	70,8	71,1	71,9	no fueling
	35	3,5	71,4	71,3	71,3	71,1	70,9	70,8	70,6	70,6	70,7	71,0	71,9	no fueling
	30	4,5	70,5	71,0	71,0	70,2	70,0	69,9	69,6	69,5	69,6	69,9	70,8	no fueling
	25	5,5	68,6	69,7	69,6	69,3	69,0	68,9	68,6	68,4	68,5	68,8	no fueling	no fueling
	20	6,6	67,1	68,9	68,8	68,4	68,1	67,9	67,5	67,4	67,4	67,7	no fueling	no fueling
	10	8,7	64,7	67,8	67,3	66,3	65,9	65,6	65,1	64,7	64,5	64,6	no fueling	no fueling
	0	12,9	60,4	67,3	66,8	65,9	64,9	64,0	63,4	63,0	62,9	63,2	no fueling	no fueling
	-10	13,6	60,4	66,8	66,3	65,4	64,5	63,5	61,5	60,8	60,6	60,9	no fueling	no fueling
	-20	14,4	60,0	66,3	65,8	65,0	64,1	63,0	61,2	59,4	57,5	no fueling	no fueling	no fueling
	-30	15,0	60,2	65,8	65,3	64,5	63,7	62,7	61,0	59,3	57,5	no fueling	no fueling	no fueling
	-40	15,7	60,2	65,3	64,8	64,1	63,3	62,4	60,7	59,1	57,5	no fueling	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D40 - H70-T40D: Capacity Category D communications

H70-T40D Capacity Category D Comm	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,6	77,9	87,5	2,8	see Top-Off	see Top-Off	81,1	86,2	86,9	86,6	85,8	84,9	83,8	82,6	81,0	no fueling
45	11,0	75,8	87,5	3,8	see Top-Off	see Top-Off	81,4	87,0	86,7	86,2	85,2	84,1	82,8	81,4	79,6	no fueling
40	14,5	72,8	87,4	4,5	see Top-Off	see Top-Off	81,2	87,0	86,4	85,9	84,6	83,3	81,8	80,2	78,2	no fueling
35	15,3	72,2	87,4	4,6	see Top-Off	see Top-Off	81,1	87,0	86,4	85,9	84,6	83,2	81,7	80,1	78,2	no fueling
30	17,9	70,5	87,4	5,0	see Top-Off	see Top-Off	81,1	86,9	86,3	85,6	84,2	82,6	81,0	79,2	77,2	no fueling
25	19,9	71,1	87,3	5,4	see Top-Off	see Top-Off	83,2	86,8	86,0	85,3	83,7	82,0	80,2	78,3	76,1	no fueling
20	19,9	77,4	87,3	5,6	see Top-Off	see Top-Off	87,1	86,4	85,5	84,7	83,0	81,2	79,3	77,4	75,0	no fueling
10	19,9	no Top-Off	no Top-Off	no Top-Off	87,3	87,1	86,6	85,7	84,8	83,9	82,0	80,0	78,0	75,9	73,4	no fueling
0	19,9	no Top-Off	no Top-Off	no Top-Off	86,6	86,3	85,7	84,6	83,4	82,3	80,0	77,7	75,4	72,9	no fueling	no fueling
-10	19,9	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,5	84,4	83,2	82,1	79,8	77,5	75,2	72,8	no fueling	no fueling
-20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	85,9	85,3	84,2	83,0	81,9	79,6	77,3	75,0	72,6	no fueling	no fueling
-30	19,9	no Top-Off	no Top-Off	no Top-Off	86,0	85,7	85,0	83,9	82,8	81,7	79,4	77,1	74,8	72,4	no fueling	no fueling
-40	19,9	no Top-Off	no Top-Off	no Top-Off	85,8	85,5	84,8	83,7	82,6	81,4	79,2	76,9	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D41 - H70-T30D: Capacity Category D communications

H70-T30D Capacity Category D Comm		APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	3,1	76,1	87,5	1,4	see Top-Off	see Top-Off	80,8	87,1	86,9	86,5	85,7	84,8	83,7	82,5	81,0	no fueling
	45	4,9	75,1	87,5	2,2	see Top-Off	see Top-Off	81,4	87,1	86,7	86,3	85,3	84,1	82,8	81,4	79,6	no fueling
	40	7,1	72,8	87,5	3,0	see Top-Off	see Top-Off	81,3	87,0	86,5	86,0	84,7	83,4	81,8	80,2	78,1	no fueling
	35	7,5	72,5	87,5	3,1	see Top-Off	see Top-Off	81,2	87,1	86,5	86,0	84,7	83,3	81,8	80,1	78,1	no fueling
	30	9,3	70,8	87,5	3,7	see Top-Off	see Top-Off	81,3	87,0	86,4	85,7	84,3	82,7	81,1	79,2	77,1	no fueling
	25	11,2	69,0	87,5	4,3	see Top-Off	see Top-Off	81,2	86,9	86,2	85,5	83,9	82,1	80,3	78,3	76,1	no fueling
	20	13,3	67,2	87,5	4,9	see Top-Off	see Top-Off	81,3	86,8	86,0	85,2	83,4	81,5	79,5	77,4	75,0	no fueling
	10	17,0	64,7	87,4	5,5	see Top-Off	see Top-Off	81,1	86,8	85,7	84,7	82,6	80,5	78,3	76,0	73,4	no fueling
	0	19,9	70,6	87,3	5,8	see Top-Off	see Top-Off	87,3	86,0	84,7	83,5	80,9	78,3	75,7	73,1	no fueling	no fueling
	-10	19,9	73,4	87,3	5,7	see Top-Off	see Top-Off	87,0	85,8	84,5	83,2	80,7	78,1	75,5	72,9	no fueling	no fueling
	-20	19,9	76,3	87,3	5,6	see Top-Off	see Top-Off	86,8	85,6	84,3	83,0	80,4	77,9	75,3	72,7	no fueling	no fueling
	-30	19,9	78,8	87,3	5,5	see Top-Off	see Top-Off	86,6	85,3	84,1	82,8	80,2	77,7	75,1	72,6	no fueling	no fueling
	-40	19,9	81,1	87,3	5,5	see Top-Off	see Top-Off	86,4	85,2	83,9	82,6	80,0	77,5	75,0	72,5	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table D42 - H70-T20D: Capacity Category D communications

H70-T20D Capacity Category D Comm	APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	1,2	no Top-Off	no Top-Off	no Top-Off	74,3	76,4	80,7	87,2	86,8	86,4	85,6	84,6	83,6	82,4	80,9	no fueling
45	2,2	74,0	87,5	1,1	see Top-Off	see Top-Off	81,6	87,2	86,7	86,3	85,2	84,1	82,8	81,3	79,6	no fueling
40	3,3	71,3	87,5	1,7	see Top-Off	see Top-Off	80,7	87,2	86,6	86,0	84,8	83,4	81,9	80,2	78,1	no fueling
35	3,5	71,4	87,5	1,8	see Top-Off	see Top-Off	80,9	87,2	86,6	86,0	84,8	83,4	81,8	80,1	78,1	no fueling
30	4,4	70,5	87,5	2,2	see Top-Off	see Top-Off	81,4	87,1	86,5	85,8	84,4	82,8	81,1	79,3	77,1	no fueling
25	5,5	68,6	87,5	2,6	see Top-Off	see Top-Off	81,0	87,1	86,4	85,6	84,0	82,3	80,4	78,4	76,0	no fueling
20	6,6	67,1	87,5	3,1	see Top-Off	see Top-Off	81,1	87,0	86,2	85,3	83,6	81,7	79,6	77,5	75,0	no fueling
10	8,7	65,1	87,5	3,6	see Top-Off	see Top-Off	81,2	86,9	85,9	84,9	82,8	80,7	78,4	76,0	73,4	no fueling
0	12,8	60,4	87,4	4,8	see Top-Off	see Top-Off	81,2	86,5	85,3	84,0	81,3	78,6	75,9	73,1	no fueling	no fueling
-10	13,6	60,4	87,4	4,8	see Top-Off	see Top-Off	81,3	86,4	85,1	83,8	81,2	78,5	75,8	73,0	no fueling	no fueling
-20	14,3	60,0	87,4	4,9	see Top-Off	see Top-Off	81,1	86,4	85,0	83,7	81,0	78,3	75,6	72,8	no fueling	no fueling
-30	15,0	60,2	87,3	4,9	see Top-Off	see Top-Off	81,2	86,3	84,9	83,6	80,9	78,2	75,5	72,7	no fueling	no fueling
-40	15,7	60,2	87,3	5,0	see Top-Off	see Top-Off	81,2	86,2	84,9	83,5	80,8	78,0	75,3	72,6	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

APPENDIX E - COLD DISPENSER (CD) OPTIONAL LOOK-UP TABLES (H70)

The following tables are optional tables that can be used for the purpose of reducing fueling time after a repeated fueling. The CD tables are for communications only. In order to use the CD, the dispenser shall utilize a SIL-rated temperature sensor at the coupling location. This reference temperature (either CD 0 °C, CD -10 °C) is the start temperature for which these tables are used. The rest of the fueling procedure is identical to the standard tables in Appendix D. See Appendix G for table value interpolation guideline. Note that the SAE J2601 tables are in the international format for commas and periods (this is opposite to the convention used for the U.S.).

Below is the key to the tables found in Appendix E:

E.1 COMMUNICATIONS COLD DISPENSER LOOK-UP TABLES

E.1.1 0 °C Communications Look-Up Tables

Table E1 H70-T40 CHSS Capacity Category A communications (CD 0 °C)
Table E2 H70-T30 CHSS Capacity Category A communications (CD 0 °C)
Table E3 H70-T40 CHSS Capacity Category B communications (CD 0 °C)
Table E4 H70-T30 CHSS Capacity Category B communications (CD 0 °C)
Table E5 H70-T40 CHSS Capacity Category C communications (CD 0 °C)
Table E6 H70-T30 CHSS Capacity Category C communications (CD 0 °C)

E.1.2 -10 °C Communications Look-Up Tables

Table E7 H70-T40 CHSS Capacity Category A communications (CD -10 °C)
Table E8 H70-T30 CHSS Capacity Category A communications (CD -10 °C)
Table E9 H70-T40 CHSS Capacity Category B communications (CD -10°C)
Table E10 H70-T30 CHSS Capacity Category B communications (CD -10 °C)
Table E11 H70-T40 CHSS Capacity Category C communications (CD -10 °C)
Table E12 H70-T30 CHSS Capacity Category C communications (CD -10 °C)

E.2 COMMUNICATIONS COLD DISPENSER LOOK-UP TABLES

E.2.1 0 °C Communications Look-Up Tables

Table E1 - H70-T40 CHSS Capacity Category A communications (CD 0 °C)

H70-T40 CHSS Capacity Category A Comm CD0	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,4	76,1	87,5	4,1	see Top-Off	see Top-Off	80,9	87,1	86,9	86,6	85,8	84,9	83,8	82,5	80,9	no fueling
45	11,1	73,6	87,5	6,1	see Top-Off	see Top-Off	81,4	87,0	86,7	86,2	85,3	84,1	82,8	81,3	79,5	no fueling
40	14,9	70,3	87,5	8,0	see Top-Off	see Top-Off	81,2	87,0	86,4	85,9	84,7	83,3	81,8	80,1	78,1	no fueling
35	15,6	70,0	87,5	8,3	see Top-Off	see Top-Off	81,0	87,0	86,5	85,9	84,7	83,3	81,8	80,1	78,0	no fueling
30	18,5	68,7	87,5	9,5	see Top-Off	see Top-Off	81,1	86,9	86,3	85,7	84,2	82,7	81,1	79,2	77,0	no fueling
25	21,4	68,0	87,4	10,2	see Top-Off	see Top-Off	81,3	86,9	86,2	85,4	83,8	82,1	80,3	78,4	76,0	no fueling
20	24,7	67,3	87,4	10,8	see Top-Off	see Top-Off	81,3	86,9	86,0	85,2	83,4	81,5	79,6	77,5	75,0	no fueling
10	28,5	69,3	87,4	8,8	see Top-Off	see Top-Off	84,3	86,7	85,7	84,7	82,6	80,5	78,4	76,1	73,3	no fueling
0	28,5	no Top-Off	no Top-Off	no Top-Off	81,5	87,2	86,5	85,5	84,3	83,2	80,7	78,3	75,8	73,2	no fueling	no fueling
-10	28,5	no Top-Off	no Top-Off	no Top-Off	86,9	86,6	86,0	84,9	83,8	82,6	80,3	77,9	75,5	72,9	no fueling	no fueling
-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,4	84,3	83,2	82,1	79,8	77,5	75,2	72,7	no fueling	no fueling
-30	28,5	no Top-Off	no Top-Off	no Top-Off	85,9	85,6	84,9	83,8	82,7	81,5	79,3	77,0	74,8	72,4	no fueling	no fueling
-40	28,5	no Top-Off	no Top-Off	no Top-Off	85,4	85,1	84,4	83,3	82,1	81,0	78,8	76,6	74,4	72,2	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E2 - H70-T30 CHSS Capacity Category A communications (CD 0 °C)

H70-T30 CHSS Capacity Category A Comm CD0 / Ambient Temperature, T_{amb} [°C]	APRR [MPa/min]	Target Pressure P_{target} [MPa] (0,5 - 5 (no interpolation))	Target Pressure Top-Off [MPa] (0,5 - 5 (no interpolation))	Top-Off-APRR [MPa/min] (0,5 - 5 (no interpolation))	Target Pressure, P_{target} [MPa] / Initial Tank Pressure, P_0 [MPa]: 0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	4,2	75,7	87,5	2,0	see Top-Off	see Top-Off	81,2	87,4	87,1	86,7	85,9	84,9	83,8	82,5	80,8	no fueling
45	6,6	73,4	87,5	3,1	see Top-Off	see Top-Off	80,9	87,3	86,9	86,5	85,4	84,2	82,9	81,3	79,5	no fueling
40	9,2	71,2	87,5	4,2	see Top-Off	see Top-Off	81,1	87,1	86,6	86,1	84,9	83,5	81,9	80,1	78,0	no fueling
35	9,6	70,9	87,5	4,3	see Top-Off	see Top-Off	81,1	87,1	86,6	86,1	84,8	83,4	81,9	80,1	78,0	no fueling
30	11,5	69,4	87,5	5,1	see Top-Off	see Top-Off	81,4	87,0	86,4	85,8	84,4	82,8	81,1	79,2	77,0	no fueling
25	13,5	67,2	87,5	5,8	see Top-Off	see Top-Off	81,1	86,9	86,2	85,5	84,0	82,3	80,4	78,4	76,0	no fueling
20	15,5	66,0	87,5	6,6	see Top-Off	see Top-Off	81,3	86,7	86,0	85,2	83,5	81,6	79,6	77,5	75,0	no fueling
10	18,8	64,4	87,4	7,2	see Top-Off	see Top-Off	81,1	86,5	85,6	84,7	82,8	80,7	78,4	76,1	73,3	no fueling
0	25,3	62,4	87,4	8,7	see Top-Off	see Top-Off	81,1	86,2	85,0	83,7	81,3	78,7	76,0	73,2	no fueling	no fueling
-10	28,1	62,7	87,4	9,0	see Top-Off	see Top-Off	81,2	85,9	84,7	83,4	80,9	78,3	75,7	73,0	no fueling	no fueling
-20	28,5	66,8	87,3	8,9	see Top-Off	see Top-Off	85,7	85,4	84,2	82,9	80,4	77,9	75,3	72,8	no fueling	no fueling
-30	28,5	71,3	87,3	8,7	see Top-Off	see Top-Off	86,2	84,9	83,6	82,4	79,9	77,4	75,0	72,5	no fueling	no fueling
-40	28,5	no fueling	no fueling	no fueling	75,5	81,9	85,7	84,4	83,2	81,9	79,4	77,0	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E3 - H70-T40 CHSS Capacity Category B communications (CD 0 °C)

H70-T40 CHSS Capacity Category B Comm CD0	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	9,7	76,5	87,5	3,9	see Top-Off	see Top-Off	81,1	87,2	86,8	86,5	85,7	84,7	83,5	82,3	80,8	no fueling
45	13,5	74,0	87,5	5,2	see Top-Off	see Top-Off	81,4	87,1	86,6	86,1	85,1	83,9	82,6	81,1	79,4	no fueling
40	17,1	71,2	87,5	6,3	see Top-Off	see Top-Off	81,1	87,0	86,4	85,8	84,5	83,1	81,5	79,9	78,0	no fueling
35	17,6	71,3	87,4	6,3	see Top-Off	see Top-Off	81,2	87,0	86,4	85,8	84,5	83,0	81,5	79,9	78,0	no fueling
30	20,2	69,8	87,4	6,7	see Top-Off	see Top-Off	81,1	87,0	86,3	85,5	84,0	82,5	80,8	79,0	77,0	no fueling
25	22,9	68,7	87,4	7,2	see Top-Off	see Top-Off	81,1	86,9	86,1	85,3	83,6	81,9	80,1	78,2	76,0	no fueling
20	25,7	67,6	87,4	8,0	see Top-Off	see Top-Off	81,1	86,9	86,0	85,0	83,2	81,3	79,3	77,3	74,9	no fueling
10	28,5	68,4	87,4	7,9	see Top-Off	see Top-Off	83,9	86,6	85,6	84,5	82,4	80,3	78,1	75,9	73,3	no fueling
0	28,5	no Top-Off	no Top-Off	no Top-Off	78,4	84,6	86,8	85,6	84,4	83,1	80,6	78,1	75,6	73,1	no fueling	no fueling
-10	28,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,9	75,4	72,9	no fueling	no fueling
-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,6	75,1	72,7	no fueling	no fueling
-30	28,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,2	74,9	72,5	no fueling	no fueling
-40	28,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,0	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E4 - H70-T30 CHSS Capacity Category B communications (CD 0 °C)

H70-T30 CHSS Capacity Category B Comm CD0		APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	4,2	75,7	87,5	2,0	see Top-Off	see Top-Off	81,2	87,4	87,0	86,6	85,8	84,8	83,6	82,3	80,7	no fueling
	45	6,6	73,4	87,5	3,1	see Top-Off	see Top-Off	80,9	87,3	86,9	86,4	85,3	84,0	82,7	81,1	79,4	no fueling
	40	9,2	71,2	87,5	3,4	see Top-Off	see Top-Off	81,0	87,2	86,7	86,0	84,7	83,2	81,7	79,9	78,0	no fueling
	35	9,4	71,4	87,5	3,5	see Top-Off	see Top-Off	81,2	87,2	86,6	86,0	84,7	83,2	81,6	79,9	77,9	no fueling
	30	11,3	69,6	87,5	4,0	see Top-Off	see Top-Off	81,1	87,1	86,5	85,8	84,3	82,7	80,9	79,1	77,0	no fueling
	25	13,1	67,8	87,5	4,6	see Top-Off	see Top-Off	81,0	87,0	86,3	85,5	83,8	82,1	80,2	78,2	76,0	no fueling
	20	15,0	66,7	87,4	4,9	see Top-Off	see Top-Off	81,3	86,9	86,1	85,2	83,4	81,4	79,4	77,3	74,9	no fueling
	10	17,9	64,4	87,3	5,5	see Top-Off	see Top-Off	81,0	86,7	85,8	84,8	82,7	80,5	78,3	76,0	73,3	no fueling
	0	23,6	61,9	87,4	7,2	see Top-Off	see Top-Off	81,2	86,4	85,1	83,8	81,2	78,5	75,9	73,1	no fueling	no fueling
	-10	25,4	61,9	87,4	7,5	see Top-Off	see Top-Off	81,1	86,2	84,9	83,6	81,0	78,3	75,6	73,0	no fueling	no fueling
	-20	27,3	61,9	87,4	7,9	see Top-Off	see Top-Off	81,2	86,1	84,7	83,4	80,7	78,0	75,4	72,8	no fueling	no fueling
	-30	28,5	62,1	87,5	8,2	see Top-Off	see Top-Off	81,3	85,9	84,5	83,2	80,4	77,8	75,2	72,6	no fueling	no fueling
	-40	28,5	62,0	87,5	8,5	see Top-Off	see Top-Off	81,1	85,8	84,4	83,0	80,2	77,6	75,0	72,4	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E5 - H70-T40 CHSS Capacity Category C communications (CD 0 °C)

H70-T40 CHSS Capacity Category C Comm CD0		APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	12,0	76,0	87,4	3,4	see Top-Off	see Top-Off	81,3	87,2	86,8	86,5	85,6	84,5	83,4	82,1	80,7	no fueling
	45	15,6	73,4	87,4	4,0	see Top-Off	see Top-Off	81,2	87,1	86,6	86,1	85,0	83,7	82,4	81,0	79,3	no fueling
	40	19,0	70,9	87,4	4,7	see Top-Off	see Top-Off	81,2	87,0	86,4	85,7	84,4	82,9	81,4	79,8	77,9	no fueling
	35	19,3	70,8	87,4	4,8	see Top-Off	see Top-Off	81,1	87,0	86,4	85,7	84,4	82,9	81,4	79,7	77,9	no fueling
	30	19,9	73,8	87,3	5,0	see Top-Off	see Top-Off	85,2	86,8	86,1	85,3	83,8	82,3	80,6	78,9	77,0	no fueling
	25	19,9	78,4	87,4	4,6	see Top-Off	see Top-Off	87,2	86,4	85,7	84,9	83,3	81,6	79,8	78,0	75,9	no fueling
	20	19,9	no Top-Off	no Top-Off	no Top-Off	83,2	87,4	86,9	86,1	85,3	84,4	82,7	80,9	79,0	77,1	74,9	no fueling
	10	19,9	no Top-Off	no Top-Off	no Top-Off	87,2	87,0	86,5	85,6	84,6	83,7	81,8	79,8	77,8	75,7	73,3	no fueling
	0	19,9	no Top-Off	no Top-Off	no Top-Off	86,6	86,3	85,7	84,6	83,4	82,3	80,0	77,7	75,4	72,9	no fueling	no fueling
	-10	19,9	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,5	84,4	83,2	82,1	79,8	77,5	75,2	72,8	no fueling	no fueling
	-20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	85,9	85,3	84,2	83,0	81,9	79,6	77,3	75,0	72,6	no fueling	no fueling
	-30	19,9	no Top-Off	no Top-Off	no Top-Off	86,0	85,7	85,0	83,9	82,8	81,7	79,4	77,1	74,8	72,4	no fueling	no fueling
	-40	19,9	no Top-Off	no Top-Off	no Top-Off	85,8	85,5	84,8	83,7	82,6	81,4	79,2	76,9	74,6	72,3	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E6 - H70-T30 CHSS Capacity Category C communications (CD 0 °C)

H70-T30 CHSS Capacity Category C Comm CD0	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	4,4	75,9	87,5	1,8	see Top-Off	see Top-Off	81,4	87,3	86,9	86,5	85,6	84,6	83,4	82,1	80,6	no fueling
45	6,7	73,9	87,5	2,6	see Top-Off	see Top-Off	81,4	87,2	86,7	86,2	85,1	83,9	82,5	81,0	79,3	no fueling
40	9,2	71,3	87,5	3,4	see Top-Off	see Top-Off	81,0	87,1	86,5	85,9	84,5	83,1	81,5	79,8	77,9	no fueling
35	9,4	71,4	87,5	3,5	see Top-Off	see Top-Off	81,2	87,1	86,5	85,9	84,5	83,1	81,5	79,8	77,9	no fueling
30	11,3	69,6	87,5	4,0	see Top-Off	see Top-Off	81,1	87,0	86,4	85,6	84,1	82,5	80,8	78,9	76,9	no fueling
25	13,1	67,8	87,5	4,6	see Top-Off	see Top-Off	81,0	87,0	86,2	85,4	83,7	81,9	80,1	78,1	75,9	no fueling
20	15,0	66,7	87,4	5,0	see Top-Off	see Top-Off	81,3	86,9	86,0	85,1	83,2	81,3	79,3	77,2	74,9	no fueling
10	17,9	64,4	87,3	5,5	see Top-Off	see Top-Off	81,0	86,8	85,7	84,7	82,6	80,4	78,2	75,9	73,3	no fueling
0	19,9	70,6	87,3	5,8	see Top-Off	see Top-Off	87,3	86,0	84,7	83,5	80,9	78,3	75,7	73,1	no fueling	no fueling
-10	19,9	73,4	87,3	5,7	see Top-Off	see Top-Off	87,0	85,8	84,5	83,2	80,7	78,1	75,5	72,9	no fueling	no fueling
-20	19,9	76,3	87,3	5,6	see Top-Off	see Top-Off	86,8	85,6	84,3	83,0	80,4	77,9	75,3	72,7	no fueling	no fueling
-30	19,9	78,8	87,3	5,5	see Top-Off	see Top-Off	86,6	85,3	84,1	82,8	80,2	77,7	75,1	72,6	no fueling	no fueling
-40	19,9	81,1	87,3	5,5	see Top-Off	see Top-Off	86,4	85,2	83,9	82,6	80,0	77,5	75,0	72,5	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

E.2.2 -10 °C Communications Look-Up Tables

Table E7 - H70-T40 CHSS Capacity Category A communications (CD -10 °C)

H70-T40 CHSS Capacity Category A Comm CD -10	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb}[°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	9,0	75,9	87,5	4,7	see Top-Off	see Top-Off	81,2	87,2	86,9	86,5	85,7	84,8	83,7	82,4	80,8	no fueling
45	13,1	72,7	87,5	6,8	see Top-Off	see Top-Off	81,1	87,1	86,7	86,2	85,2	84,0	82,7	81,2	79,4	no fueling
40	17,2	70,0	87,5	8,6	see Top-Off	see Top-Off	81,1	87,0	86,5	85,9	84,6	83,2	81,7	80,0	78,0	no fueling
35	18,0	70,0	87,5	8,8	see Top-Off	see Top-Off	81,2	87,0	86,5	85,9	84,6	83,2	81,6	80,0	78,0	no fueling
30	21,1	69,1	87,4	9,6	see Top-Off	see Top-Off	81,2	87,0	86,3	85,6	84,1	82,6	80,9	79,1	77,0	no fueling
25	24,4	68,4	87,4	10,2	see Top-Off	see Top-Off	81,1	87,0	86,2	85,4	83,7	82,0	80,2	78,2	76,0	no fueling
20	27,8	67,5	87,4	8,4	see Top-Off	see Top-Off	81,2	86,9	86,0	85,1	83,3	81,4	79,4	77,3	74,9	no fueling
10	28,5	73,1	87,4	8,6	see Top-Off	see Top-Off	87,2	86,3	85,4	84,4	82,3	80,3	78,1	75,9	73,3	no fueling
0	28,5	no Top-Off	no Top-Off	no Top-Off	85,5	86,8	86,2	85,1	84,0	82,8	80,5	78,1	75,6	73,0	no fueling	no fueling
-10	28,5	no Top-Off	no Top-Off	no Top-Off	86,9	86,6	86,0	84,9	83,8	82,6	80,3	77,9	75,5	72,9	no fueling	no fueling
-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,4	84,3	83,2	82,1	79,8	77,5	75,2	72,7	no fueling	no fueling
-30	28,5	no Top-Off	no Top-Off	no Top-Off	85,9	85,6	84,9	83,8	82,7	81,5	79,3	77,0	74,8	72,4	no fueling	no fueling
-40	28,5	no Top-Off	no Top-Off	no Top-Off	85,4	85,1	84,4	83,3	82,1	81,0	78,8	76,6	74,4	72,2	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E8 - H70-T30 CHSS Capacity Category A communications (CD -10 °C)

H70-T30 CHSS Capacity Category A Comm CD -10		APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb}[°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	4,7	75,3	87,5	2,2	see Top-Off	see Top-Off	81,2	87,3	87,0	86,6	85,8	84,8	83,7	82,3	80,7	no fueling
	45	7,4	73,3	87,5	3,3	see Top-Off	see Top-Off	81,2	87,2	86,8	86,3	85,3	84,1	82,8	81,2	79,4	no fueling
	40	10,2	70,7	87,5	4,4	see Top-Off	see Top-Off	81,0	87,0	86,5	86,0	84,8	83,3	81,7	80,0	78,0	no fueling
	35	10,6	70,5	87,5	4,5	see Top-Off	see Top-Off	81,1	87,0	86,5	85,9	84,7	83,3	81,7	80,0	77,9	no fueling
	30	12,6	68,8	87,5	5,3	see Top-Off	see Top-Off	81,1	86,9	86,3	85,7	84,3	82,7	81,0	79,1	77,0	no fueling
	25	14,7	67,0	87,5	6,0	see Top-Off	see Top-Off	81,0	86,8	86,1	85,4	83,8	82,1	80,2	78,2	75,9	no fueling
	20	16,8	66,0	87,5	6,7	see Top-Off	see Top-Off	81,2	86,6	85,8	85,0	83,4	81,5	79,5	77,3	74,9	no fueling
	10	20,3	64,6	87,4	7,2	see Top-Off	see Top-Off	81,0	86,4	85,5	84,5	82,6	80,5	78,3	75,9	73,3	no fueling
	0	27,2	62,6	87,4	8,9	see Top-Off	see Top-Off	81,1	86,0	84,8	83,5	81,0	78,5	75,8	73,1	no fueling	no fueling
	-10	28,1	62,7	87,4	9,0	see Top-Off	see Top-Off	81,2	85,9	84,7	83,4	80,9	78,3	75,7	73,0	no fueling	no fueling
	-20	28,5	66,8	87,3	8,9	see Top-Off	see Top-Off	85,7	85,4	84,2	82,9	80,4	77,9	75,3	72,8	no fueling	no fueling
	-30	28,5	71,3	87,3	8,7	see Top-Off	see Top-Off	86,2	84,9	83,6	82,4	79,9	77,4	75,0	72,5	no fueling	no fueling
	-40	28,5	no Top-Off	no Top-Off	no Top-Off	75,5	81,9	85,7	84,4	83,2	81,9	79,4	77,0	74,6	72,3	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E9 - H70-T40 CHSS Capacity Category B communications (CD -10 °C)

H70-T40 CHSS Capacity Category B Comm CD -10		APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	11,1	75,9	87,5	4,1	see Top-Off	see Top-Off	81,2	87,2	86,8	86,5	85,6	84,6	83,4	82,2	80,7	no fueling
	45	15,1	73,1	87,5	5,4	see Top-Off	see Top-Off	81,1	87,1	86,6	86,1	85,0	83,8	82,4	81,0	79,3	no fueling
	40	18,9	70,9	87,4	6,2	see Top-Off	see Top-Off	81,1	87,0	86,4	85,8	84,4	82,9	81,4	79,8	77,9	no fueling
	35	19,4	71,0	87,4	6,2	see Top-Off	see Top-Off	81,2	87,0	86,4	85,8	84,4	82,9	81,4	79,7	77,9	no fueling
	30	22,2	69,8	87,4	6,7	see Top-Off	see Top-Off	81,3	87,0	86,3	85,5	84,0	82,3	80,7	78,9	76,9	no fueling
	25	24,9	68,5	87,4	7,5	see Top-Off	see Top-Off	81,1	87,0	86,1	85,3	83,5	81,8	79,9	78,1	75,9	no fueling
	20	27,7	67,0	87,5	7,4	see Top-Off	see Top-Off	81,1	86,9	86,0	85,0	83,1	81,1	79,2	77,2	74,9	no fueling
	10	28,5	71,0	87,4	7,6	see Top-Off	see Top-Off	86,7	86,4	85,4	84,3	82,2	80,1	78,0	75,8	73,3	no fueling
	0	28,5	no Top-Off	no Top-Off	no Top-Off	81,0	87,2	86,5	85,3	84,1	82,9	80,4	77,9	75,5	73,0	no fueling	no fueling
	-10	28,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,9	75,4	72,9	no fueling	no fueling
	-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,6	75,1	72,7	no fueling	no fueling
	-30	28,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,2	74,9	72,5	no fueling	no fueling
	-40	28,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,0	74,6	72,3	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E10 - H70-T30 CHSS Capacity Category B communications (CD -10 °C)

H70-T30 CHSS Capacity Category B Comm CD -10		APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C]	>50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	4,7	75,3	87,5	2,2	see Top-Off	see Top-Off	81,1	87,4	87,1	86,7	85,7	84,7	83,5	82,2	80,7	no fueling
	45	7,3	73,2	87,5	2,7	see Top-Off	see Top-Off	81,0	87,3	86,9	86,3	85,2	84,0	82,6	81,0	79,3	no fueling
	40	9,9	71,2	87,5	3,5	see Top-Off	see Top-Off	81,3	87,2	86,6	86,0	84,6	83,1	81,5	79,8	77,9	no fueling
	35	10,1	71,1	87,5	3,6	see Top-Off	see Top-Off	81,2	87,1	86,6	86,0	84,6	83,1	81,5	79,8	77,9	no fueling
	30	12,0	69,5	87,5	4,1	see Top-Off	see Top-Off	81,3	87,0	86,4	85,7	84,2	82,5	80,8	79,0	76,9	no fueling
	25	14,0	67,7	87,4	4,6	see Top-Off	see Top-Off	81,2	86,9	86,2	85,4	83,7	81,9	80,1	78,1	75,9	no fueling
	20	15,9	66,1	87,4	5,0	see Top-Off	see Top-Off	81,1	86,8	86,0	85,1	83,3	81,3	79,3	77,2	74,9	no fueling
	10	18,9	64,5	87,3	5,6	see Top-Off	see Top-Off	81,1	86,6	85,6	84,6	82,5	80,4	78,1	75,8	73,3	no fueling
	0	24,9	61,9	87,4	7,4	see Top-Off	see Top-Off	81,1	86,3	85,0	83,7	81,0	78,4	75,7	73,0	no fueling	no fueling
	-10	25,4	61,9	87,4	7,5	see Top-Off	see Top-Off	81,1	86,2	84,9	83,6	81,0	78,3	75,6	73,0	no fueling	no fueling
	-20	27,3	61,9	87,4	7,9	see Top-Off	see Top-Off	81,2	86,1	84,7	83,4	80,7	78,0	75,4	72,8	no fueling	no fueling
	-30	28,5	62,1	87,5	8,2	see Top-Off	see Top-Off	81,3	85,9	84,5	83,2	80,4	77,8	75,2	72,6	no fueling	no fueling
	-40	28,5	62,0	87,5	8,5	see Top-Off	see Top-Off	81,1	85,8	84,4	83,0	80,2	77,6	75,0	72,4	no fueling	no fueling
	<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E11 - H70-T40 CHSS Capacity Category C communications (CD -10 °C)

H70-T40 CHSS Capacity Category C Comm CD -10	APRR [MPa/ min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/ min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	13,2	75,4	87,4	3,4	see Top-Off	see Top-Off	81,3	87,2	86,8	86,4	85,5	84,5	83,3	82,0	80,6	no fueling
45	16,8	72,8	87,4	4,1	see Top-Off	see Top-Off	81,2	87,1	86,6	86,1	84,9	83,6	82,3	80,8	79,3	no fueling
40	19,9	71,4	87,4	4,7	see Top-Off	see Top-Off	81,9	87,0	86,3	85,7	84,3	82,8	81,3	79,6	77,9	no fueling
35	19,9	72,1	87,4	4,8	see Top-Off	see Top-Off	82,6	87,0	86,3	85,6	84,2	82,8	81,2	79,6	77,8	no fueling
30	19,9	76,6	87,3	5,0	see Top-Off	see Top-Off	87,3	86,6	85,9	85,2	83,7	82,1	80,5	78,8	76,9	no fueling
25	19,9	no Top-Off	no Top-Off	no Top-Off	81,4	85,6	87,0	86,3	85,5	84,7	83,1	81,4	79,7	77,9	75,9	no fueling
20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	87,2	86,8	86,0	85,1	84,3	82,5	80,7	78,9	77,0	74,9	no fueling
10	19,9	no Top-Off	no Top-Off	no Top-Off	87,1	86,9	86,3	85,4	84,5	83,6	81,7	79,7	77,7	75,6	73,3	no fueling
0	19,9	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,5	84,4	83,3	82,2	79,9	77,6	75,2	72,8	no fueling	no fueling
-10	19,9	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,5	84,4	83,2	82,1	79,8	77,5	75,2	72,8	no fueling	no fueling
-20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	85,9	85,3	84,2	83,0	81,9	79,6	77,3	75,0	72,6	no fueling	no fueling
-30	19,9	no Top-Off	no Top-Off	no Top-Off	86,0	85,7	85,0	83,9	82,8	81,7	79,4	77,1	74,8	72,4	no fueling	no fueling
-40	19,9	no Top-Off	no Top-Off	no Top-Off	85,8	85,5	84,8	83,7	82,6	81,4	79,2	76,9	74,6	72,3	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Table E12 - H70-T30 CHSS Capacity Category C communications (CD -10 °C)

H70-T30 CHSS Capacity Category C Comm CD -10	APRR [MPa/min]	Target Pressure P_{target} [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
		0,5 - 5 (no interpolation)			0,5	2	5	10	15	20	30	40	50	60	70	>70
Ambient Temperature, T_{amb} [°C] >50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	4,8	75,1	87,5	1,9	see Top-Off	see Top-Off	80,9	87,3	86,9	86,5	85,6	84,6	83,4	82,1	80,6	no fueling
45	7,3	73,2	87,5	2,7	see Top-Off	see Top-Off	81,0	87,2	86,7	86,2	85,1	83,8	82,4	80,9	79,2	no fueling
40	9,9	71,2	87,5	3,5	see Top-Off	see Top-Off	81,3	87,1	86,5	85,9	84,5	83,0	81,4	79,7	77,8	no fueling
35	10,1	71,1	87,5	3,6	see Top-Off	see Top-Off	81,2	87,1	86,5	85,9	84,5	83,0	81,4	79,7	77,8	no fueling
30	12,0	69,5	87,5	4,1	see Top-Off	see Top-Off	81,3	87,0	86,3	85,6	84,0	82,4	80,7	78,8	76,9	no fueling
25	14,0	67,7	87,4	4,6	see Top-Off	see Top-Off	81,2	87,0	86,2	85,3	83,6	81,8	79,9	78,0	75,9	no fueling
20	15,9	66,1	87,4	5,0	see Top-Off	see Top-Off	81,1	86,9	86,0	85,1	83,2	81,2	79,2	77,1	74,9	no fueling
10	18,9	64,4	87,3	5,6	see Top-Off	see Top-Off	81,1	86,8	85,7	84,6	82,5	80,3	78,0	75,8	73,3	no fueling
0	19,9	72,5	87,3	5,7	see Top-Off	see Top-Off	87,1	85,9	84,6	83,3	80,7	78,1	75,6	72,9	no fueling	no fueling
-10	19,9	73,4	87,3	5,7	see Top-Off	see Top-Off	87,0	85,8	84,5	83,2	80,7	78,1	75,5	72,9	no fueling	no fueling
-20	19,9	76,3	87,3	5,6	see Top-Off	see Top-Off	86,8	85,6	84,3	83,0	80,4	77,9	75,3	72,7	no fueling	no fueling
-30	19,9	78,8	87,3	5,5	see Top-Off	see Top-Off	86,6	85,3	84,1	82,8	80,2	77,7	75,1	72,6	no fueling	no fueling
-40	19,9	81,1	87,3	5,5	see Top-Off	see Top-Off	86,4	85,2	83,9	82,6	80,0	77,5	75,0	72,5	no fueling	no fueling
<-40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

APPENDIX F - DISPENSER FUEL DELIVERY TEMPERATURE AND CONTROL SPECIFICATION

F.1 DISPENSER FUEL DELIVERY TEMPERATURE AND COMMUNICATIONS SPECIFICATION

Fueling dispenser flow restriction shall be upstream of vehicle interface. Fueling dispenser shall be capable of setting the temperature of the fuel delivery temperature hydrogen gas at the break-away consistent with the fueling protocol.

Installation of fuel delivery temperature equipment shall be downstream of the smallest flow restriction in the complete fueling path. Otherwise, the Joule-Thomson effect will lead to a significant temperature increase of the hydrogen gas delivered to the vehicle, thereby making the fuel delivery temperature less effective.

If a station has communications fueling capability, the fueling dispenser shall be capable of fueling vehicles with and without communications between the vehicle and dispenser.

F.2 PRESSURE CONTROL

The fueling station shall execute three levels of pressure control; see Table F1 for pressure levels and fault management.

- 1st Level (normal control process): Terminate fueling when target pressure (from SAE J2601 tables) is reached.
- 2nd Level (principal fault management: redundant electronic protection level): Terminate fueling when 125% NWP (87.5 MPa for a 70 MPa dispenser; 43.8 MPa for a 35 MPa dispenser) is reached.
- 3rd Level (secondary fault management: fully mechanical protection level): When fueling station PRV set point is reached. The PRV set point should be no greater than 1.25*NWP +10% = 1.375*NWP (96.25 MPa for a 70 MPa dispenser and 48.13 MPa for a 35 MPa dispenser).

Table F1 - Pressure levels and fault management from SAE J2579

Pressure Vessel Terminology	**Terminology Used in SAE J2579 to “Bridge the Gap”**	**Container Terminology**
Secondary Relief Fault Management (less than 1.2 x MAWP)	← Maximum Developed Pressure (MDP)	
Primary Relief Fault Management (less than 1.1 x MAWP)	MDP for Fueling Station Faults →	1.5 x NWP (or SP)
MAWP Relief Device Set point	← Maximum Allowable Working Pressure Initiation of Fault Management by Relief Device(s) (Relief Device Set point) →	1.38 x NWP (or SP) (Fill station fueling relief valve set point)
Maximum Operating Pressure (MOP)	← Maximum Operating Pressure (MOP) Initiation of Fault Management by Dispenser →	1.25 X NWP (or SP) (Principal fault protection during fueling)
	Nominal Working Pressure (NWP) →	Service pressure (SP) or working pressure

F.3 ASSUMPTIONS FOR SAE J2601 DISPENSER CONTROL

The following are dispenser control guideline assumptions for SAE J2601 to maintain fueling protocols.

1. Validated to SAE J2601, in accordance with CSA HGV 4.3, or equivalent, to ensure proper execution of fill;

2. Fuel delivery temperature measurement, ambient temperature measurement and station pressure measurement meet the requirements in 6.2; and

3. Has a ("watch-dog") monitoring timer or equivalent (to ensure that the controller is executing and not hung-up) then the above is adequate fault detection/management to ensure safety of the fueling process.

APPENDIX G - INTERPOLATION OF TABLES - EXAMPLES

G.1 CONVENTIONAL INTERPOLATION (CHSS CAPACITY CATEGORY IS DETERMINED)

Linear interpolation shall be used to derive actual parameters from table values. This will be one-dimensional interpolation for the $APRR_{actual}$ (based on ambient temperature; see Figure G1) and two-dimensional interpolation for the target pressure (based on ambient temperature and initial CHSS pressure; see Figure G2). Note: If one of the interpolation values is in the "no fueling" zone of the table, then the dispenser should not fuel the vehicle.

EXAMPLE A: Interpolate average pressure ramp rate at 18 °C ambient temperature.

The ambient temperature measured from the station is used to linear interpolate an average pressure ramp rate (see Figure G1).

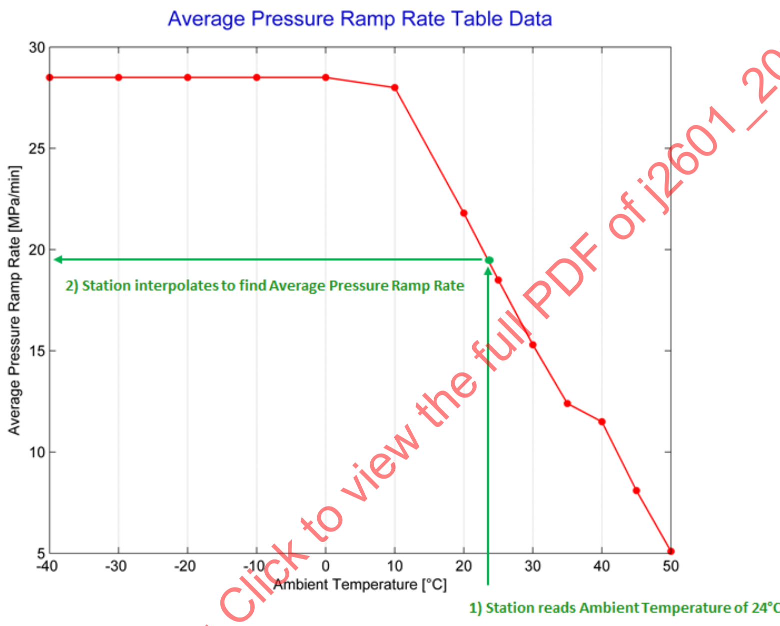

Figure G1 - Interpolation of average pressure ramp rate and ambient temperature

EXAMPLE B: Interpolate fueling target pressure at an Initial CHSS Pressure of 35 MPa. Note that the example table below uses the international format for commas and periods (the U.S. format is the opposite).

Using the tables - target pressure example:

H70-T40 4-7kg non-comm		Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure, P_{target} [MPa] (1)											
			Initial Tank Pressure, P_0 [MPa]											
			0,5	2	5	10	15	20	30	40	50	60	70	> 70
Ambient Temperature, T_{amb} [°C]	> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	5,1	77,8	77,6	77,3	76,9	76,6	76,2	75,7	75,3	74,7	73,9	72,8	no fueling
	45	8,1	76,3	77,2	76,9	76,5	76,4	76,2	75,6	75,3	74,7	73,9	72,7	no fueling
	40	11,5	73,2	75,6	76,8	76,3	76,4	76,2	75,6	75,3	74,6	73,9	72,7	no fueling
	35	12,4	72,9	75,3	76,4	76,0	76,1	75,9	75,3	75,1	74,5	73,8	72,7	no fueling
	30	15,3	70,6	73,9	75,8	75,2	75,4	75,1	74,3	74,1	73,3	72,4	71,3	no fueling
	25	18,5	69,0	72,8	75,1	74,5	74,7	74,3	73,3	73,0	72,0	71,1	no fueling	no fueling
(1)	20	21,8	67,9	72,1	74,5	73,7	74,0	(2)	72,2	71,9	(3)	69,7	no fueling	no fueling
	10	28,0	66,3	71,1	74,1	73,2	72,4		70,9	69,6		66,9	no fueling	no fueling
	0	28,5	74,0	73,4	72,4	70,6	70,7	69,6	68,6	67,1	65,7	64,0	no fueling	no fueling
	-10	28,5	73,4	72,9	71,9	70,0	70,0	68,4	66,5	64,4	62,9	61,2	no fueling	no fueling
	-20	28,5	72,9	72,3	71,3	71,0	69,5	68,0	65,7	62,4	60,0	no fueling	no fueling	no fueling
	-30	28,5	72,1	71,6	70,6	70,4	69,0	67,4	65,2	61,8	58,7	no fueling	no fueling	no fueling
	-40	28,5	71,6	71,1	70,2	70,0	68,5	66,9	64,8	61,5	58,5	no fueling	no fueling	no fueling
	< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Figure G2 - H70-T40, 7 to 10 kg non-comm table example

Steps:

1. Interpolate engulfing points in table for boundary conditions:

   - For Ambient Temperature of 18 °C: 10 °C and 20 °C

   - For Initial CHSS Pressure of 35 MPa: 30 MPa and 40 MPa

2. Interpolate linear between fueling target pressure values for the **first** initial CHSS pressure support point (30 MPa) and the two ambient temperature support points: $P_{target2}$ = 70,9 MPa + (72,2 MPa - 70,9 MPa) * (18 °C - 10 °C)/(20 °C - 10 °C) = 71,94 MPa

3. Interpolate linear between fueling target pressure values for the **second** initial CHSS pressure support point (40 MPa) and the two ambient temperature support points: $P_{target3}$ = 69,6 MPa + (71,9 MPa - 69,6 MPa) * (18 °C - 10 °C)/(20 °C - 10 °C) = 71,44 MPa

4. Interpolate linear between interim fueling target pressure values from (2) and (3) using the initial CHSS pressure support points: **Fueling Target Pressure** = 71,94 + (71,44 MPa - 71,94 MPa) * (35 MPa - 30 MPa)/(40 MPa - 30 MPa) = 71,69 MPa ≈ **71,7 MPa**

EXAMPLE C: Interpolate Top-Off Average Pressure Ramp Rate

For ambient temperatures where top-off is available in the tables and the initial CHSS pressure is between 0.5 MPa and 5 MPa, do the interpolation as described in Figure G1. Use the average pressure ramp rates for the first part of the fueling (standard fueling) and interpolate the top-off-APRR for the second part of the fueling (top-off fueling) in the same way using the top-off-APRR values (see values framed in red in Figure G3). Note that the example in Figure G3 uses the international format for commas and periods (the U.S. format is the opposite).

For conditions where the fueling table does not provide clear instructions, such as in Figure G3, 15 °C T_{amb} and 1 MPa P_0, the dispenser should utilize the values for the next warmest explicitly described conditions; i.e., use 20 °C T_{amb} and 1 MPa P_0.

H70-T40 7-10kg comm	Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure Ptarget [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation allowed)			0,5	2	5	10	15	20	30	40	50	60	70	> 70
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,6	77,9	87,5	2,8	see Top-Off	see Top-Off	81,1	86,2	86,9	86,6	85,8	84,9	83,8	82,6	81,0	no fueling
45	11,0	75,8	87,5	3,8	see Top-Off	see Top-Off	81,4	87,0	86,7	86,2	85,2	84,1	82,8	81,4	79,6	no fueling
40	14,5	72,8	87,4	4,5	see Top-Off	see Top-Off	81,2	87,0	86,4	85,9	84,6	83,3	81,8	80,2	78,2	no fueling
35	15,3	72,2	87,4	4,6	see Top-Off	see Top-Off	81,1	87,0	86,4	85,9	84,6	83,2	81,7	80,1	78,2	no fueling
30	17,9	70,5	87,4	5,0	see Top-Off	see Top-Off	81,1	86,9	86,3	85,6	84,2	82,6	81,0	79,2	77,2	no fueling
25	19,9	71,1	87,3	5,4	see Top-Off	see Top-Off	83,2	86,8	86,0	85,3	83,7	82,0	80,2	78,3	no fueling	no fueling
20	19,9	77,4	87,3	5,6	see Top-Off	see Top-Off	87,1	86,4	85,5	84,7	83,0	81,2	79,3	77,4	no fueling	no fueling
10	19,9	no Top-Off	no Top-Off	no Top-Off	87,3	87,1	86,6	85,7	84,8	83,9	82,0	80,0	78,0	75,9	no fueling	no fueling
0	19,9	no Top-Off	no Top-Off	no Top-Off	86,6	86,3	85,7	84,6	83,4	82,3	80,0	77,7	75,4	72,9	no fueling	no fueling
-10	19,9	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,5	84,4	83,2	82,1	79,8	77,5	75,2	72,8	no fueling	no fueling
-20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	85,9	85,3	84,2	83,0	81,9	79,6	77,3	75,0	no fueling	no fueling	no fueling
-30	19,9	no Top-Off	no Top-Off	no Top-Off	86,0	85,7	85,0	83,9	82,8	81,7	79,4	77,1	74,8	no fueling	no fueling	no fueling
-40	19,9	no Top-Off	no Top-Off	no Top-Off	85,8	85,5	84,8	83,7	82,6	81,4	79,2	76,9	74,6	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Figure G3 - H70-T40, 7 to 10 kg comm table example

EXAMPLE D: Interpolate Fueling Target Pressure at an Initial CHSS Pressure of 35 MPa

For ambient temperatures where top-off is available in the tables and the initial CHSS pressure is between 0.5 MPa and 5 MPa, interpolate the target pressure linear between the support points for ambient temperature for the first part of the fueling (standard fueling) and interpolate the target pressure top-off for the second part of the fueling (top-off fueling) in the same way using the target pressure top-off values (see values framed in red in Figure G4).

H70-T40 7-10kg comm	Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure Ptarget [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
		Initial Tank Pressure, P_0 [MPa]														
Ambient Temperature, T_{amb} [°C]		0,5 - 5 (no interpolation allowed)			0,5	2	5	10	15	20	30	40	50	60	70	> 70
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	7,6	77,9	87,5	2,8	see Top-Off	see Top-Off	81,1	86,2	86,9	86,6	85,8	84,9	83,8	82,6	81,0	no fueling
45	11,0	75,8	87,5	3,8	see Top-Off	see Top-Off	81,4	87,0	86,7	86,2	85,2	84,1	82,8	81,4	79,6	no fueling
40	14,5	72,8	87,4	4,5	see Top-Off	see Top-Off	81,2	87,0	86,4	85,9	84,6	83,3	81,8	80,2	78,2	no fueling
35	15,3	72,2	87,4	4,6	see Top-Off	see Top-Off	81,1	87,0	86,4	85,9	84,6	83,2	81,7	80,1	78,2	no fueling
30	17,9	70,5	87,4	5,0	see Top-Off	see Top-Off	81,1	86,9	86,3	85,6	84,2	82,6	81,0	79,2	77,2	no fueling
25	19,9	71,1	87,3	5,4	see Top-Off	see Top-Off	83,2	86,8	86,0	85,3	83,7	82,0	80,2	78,3	no fueling	no fueling
20	19,9	77,4	87,3	5,6	see Top-Off	see Top-Off	87,1	86,4	85,5	84,7	83,0	81,2	79,3	77,4	no fueling	no fueling
10	19,9	no Top-Off	no Top-Off	no Top-Off	87,3	87,1	86,6	85,7	84,8	83,9	82,0	80,0	78,0	75,9	no fueling	no fueling
0	19,9	no Top-Off	no Top-Off	no Top-Off	86,6	86,3	85,7	84,6	83,4	82,3	80,0	77,7	75,4	72,9	no fueling	no fueling
-10	19,9	no Top-Off	no Top-Off	no Top-Off	86,4	86,1	85,5	84,4	83,2	82,1	79,8	77,5	75,2	72,8	no fueling	no fueling
-20	19,9	no Top-Off	no Top-Off	no Top-Off	86,2	85,9	85,3	84,2	83,0	81,9	79,6	77,3	75,0	no fueling	no fueling	no fueling
-30	19,9	no Top-Off	no Top-Off	no Top-Off	86,0	85,7	85,0	83,9	82,8	81,7	79,4	77,1	74,8	no fueling	no fueling	no fueling
-40	19,9	no Top-Off	no Top-Off	no Top-Off	85,8	85,5	84,8	83,7	82,6	81,4	79,2	76,9	74,6	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

Figure G4 - H70-T40, 7 to 10 kg comm table example

Interpolation is not allowed in Initial CHSS pressure direction for initial CHSS pressures between 0.5 MPa and 5 MPa and for ambient temperatures which show values for top-off fueling.

It shall be used the same way as described in EXAMPLE B for higher initial CHSS pressures at these top-off indicating ambient temperatures or for ambient temperatures where no top-off is allowed.

For ambient temperatures, e.g., 18 °C in Figure G4, where at least one interpolation point for fueling target pressure states "no top-off," no top-off shall be applied and the fueling target pressure interpolation shall be used following EXAMPLE B, applying the target pressure, e.g., 77,4 MPa at 20 °C ambient temperature for 0,5 to 5 MPa initial pressure as one or two of the interpolation support points to calculate $P_{target2}$ and $P_{target3}$ (described in EXAMPLE B).

G.2 INTERPOLATION WHEN CHSS CAPACITY CATEGORY IS INDETERMINATE (CONSERVATIVE APPROACH)

Given the starting conditions (ambient temperature, vehicle start pressure and the anticipated temperature window for the refueling), the APRR and target pressure is identified according to each of the three applicable tables for CHSS Capacity Categories A, B, and C. Of these three values, the lowest (slowest pressure ramp rate and lowest target pressures) shall be used for the fueling.

NOTE: The APRR and target pressure chosen will not necessarily come from the same table.

An example is worked through below:

Step 1		
Identify initial conditions for fueling.		
Initial Conditions		
Initial Pressure	5.5	MPa
Ambient Temp.	15	°C
Pre-cooling	T40	
IR Com?	No	
Pressure Rating	H70	
Volume	Unknown	

Step 2

Select relevant tables for these initial conditions.

D19 - H70-T40, 2-4 kg, noncom

T_amb [°C]	APRR [MPa/min]	Target Pressure [MPa]			
		Initial Pressure [MPa]			
		...	5	10	...
...	...	...	...	...	...
20	19.3	...	74.0	73.1	...
10	27.0	...	73.1	71.7	...
...	...	...	...	...	...

D25 - H70-T40, 4-7 kg, noncom

T_amb [°C]	APRR [MPa/min]	Target Pressure [MPa]			
		Initial Pressure [MPa]			
		...	5	10	...
...	...	...	...	...	...
20	21.8	...	74.5	73.7	...
10	28.0	...	74.1	73.2	...
...	...	...	...	...	...

D31 - H70-T40, 7-10 kg, noncom

T_amb [°C]	APRR [MPa/min]	Target Pressure [MPa]			
		Initial Pressure [MPa]			
		...	5	10	...
...	...	...	...	...	...
20	19.9	...	75.0	74.1	...
10	19.9	...	73.1	72.0	...
...	...	...	...	...	...

Step 3

Perform interpolation of Table values within the table they came from.

Table D19 - Interpolated values

APRR	23,150	MPa/ min
P_Target	73,435	MPa

Table D25 - Interpolated values

APRR	24,900	MPa/ min
P_Target	74,215	MPa

Table D31 - Interpolated values

APRR	19,900	MPa/ min
P_Target	73,950	MPa

Step 4

Select most conservative values.

Final Values used as Fueling Parameters

APRR	19,900	MPa/min	*from*	*Table D31 Interpolated values*
P_Target	73,435	MPa	*from*	*Table D19 Interpolated values*

Figure G5 - Example of steps to determine conservative APRR and pressure targets

G.2.1 Communications Loss During Fueling Using the Conservative Approach

Follow the Steps 1 through 4 in Figure G5 for a fueling with communications, then at the point when the communications between the vehicle and station are lost, use the same information (ambient temperature and start pressure) to determine the equivalent values for a non-comms fueling.

NOTE: The most conservative value may not necessarily come from the same table for non-comms fueling as for comms fueling.

As an example, for the initial conditions for an H70-T40 fueling:

- Ambient temp = 30 °C
- Start pressure = 30 MPa

Conservative APRR is 12.5 MPa/min

(from the 2 to 4 kg table, instead of 15.3 MPa/min from the 4 to 7 kg table or 17.9 MPa/min from the 7 to 10 kg table)

Conservative Comms target pressure = 84.2 MPa

(from the 7 to 10 kg table - instead of 84.5 MPa from the 2 to 4 kg table or 84.3 MPa from the 4 to 7 kg table)

=> loss of Comms =>

Conservative APRR remains as 12.5 MPa/min

(from the 2 to 4 kg table, instead of 15.3 MPa/min from the 4 to 7 kg table or 17.9 MPa/min from the 7 to 10 kg table)

Conservative Non-comms target pressure = 73.9 MPa

(from the 2 to 4 kg table - instead of 74.3 MPa from the 4 to 7 kg table or 74.5 MPa from the 7 to 10 kg table)

G.2.2 Temperature Fallback During Fueling Using the Conservative Approach

Follow the Steps 1 through 4 above for a fueling with the expected temperature window, then at the point when the temperature falls outside of the appropriate window, use the same information (ambient temperature and start pressure) to determine the equivalent values for a fueling under the new pre-cooling conditions.

NOTE: The most conservative value may not necessarily come from the same table for the different pre-cooling conditions. Also, note that this does not apply for non-comms fueling, which cannot "fallback."

As an example, for the initial conditions for an H70-T40 fueling:

- Ambient temp = 30 °C
- Start pressure = 30 MPa

Conservative T40 APRR is 12.5 MPa/min

(from the 2 to 4 kg table, instead of 15.3 MPa/min from the 4 to 7 kg table or 17.9 MPa/min from the 7 to 10 kg table)

Conservative T40 target pressure = 84.2 MPa

(from the 7 to 10 kg table - instead of 84.5 MPa from the 2 to 4 kg table or 84.3 MPa from the 4 to 7 kg table)

=> reduction in T_{fuel} => T30 tables (Comms)

Conservative T30 APRR is now 8.7 MPa/min

(from the 2 to 4 kg table, instead of 8.8 MPa/min from the 4 to 7 kg table or 9.3 MPa/min from the 7 to 10 kg table)

Conservative T30 target pressure = 84.3 MPa

(from the 7 to 10 kg table - instead of 84.7 MPa from the 2 to 4 kg table or 84.5 MPa from the 4 to 7 kg table)

Therefore, the conservative FPRR target = (84.3 MPa - P1)/[1/(8.7 * (84.3 - 30) - $t_{station\ fallback}$)]

G.2.3 Top-Off During Fueling Using the Conservative Approach

Follow the Steps 1 through 4 above for a fueling up to the top-off point, then at the point when top-off is applicable, use the same information (ambient temperature) to determine the equivalent values for the top-off fueling.

NOTE: The most conservative value may not necessarily come from the same table for before and after top-off. Also, note that this does not apply for non-comms fueling, which cannot “top-off.”

As an example, for the initial conditions for an H70-T40 fueling:

- Ambient temp = 30 °C
- Start pressure = 3 MPa

Conservative APRR is 12.5 MPa/min

(from the 2 to 4 kg table, instead of 15.3 MPa/min from the 4 to 7 kg table or 17.9 MPa/min from the 7 to 10 kg table)

Conservative comms target pressure (before top-off) = 69.1 MPa

(from the 2 to 4 kg table - instead of 70.6 MPa from the 4 to 7 kg table or 70.5 MPa from the 7 to 10 kg table)

=> TopOff =>

Conservative top-off APRR is 5.0 MPa/min

(from the 7 to 10 kg table, instead of 7.8 MPa/min from the 2 to 4 kg table or 6.6 MPa/min from the 4 to 7 kg table),

Top-off target pressure = 87.4 MPa

(from the 7 to 10 kg table, instead of 87.5 MPa from the 2 to 4 kg and 4 to 7 kg tables)

G.2.4 Additional Examples - APRR

Table G1 includes an example of APRRs for demonstrating selection of the "conservative" APRR from the ambient temperature:

Table G1 - Table of conservative APRR

APRR 70 MPa, T40			
Ambient Temperature, T_{amb} [°C]	2 to 4 kg Category	4 to 7 kg Category	7 to 10 kg Category
50	3.2	5.1	7.6
45	5.8	8.1	11.0
40	8.6	11.5	14.5
35	9.7	12.4	15.3
30	12.5	15.3	17.9
25	15.7	18.5	19.9
20	19.3	21.8	19.9
10	27.0	28.0	19.9
0	28.5	28.5	19.9
-10	28.5	28.5	19.9
-20	28.5	28.5	19.9
-30	28.5	28.5	19.9
-40	28.5	28.5	19.9

If the ambient temperature is 20 °C, the lowest value shall be selected; that of the 2 to 4 kg category: 19.3 MPa/min.

If the ambient temperature is 10 °C, the lowest value shall be selected; that of the 7 to 10 kg category: 19.9 MPa/min.

When interpolating between values, for instance if the ambient temperature is 15 °C, the value should be chosen from the lowest of the three: 23.15 MPa/min (2 to 4 kg category), 24.9 MPa/min (4 to 7 kg category), and 19.9 MPa/min (7 to 10 kg category); therefore, the value 19.9 MPa/min is chosen from the 7 to 10 kg category table.

If, however, the ambient temperature is 19.5 °C, the value should be chosen from the lowest of the three: 19.685 MPa/min (2 to 4 kg category), 22.11 MPa/min (4 to 7 kg category), and 19.9 MPa/min (7 to 10 kg category); therefore, the value 19.685 MPa/min is chosen from the 2 to 4 kg category table.

G.2.5 Additional Examples - Target Pressure

Table G2 includes an example for selection, by interpolation, of the "conservative" target pressures from the ambient temperature and vehicle start pressure:

Table G2 - Truncated table of conservative target pressures

APRR 70 MPa, T40									
	2 to 4 kg Category			4 to 7 kg Category			7 to 10 kg Category		
Vehicle start pressure:	10 MPa	15 MPa	20 MPa	10 MPa	15 MPa	20 MPa	10 MPa	15 MPa	20 MPa
Ambient Temperature, T_{amb} [°C]									
…									
35	86.8	86.4	86.0	86.9	86.4	85.9	87.0	86.4	85.9
30	86.8	86.3	85.7	86.8	86.3	85.6	86.9	86.3	85.6
…									

If the ambient temperature is 35 °C and the vehicle start pressure is 10 MPa, the lowest value shall be selected; that of the 2 to 4 kg category: 86.8 MPa.

If the ambient temperature is 30 °C and the vehicle start pressure is 20 MPa, the lowest value shall be selected; that of either the 4 to 7 kg or 7 to 10 kg category: 85.6 MPa.

If the ambient temperature is 32.5 °C and the vehicle start pressure is 12.5 MPa, the target pressure value should be chosen from the lowest of the 3: 86.583 MPa (2 to 4 kg category), 86.598 (4 to 7 kg category) and 86.645 (7 to 10 kg category); therefore, the value 86.583 MPa is chosen from the 2 to 4 kg category table.

If, however, the ambient temperature is 32.5 °C and the vehicle start pressure is 17.5 MPa, the target pressure value should be chosen from the lowest of the 3: 86.107 MPa (2 to 4 kg category), 86.043 (4 to 7 kg category) and 86.038 (7 to 10 kg category); therefore, the value 86.038 MPa is chosen from the 7 to 10 kg category table.

(The accompanying APRR would be 11.07 MPa/min in both of the latter two cases.)

APPENDIX H - MC FORMULA-BASED FUELING PROTOCOL RATIONALE AND DEVELOPMENT PROCESS

H.1 INTRODUCTION

The MC Formula-based fueling protocol described in Section 9 is an adaptive fueling protocol, which dynamically adjusts the rate of change in dispenser pressure and the end of fill target pressure, based on inputs which are measured by the dispenser, namely the ambient temperature, the initial gas pressure in the CHSS, mass flow and the measured gas pressure and temperature at the dispenser outlet. Like the table-based protocol described in Section 8, the MC Formula-based protocol utilizes initial conditions measured by the dispenser to calculate the appropriate pressure ramp rate and ending pressure target. However, unlike the table-based protocol which utilizes these parameters throughout the fill, the MC Formula-based protocol utilizes these fixed parameters only for the first 30 seconds of the fill, after which they are calculated and updated at a frequency of once every second for the remainder of the fill.

The MC Formula-based protocol follows the operating boundaries (Section 5), process requirements (Section 6), and key modeling assumptions (Section 7). Similar to the table-based protocol, the MC Formula-based protocol was developed using computer modeling. The same fueling model described in A.1 was used in deriving the coefficients and parameters for the equations which dictate the overall fueling time, the instantaneous pressure ramp rate and the ending pressure target. Likewise, the same general assumptions (A.2), and hot case and cold case assumptions (A.3) are utilized in the MC Formula-based protocol.

The structure of the MC Formula-based protocol is divided into two parts - pressure ramp rate control, and ending pressure control. The pressure ramp rate control dictates the instantaneous pressure ramp rate (PRR) and is based off the hot case assumptions. It is based on a regression equation which defines the amount of time (t_{final}) required to fill from the minimum pressure (P_{min}) to the final pressure (P_{final}) without exceeding the gas temperature limit of 85 °C within the hot case CHSS. The regression equation for t_{final} is a cubic polynomial based on the mass average of the fuel delivery temperature (T_{fuel}). The coefficients for this cubic equation are calculated for discrete ambient temperatures, resulting in a table of coefficients, which are looked up. t_{final} is the control input parameter to a pressure ramp rate equation, which dictates the instantaneous pressure ramp rate and the control pressure the dispenser should follow.

The ending pressure control is calculated separately from the pressure ramp rate control and dictates the station pressure at which the fill should end. The ending pressure control utilizes the cold case assumptions, just like the table-based protocol. There are two options for ending pressure control: the MC Method or ending pressure tables.

The first option is based on a methodology called the MC Method which calculates the end of fill gas temperature within the CHSS based on the initial CHSS pressure and CHSS gas temperature in combination with the measured enthalpy of the dispenser and elapsed fueling time. Because of the cold case assumptions, this end of fill gas temperature is the coldest expected temperature. The end of fill gas temperature is then used to calculate a pressure target which ensures the fill stops at the appropriate density. The MC Method is a lumped heat capacity model where MC represents the combined heat mass of the control volume and is denoted in units of kJ/K. The M and the C in the name are derived from the concept of mass times specific heat capacity.

The second option for ending pressure control is a set of lookup tables providing non-communication fueling pressure targets, and communication fueling pressure limits. These lookup tables function the same way as those utilized in the table-based protocol. However, the determination of which ending pressure table to be used is based on the mass average of the fuel delivery temperature, which is updated continuously throughout the fill.

The dispenser manufacturer should choose one or the other of these two ending pressure control options.

H.2 PRESSURE RAMP RATE CONTROL

Sections A.1 through A.3 should be referenced for an understanding of the computer model, assumptions and boundary conditions utilized in the derivation of the t_{final} cubic equation coefficients. This section will describe the simulations conducted, the derivation of the coefficients, and how the coefficients are utilized in the MC Formula-based protocol for pressure ramp rate control.

H.2.1 Constant Pressure Ramp Rate Simulations

The t_{final} cubic equation coefficients are derived from a series of fueling simulations conducted at a constant pressure ramp rate. Pressure ramp rates are generally designed to avoid overheating a CHSS under worst-case conditions. These worst-case conditions for overheating are collected in the set of hot case assumptions. The simulation runs for determining the highest pressure ramp rate that will still not overheat the CHSS therefore use hot case parameters, initial and boundary conditions. Figure H1 illustrates a H70 fueling simulation in a pressure-temperature state diagram for an exemplary ambient temperature 0 °C. The CHSS temperature is initialized at the hot soak temperature 15 °C. During fueling, there is a rapid temperature increase inside the CHSS at the beginning; later the slope of the fueling curve becomes steeper because the pressure increase dominates over the temperature increase. The simulation stops whenever the CHSS is “full” (97% SOC) or reaches the upper temperature limit 85 °C. During the simulation, the pressure ramp rate at the station is held constant. The procedure of computing the optimal pressure ramp rate that fulfills both SOC and temperature conditions at the end is an iterative process. It requires a number of fueling simulations with different pressure ramp rates to find the optimal ramp rate. There is a third condition to be fulfilled by the optimal ramp rate: the peak flow rate which may occur at any time during the fueling simulation shall not exceed 60 g/s. This is illustrated in Figure H2. If it does, the pressure ramp rate must be decreased, automatically decreasing the peak flow rate. Therefore, the resulting pressure ramp rate will generally satisfy only one of the conditions: (a) the final gas temperature reaches 85 °C (this typically occurs for high ambient temperatures and small CHSSs), or (b) the peak flow rate reaches 60 g/s (this typically occurs for cold ambient conditions and large CHSSs). The final SOC however is always 97%. Note that the SOC target 97% is a tradeoff to increase the resulting pressure ramp rate (and decrease the fueling time).

A second tradeoff was made in order to generate higher pressure ramp rates; two sets of coefficients were derived: one with an initial CHSS pressure of 5 MPa, and another with an initial CHSS pressure of 0.5 MPa. The end of fill gas temperature is strongly a function of the initial gas pressure; higher initial pressures result in lower ending gas temperatures. Thus, the coefficients derived for an initial CHSS pressure of 5 MPa result in a reduction of the fueling time over those derived with an initial CHSS pressure of 0.5 MPa. The justification for utilizing two sets of coefficients based on the initial CHSS pressure is that the majority of fills are initiated with an initial CHSS pressure higher than 5 MPa. For the small fraction of fills initiated at an initial CHSS pressure below 5 MPa, to avoid overheating, a separate set of coefficients are utilized. This approach is similar to that employed for the table-based protocol (see A.4) where, instead of utilizing two sets of APRRs, a pressure target in combination with a significantly reduced top-off pressure ramp rate is utilized. The top-off pressure ramp rate approach could not be utilized with the MC Formula-based protocol because it is based on a known APRR, whereas the PRR for the MC Formula-based protocol is variable. The end result is essentially the same, however, in that the overall fueling time is reduced for fills initiated with a CHSS pressure below 5 MPa.

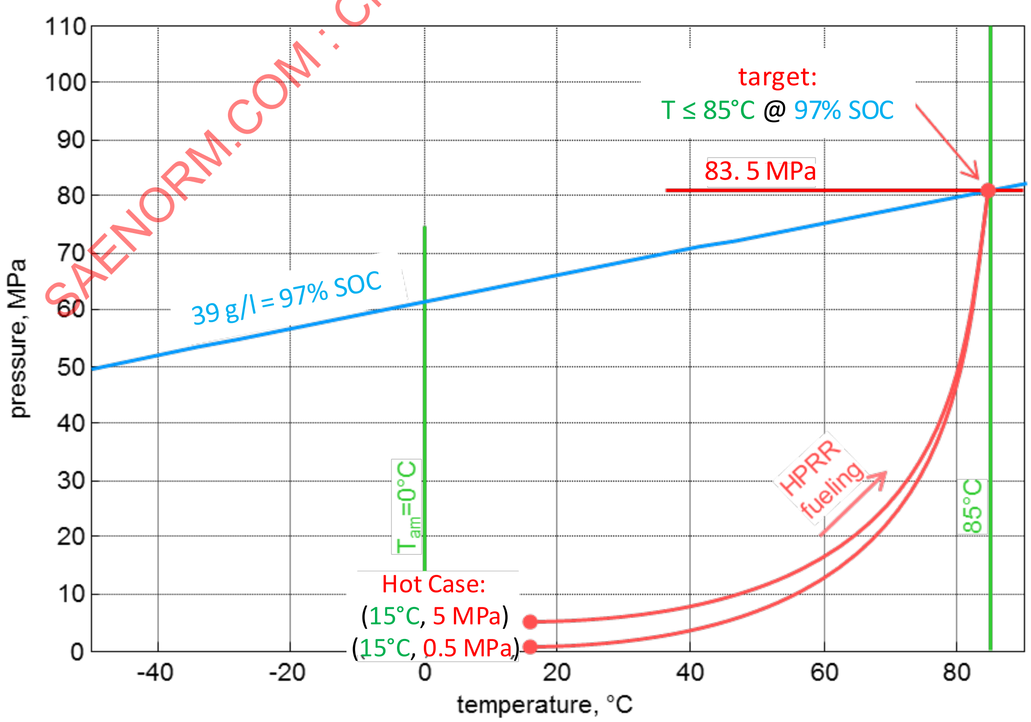

Figure H1 - Step 1 - Pressure ramp rate simulation

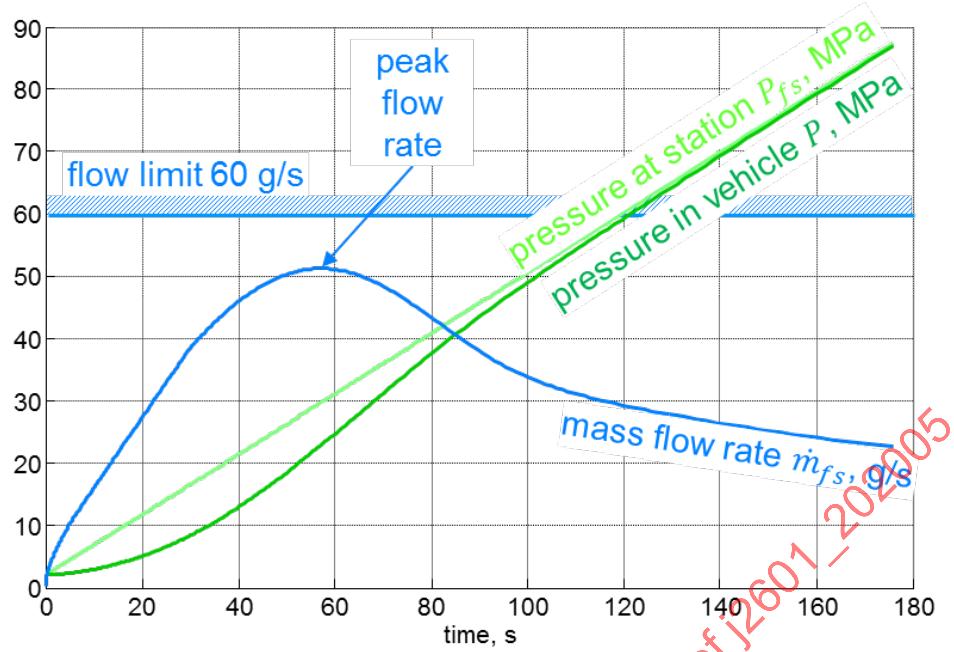

Figure H2 - Typical pressure and mass flow development

Simulations were conducted under hot case conditions on the four boundary single vessel H70 spec CHSS: 49.7 L (2 kg), 99.4 L (4 kg), 174.0 L (7 kg), and 248.6 L (10 kg) (see Table A3). A separate set of simulations for the H35 pressure class were not conducted, as the coefficients utilized for H35 and H70 are the same. This is done to account for potential historical fueling where a fill is conducted first at an H35 dispenser and then immediately followed by a completion of the fill at an H70 dispenser. Each fueling simulation was run with the fuel delivery temperature starting at ambient temperature and then declining linearly over a 30 second period to a predetermined fuel delivery temperature, which is then held constant for the remainder of the fill.

Fueling simulations were conducted at the ambient temperatures, fuel delivery temperatures, and initial CHSS pressures listed in Table H1.

Table H1 - Matrix of fueling simulation conditions

T_{amb} (°C/K)	Fuel Delivery Temperature					
	-40 °C	-35 °C	-30 °C	-25 °C	-20 °C	-15 °C
	$P_{initial}$ (MPa)	$P_{initial}$ (MPa)	$P_{initial}$ (MPa)	$P_{initial}$ (MPa)	$P_{initial}$ (MPa)	$P_{initial}$ (MPa)
50/323.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
45/318.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
40/313.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
35/308.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
30/303.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
25/298.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
20/293.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
15/288.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
10/283.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
5/278.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
0/273.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
-10/263.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
-20/253.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
-30/243.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)
-40/233.15	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)	(0.5, 5)

The output for each of the simulation conditions listed in Table H1 was the fueling time t_{final}, defined as the time required to fill the CHSS from initial CHSS pressure of $P_{initial}$ to the pressure P_{final} of 83.5 MPa, as well as the mass average of the fuel delivery temperature over this time period, referred to as MAT (see Equation H1, where j represents a time step of 1 second). For each ambient temperature and initial CHSS pressure, t_{final} is plotted against MAT and then a regression best fit approach is utilized to derive a set of coefficients for the t_{final} cubic equation, a, b, c, and d (see Equation H2). This approach is illustrated in Figure H3. Those simulations where the pressure ramp rate was constrained by the limitation of peak flow rate not exceeding 60 g/s were not utilized in the regression fit.

$$MAT = \frac{\sum_0^j[(m_{(j)}-m_{(j-1)})\times 0.5(T_{fuel(j)}+T_{fuel(j-1)})]}{\sum_0^j(m_{(j)}-m_{(j-1)})} \quad \text{(Eq. H1)}$$

$$t_{final} = a\times MAT^3 + b\times MAT^2 + c\times MAT + d \quad \text{(Eq. H2)}$$

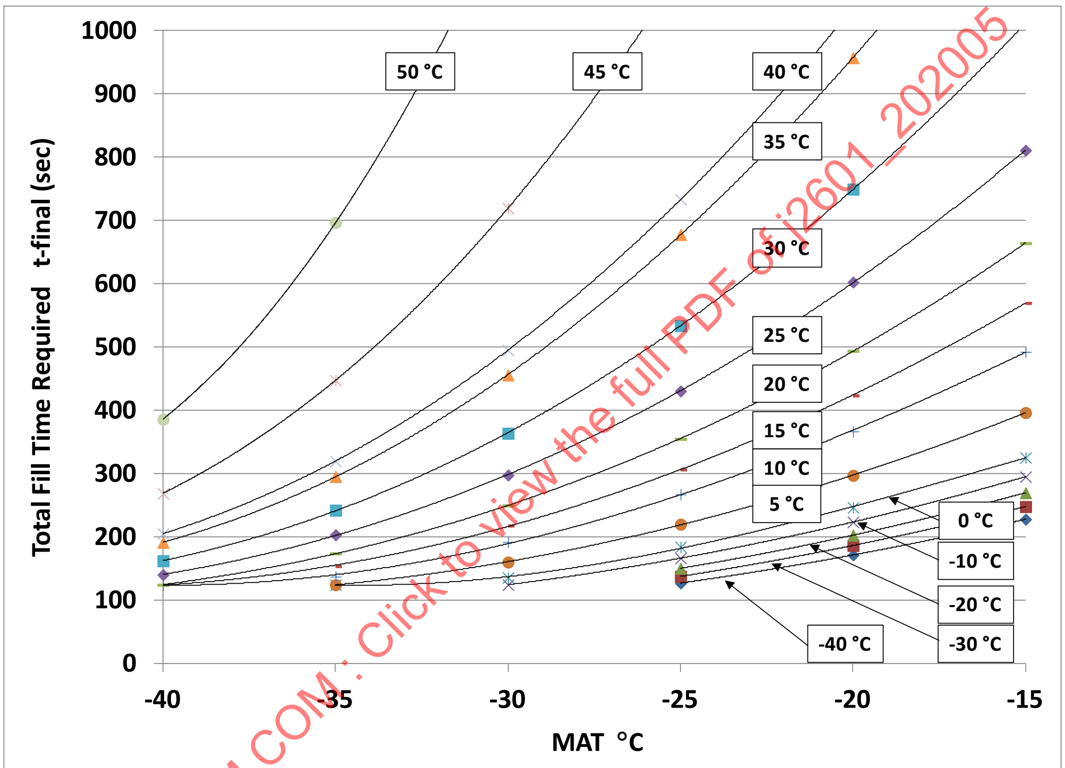

Figure H3 - Regression fit of t_{final} to MAT

The statistical accuracy of a regression fit can be defined by the coefficient of determination, denoted as R^2. Except for ambient temperatures of 45 °C and above, R^2 is higher than 0.9999 in all cases. For ambient temperatures of 45 °C and above, where fueling times can become exponentially longer at the warmer fuel delivery temperatures, a manual process was utilized to generate a best regression fit while also ensuring that all t_{final} values are conservative; i.e., equal to or longer than the simulation resultant t_{final} value under all fuel delivery temperatures.

H.2.2 Calculation of t_{final}

Equation H2 provides a means for calculating t_{final} as a function of the MAT and a set of coefficients (a, b, c, and d), for a specific ambient temperature and a specific CHSS vessel. A set of coefficients (a, b, c, and d), were derived for each ambient temperature under which simulations were conducted, for each CHSS vessel size (49.7 L, 99.4 L, 174.0 L, and 248.6 L), and for the minimum initial pressures P_{min} = 0.5 MPa and P_{min} = 5 MPa. This creates a set of eight tables of coefficients (four for each CHSS vessel size and two for each P_{min} value). These tables of coefficients are found in Tables J1 through J8 for a warm dispenser, and Tables J9 through J16 for a cold dispenser.

Once the initial pressure has been determined after the initial pressure pulse, P_{min} can be determined. Thus, 4 sets of coefficients (a, b, c, and d), need to be calculated for each boundary CHSS vessel. The coefficients are interpolated between the ambient temperatures listed in Tables J1-J16, as shown in Equation H3, as an example, for the 49.7 L boundary CHSS vessel. This is done for each of the boundary CHSS vessels: 49.7 L, 99.4 L, 174.0 L, and 248.6 L.

Interpolation for 49.7 L boundary CHSS (Eq. H3)

$$a_{49.7} = a(T_{amb\_below}) + \frac{[a(T_{amb\_above}) - a(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$b_{49.7} = b(T_{amb\_below}) + \frac{[b(T_{amb\_above}) - b(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$c_{49.7} = c(T_{amb\_below}) + \frac{[c(T_{amb\_above}) - c(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$d_{49.7} = d(T_{amb\_below}) + \frac{[d(T_{amb\_above}) - d(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

t_{final} is then calculated for each boundary CHSS vessel. If the CHSS Capacity Category is determined, there are two options for calculating t_{final}. The dispenser manufacturer may choose either option. When Option1 is utilized, t_{final} is chosen based on the more conservative t_{final} of the lower boundary CHSS and upper boundary CHSS, or the minimum value t_{final_min}, whichever is higher. When Option 2 is utilized, t_{final} is determined by interpolating between t_{final} of the upper and lower boundary CHSS based on the measured CHSS volume, or the minimum value t_{final_min}, whichever is higher. If the CHSS Capacity Category is not determined, then the highest t_{final} value of all four of the boundary CHSS vessels is utilized. See J.2.4 and Equation J63.

H.2.3 Variable Pressure Ramp Rate

Consider a case where the value t_{final} is pre-determined and doesn't change during the fill. In this case, t_{final} is the denominator of the equation for average pressure ramp rate (APRR), as shown in Equation H4. Because t_{final} doesn't change during the fill, regardless of the starting pressure, the fill will always utilize the APRR.

$$APRR = \frac{P_{final} - P_{min}}{t_{final}} \quad \text{(Eq. H4)}$$

Now, consider the case where t_{final} changes during the fill. When t_{final} is allowed to change during the fill, an equation for the pressure ramp rate (PRR) must be derived that ensures that the dispenser pressure follows a rate of change path that arrives at P_{final} at the elapsed time of t_{final}. An illustration of this is shown in Figures H4 and H5. In Figure H4, the exemplary fill starts at $P_{initial}$ with a calculated t_{final} shown in black. As the fill progresses, at point P_{ramp} and t, t_{final} changes to a higher value shown in blue, causing the rate of change of the pressure to decrease such that it arrives at P_{final} at the elapsed time of the new t_{final}. In Figure H5, the exemplary fill starts at $P_{initial}$ with a calculated t_{final} shown in black. As the fill progresses, at point P_{ramp} and t, t_{final} changes to a lower value shown in blue, causing the rate of change of the pressure to increase such that it arrives at P_{final} at the elapsed time of the new t_{final}.

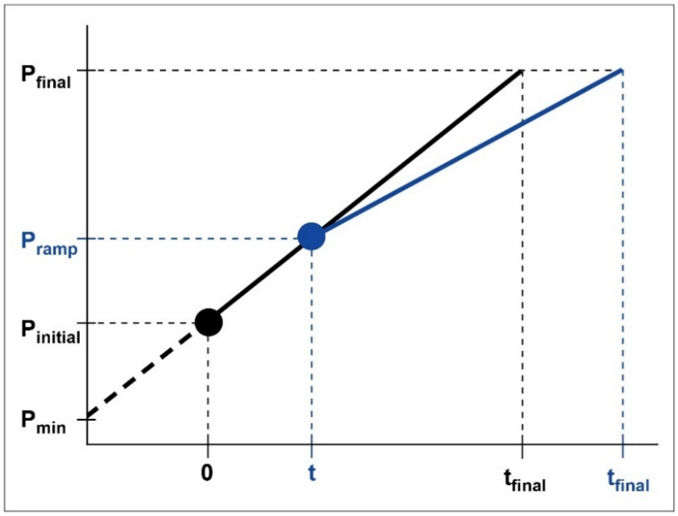

Figure H4 - Illustration of the effect on the pressure path with an increase in t_{final}

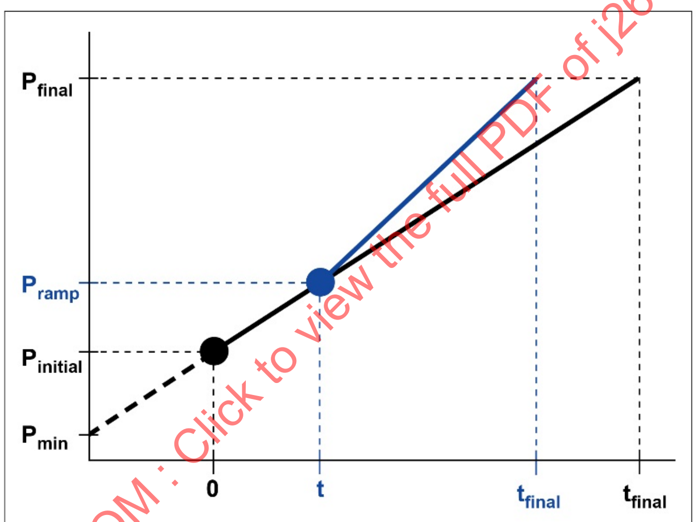

Figure H5 - Illustration of the effect on the pressure path with a decrease in t_{final}

To keep the illustration simple, the change in PRR is only shown to occur once in Figures H4 and H5, but the same approach is used whenever t_{final} changes. The equation which dictates the PRR with a changing t_{final} is Equation H5. In Equation H5, P_{ramp} represents the ramp pressure at an elapsed time of t during the fill.

$$PRR = \frac{P_{final} - P_{ramp}}{t_{final} \times \left(\frac{P_{final} - P_{initial}}{P_{final} - P_{min}}\right) - t} \quad \text{(Eq. H5)}$$

The equation which dictates the ramp pressure P_{ramp} as a function of the PRR is Equation H6, where j represents a time step of 1 second.

$$P_{ramp_{j+1}} = P_{ramp} + PRR \quad \text{(Eq. H6)}$$

H.2.4 Mass Average Fuel Delivery Temperature

Equation H2 expresses t_{final} as a function of the mass average fuel delivery temperature MAT (Equation H1). The relationship between t_{final} and MAT is based on the MAT at P_{final} or the end of the fill. At the beginning of the fill, MAT can be significantly warmer than at the end of the fill, especially if the dispenser is initially warm. If MAT were used directly in the equation for t_{final}, t_{final} would be very large at the beginning of the fill and get progressively smaller as the fuel delivery temperature cools and MAT becomes colder. This would create a PRR which is very small at the beginning of the fill and very large at the end of the fill. This is not desirable for a number of reasons. A small PRR at the beginning of the fill when the dispenser is warm causes the cool-down period to be significantly longer than it otherwise would be due to the small mass flow rate. Additionally, large changes in the PRR increase enthalpy, which if not compensated for could cause overheating, and if accounted for, will cause the overall fueling time to be longer. And finally, there must be a limit or cap placed on PRR to constrain the maximum flow rate, so if PRR is small at the beginning of the fill, PRR cannot fully compensate later in the fill due to this limit, again causing the overall fueling time to be longer than it should be.

To minimize the above detrimental effects, PRR should be as constant as possible, which in turn requires t_{final}, and thus MAT, to be as constant as possible. The approach chosen breaks the fill into sections and establishes a set of rules for the MAT input used in the equation for t_{final}. The sectioning of the fill into Rules 1 through 3 is illustrated in Figure H6.

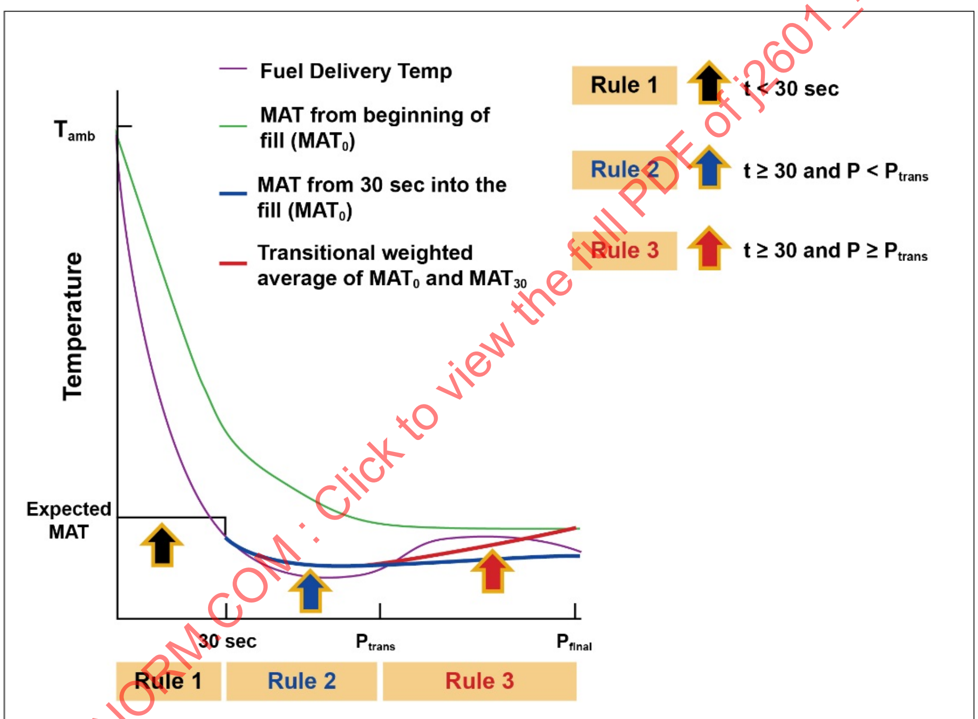

Figure H6 - Illustration of sectioning of the fill into regions where specific rules are applied for MAT

Instead of using MAT directly in the equation for t_{final}, a proxy for MAT named MAT_C (C stands for control input) is utilized. MAT_C is determined based on the region of the fill, where specific rules are applied, as illustrated in Figure H6.

H.2.4.1 Rule 1

The first region where Rule 1 is applied is defined by the fueling time t being less 30 seconds. When the fill is in this region, the Expected MAT (symbol $MAT_{expected}$) is utilized for MAT_C. Expected MAT is defined as the expected value for MAT_0 at the end of the fill. It is not important that this value be precisely correct, as its purpose is to serve as a proxy for MAT during the cool-down phase of the fill. The acceptable range for Expected MAT is 237.15 K ≤ $MAT_{expected}$ ≤ 255.65 K. The upper value of 255.65 K is because this corresponds to the upper boundary of a T20 station, which is the warmest MAT allowed. The lower value of 237.15 K is due to running worst-case fueling simulations with different $MAT_{expected}$ values where the fuel delivery temperature only reached 255.65 K at t = 30 seconds. Under this worst-case scenario, no overheating was seen with $MAT_{expected}$ as cold as 255.65 K. There may be situations where the dispenser utilizes an $MAT_{expected}$ which is colder than what is actually expected. For example, under hot ambient temperatures, in order to achieve a fuel delivery temperature of at least 255.65 K within 30 seconds, it may require the dispenser to input an $MAT_{expected}$ which is significantly colder than the MAT expected at the end of the fill. As long as is $MAT_{expected}$ ≥ 237.15 K and $MAT_{expected}$ ≤ 255.65 K, any value may be used.

H.2.4.2 Rule 2

After a total of 30 seconds of mass flow have elapsed, the fuel delivery temperature should be close to its target temperature and remain relatively stable for the remainder of the fill. Thus, the second region where Rule 2 is applied is defined by the fueling time t being greater than or equal to 30 seconds and the control pressure (symbol $P_{control}$) being less than the transitional pressure (symbol P_{trans}). P_{trans} is defined as the midpoint between the initial pressure $P_{initial}$, and the final pressure P_{final}. For example, for a fill with an initial pressure of 10 MPa, since P_{final} is always equal to 83.5 MPa, P_{trans} would be equal to 46.75 MPa. In this region where Rule 2 is applicable, the mass average of the fuel delivery temperature after the first 30 seconds of mass flow (symbol MAT_{30}) is utilized for MAT_C. The equation for MAT_{30} is shown in Equation H7, where j represents a time step of 1 second. Note that for illustration purposes, in Equation H7 for MAT_{30}, it is assumed that no intended non-fueling events, such as a leak check or bank switch, occur during the first 30 seconds of the fill. In the actual calculation of MAT_{30} in J.2.3.1, a counter named n is utilized, which advances at the same time step frequency as the time step j (i.e., every 1 second), but only if there is mass flow. If there is an intended non-fueling event during the first 30 seconds of the fill, then the point at which the calculation of MAT_{30} commences will be when the counter n reaches 30, which will occur at a j value, and fueling time t value, higher than 30.

$$MAT_{30} = \frac{\sum_{30}^{j}\left[\left(m_{(j)} - m_{(j-1)}\right) \times 0.5\left(T_{fuel\_inst(j)} + T_{fuel\_inst(j-1)}\right)\right]}{\sum_{30}^{j}\left(m_{(j)} - m_{(j-1)}\right)} \quad \text{(Eq. H7)}$$

H.2.4.3 Rule 3

Once the control pressure $P_{control}$ has exceeded the transitional pressure P_{trans}, it is important that the control input MAT_C gradually transition to MAT_0 by the end of the fill, as this is the value upon which t_{final} is based. Thus, the third region where Rule 3 is applied is defined by the fueling time t being greater than or equal to 30 seconds (again, assuming no intended non-fueling events during the first 30 seconds for illustration purposes) and the control pressure $P_{control}$ being greater than or equal to the transitional pressure P_{trans}. This transition to MAT_0 is realized by using a weighted average of MAT_{30} and MAT_0 where the weighting factor is a function of the control pressure $P_{control}$. The equation for this weighted average is shown in Equation H8.

$$IF\ P_{control} < P_{final},\ MAT_C = MAT_{30} \times \left(\frac{P_{final} - P_{control}}{P_{final} - P_{trans}}\right) + MAT_0 \times \left(1 - \frac{P_{final} - P_{control}}{P_{final} - P_{trans}}\right) \quad \text{(Eq. H8)}$$

$$ELSE\ \ MAT_C = MAT_0$$

H.2.5 Limits on Pressure Ramp Rate

H.2.5.1 Minimum Limit on t_{final}

In the derivation of the coefficients for the t_{final} equation, some of the fueling simulations were limited by the constraint of not exceeding the peak flow rate of 60 g/s. As noted in H.2.1, these simulations were not utilized in the regression fit. Therefore, the t_{final} equation itself cannot be relied upon to limit the pressure ramp rate such that the peak flow rate does not exceed 60 g/s. An additional constraint on t_{final} must be applied. The approach utilized is to set a minimum t_{final} value for each CHSS volume category. A parameter labeled t_{final_min} is utilized for this purpose. t_{final_min} is determined such that the peak flow rate will not exceed 60 g/s for the largest CHSS volume in a given CHSS volume category. t_{final_min} also ensures that the highest pressure ramp rate, defined as the hot pressure ramp rate (HPRR; see A.3.5), is the same for both the table-based protocol and the MC Formula-based protocol. Because a separate set of t_{final} coefficients are utilized for P_{min} of 0.5 MPa and 5 MPa, t_{final_min} is also a function of P_{min}. The t_{final_min} values, along with the corresponding maximum HPRR, for each CHSS volume category and P_{min} are shown in Table H2.

Table H2 - t_{final_min} as a function of CHSS volume category and P_{min}

CHSS Volume Category	Maximum HPRR (MPa/min)	t_{final_min} (Seconds)	
		P_{min} = 0.5 MPa	P_{min} = 5 MPa
A (49.7 - 99.4 L)	32.1	155	147
B (99.4 - 174.0 L)	32.1	155	147
C (174.0 - 248.6 L)	22.4	222	210

H.2.5.2 Maximum Limit on PRR

The minimum limit on t_{final} ensures that the overall fueling time and maximum HPRR are limited with sufficient margin so as not to exceed the peak flow rate of 60 g/s under a constant pressure ramp rate. However, because the MC Formula-based protocol uses a variable pressure ramp rate approach, it is also necessary to place a limit or cap on the instantaneous pressure ramp rate PRR to further ensure that the peak flow rate is not exceeded. The limit utilized for the instantaneous PRR is 110% of the maximum HPRR. Because some stations may not be able to sustain a pressure ramp this high, the cap on pressure ramp rate is defined as a range of values, from 90% of the maximum HPRR to 110% of the maximum HPRR, represented by a factor named PRR_{CAP_Factor}. The appropriate value for PRR_{CAP_Factor} is chosen by the station manufacturer. The equation defining this range for the cap on pressure ramp rate is Equation H9.

$$0.9 \leq PRR_{CAP\_Factor} \leq 1.1 \quad \text{(Eq. H9)}$$

$$PRR_{CAP} = PRR_{CAP\_Factor} \times \frac{P_{final} - P_{min}}{t_{final\_min}}$$

H.2.6 Accounting for Deviations from Ideal Conditions

Sections H.1 through H.2.4 have described the process whereby the pressure ramp rate and ramp pressure can be calculated as a function of the fuel delivery temperature and elapsed fueling time. However, in the application of this approach to actual fueling, there are a number of factors which must be accounted for. These factors are explained below.

H.2.6.1 Increase in Enthalpy Due to Variation in PRR

The derivation of the t_{final} equation is based on constant pressure ramp rate fueling simulations. Because the MC Formula-based protocol allows the PRR to vary, the effect of this variation in PRR on the ending gas temperature must be accounted for. In conducting fueling simulations at a constant pressure ramp rate and a given MAT, the required fueling time t_{final} is based on the mass average of the enthalpy dispensed. If the PRR during the fill deviates from the constant pressure ramp rate, the mass average of the enthalpy dispensed will be different. Typically, the mass average enthalpy will be higher for a fill with a variable pressure ramp rate versus a constant pressure ramp rate, regardless of whether the PRR is lower in the early part of the fill and higher in the latter part, or vice-versa. This effect is illustrated in Figure H7.

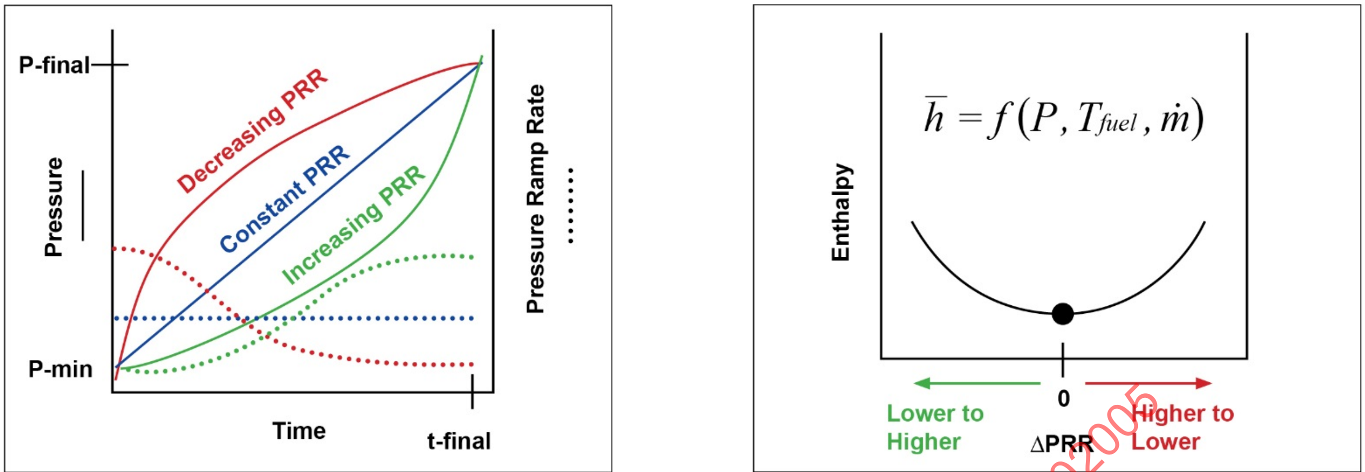

Figure H7 - Illustration of the effect on mass average enthalpy due to variable pressure ramp rate

Other phenomena affect the ending gas temperature as well, such as the heat transfer rate between the gas and the CHSS vessel liner. In some cases—for example, when the pressure ramp rate starts high and then decreases—the increase in enthalpy can be offset, at least partially, by the higher heat transfer rate due to a higher gas temperature earlier in the fill. However, these effects and the relationship between them are quite complex, and while accounted for in the fueling simulation model, they are difficult to account for in a theoretically thorough manner in the fueling protocol itself. Thus, a practical empirical approach was utilized to account for the potential increase in enthalpy due to a variable PRR.

The empirical approach was developed by studying the effect that a variable PRR has on the ending gas temperature in the fueling simulations. Larger variations in PRR caused larger changes in enthalpy, and thus higher ending gas temperatures. To offset the higher ending gas temperature, the fueling time needs to be extended. Thus, an approach which extends the fueling time by a factor which is a function of the variation in the PRR was chosen. The factor which is used to extend the fueling time is α, shown mathematically in Equation H10, where j represents a time step of 1 second, and PRR, RR_{min}, and RR_{max} are in units of MPa/s.

$$IF\ j = 0,\ \alpha\ = 1 \qquad \text{(Eq. H10)}$$

$$ELSE\ \ IF\ \ j > 0$$

$$IF\ \ PRR < RR_{min},\ RR_{min} = PRR$$

$$IF\ \ PRR > RR_{max},\ RR_{max} = PRR$$

$$IF\ \dot{m} = 0\ for\ greater\ than\ 5\ seconds,\ RR_{min} = 0$$

$$\alpha\ = \left[\frac{100 + 18.5(RR_{max} - RR_{min})}{100}\right]$$

$$t_{final} =\ \alpha \times [a \times MAT^3 + b \times MAT^2 + c \times MAT + d]$$

To verify the efficacy of this approach, multiple fueling simulations were run where parameters which influence the PRR were allowed to deviate from the norm. For example, fuel delivery temperature cool-down periods from 0 to 60 seconds were tested, mismatch in expected MAT from actual MAT were tested, both warmer and colder than actual were tested, large swings in the fuel delivery temperature using a sinusoidal function with an amplitude of ±5 °C were tested, and finally a combination of all of these variation in parameters together were tested. The result of the latter simulation where all of these parameters were varied together is shown in Figure H8. α extended the fill time by approximately 6%, while keeping the peak gas temperature below 85 °C.

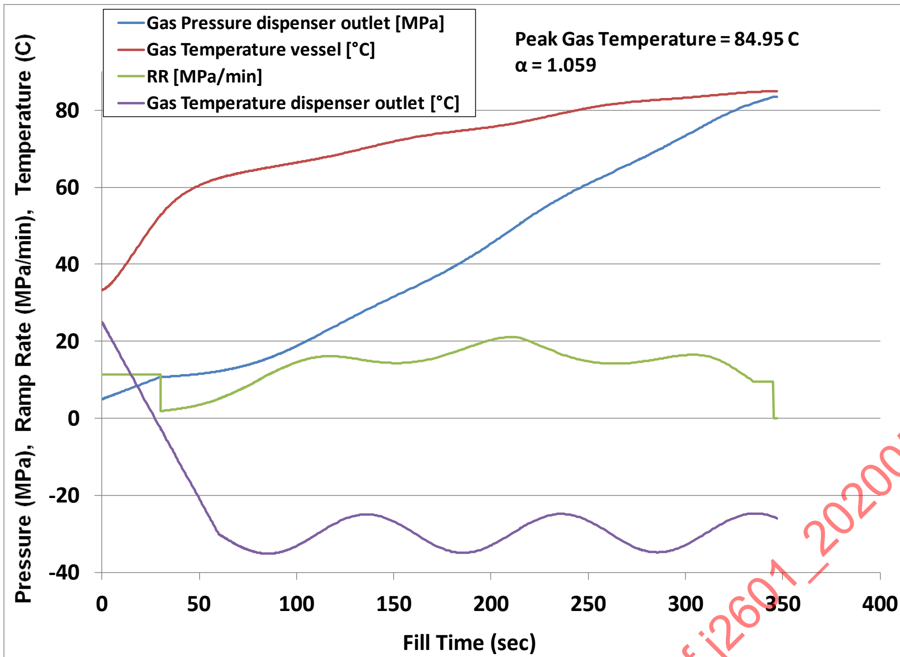

Figure H8 - Fueling simulation where the efficacy of α was verified based on variations in multiple parameters

Another function of α is to facilitate the inclusion of pauses in the fill due to leak checks or extended bank switches (i.e., intended non-fueling time events) as fueling time. The rationale for counting these pauses as fueling time is that heat transfer between the gas and the CHSS vessel liner continues during these pauses in mass flow. During any pause in the mass flow rate greater than the control time step of 1 second, the ramp pressure P_{ramp} is held constant. Short pauses in flow have very little effect on the enthalpy, and the small variation in PRR these pauses cause will be accounted for by the α equation. However, for longer pauses, i.e., those of duration 5 seconds or greater, the effective PRR is zero since P_{ramp} is held constant. This is not accounted for in the PRR equation as the PRR is actually increasing during these pauses. Thus, if the mass flow rate is zero for longer than 5 seconds, RR_{min} is set to zero in the α equation, as shown in Equation H10.

To verify the efficacy of the α equation in accounting for pauses in the fill greater than 5 seconds in duration, the same fueling simulation as shown in Figure H8 was run with pauses at 22, 43, and 58 MPa, for durations of 15, 20, and 25 seconds, respectively (total of 60 seconds). Because RR_{min} was set to zero, α increased from 1.059 in the case without pauses, to 1.089 in the case with pauses, causing the overall fueling time to be extended by 17 seconds. This was more than sufficient to account for the increase in mass average enthalpy of approximately 11 kJ/kg, resulting in a peak gas temperature less than 85 °C, as shown in Figure H9.

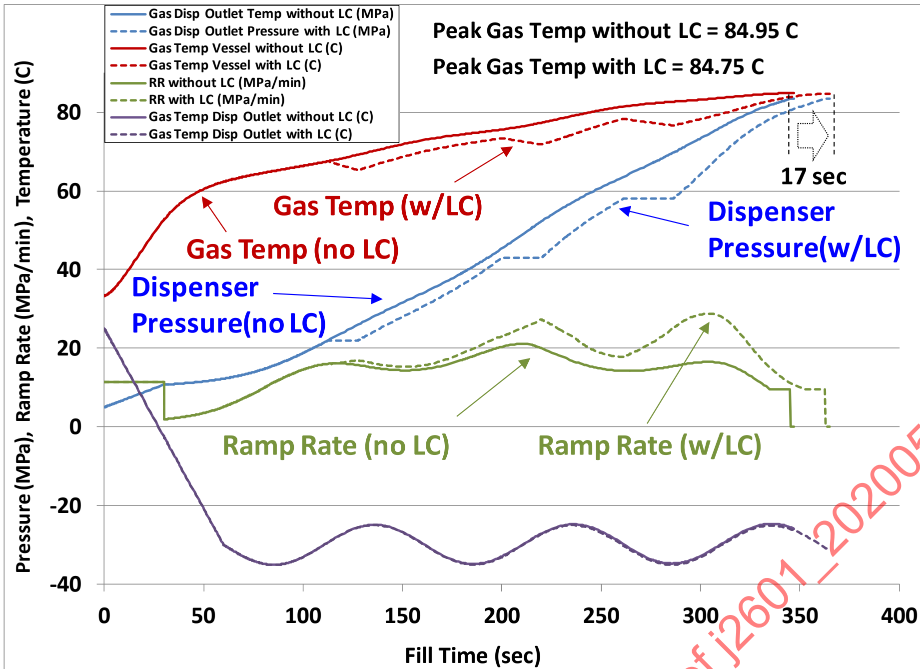

Figure H9 - Fueling simulation where the efficacy of α was verified with three pauses in mass flow

H.2.6.2 Deviations in Station Pressure

The MC Formula-based protocol calculates a ramp pressure that ideally should be followed by the dispenser. This ramp pressure, P_{ramp}, is calculated based on the dispenser having perfect control. In actual application, it is impossible for the station to control the station pressure $P_{station}$ to match the ramp pressure P_{ramp} perfectly. Deviations between $P_{station}$ and P_{ramp} must be limited and accounted for. The following two sections explain the approach utilized to account for fluctuations in the station pressure.

H.2.6.2.1 Station Pressure Corridor

To allow for deviations of the station pressure $P_{station}$ during fueling, a pressure corridor is built around the ramp pressure P_{ramp}. This pressure corridor defines an upper limit pressure and a lower limit pressure. The width of the corridor is 9.5 MPa, the same as that used for the table-based protocol, as defined in 8.3.2 and A.3.5. To define the upper and lower pressure limits of the corridor, a tolerance above and below the ramp pressure is used. The upper tolerance is 7.0 MPa and the lower tolerance is 2.5 MPa, again, the same as is utilized for the table-based protocol. This is expressed mathematically in Equation H11.

$$P_{limit\_high} = P_{ramp} + \Delta P_{tol\_high}, \quad where\ \Delta P_{tol\_high} = 7\ MPa \qquad \text{(Eq. H11)}$$

$$P_{limit\_low} = P_{ramp} - \Delta P_{tol\_low}, \quad where\ \Delta P_{tol\_low} = 2.5\ MPa$$

By creating a tolerance above the ramp pressure, it is also necessary to extend the fueling time t_{final} such that the station pressure $P_{station}$ cannot reach P_{final} before t_{final} is reached. This is illustrated in Figure H10. In Figure H10, the rise in station pressure is assumed to start at time t_{tol_low} (i.e., a delayed start), and then proceed at the highest pressure ramp rate HPRR, defined by reaching the pressure P_{final} at the time $t_{tol\_low} + t_{final}$. To allow for a constant upper and lower tolerance around the ramp pressure, t_{final} must be extended by a factor β, the derivation of which is shown in Equation H12. By extending t_{final} in this way, even if $P_{station} = P_{limit\_high}$, it will not reach P_{final} before t_{final} is reached.

$$\frac{P_{final}-\Delta P_{tol\_high}-\Delta P_{tol\_low}-P_{min}}{(t_{final}+t_{tol\_low})-t_{tol\_low}} = \frac{P_{final}-P_{min}}{(\acute{t}_{final}+t_{tol\_low})-t_{tol\_low}} \quad \text{(Eq. H12)}$$

$$\acute{t}_{final} = t_{final} \times \left[\frac{P_{final}-P_{min}}{P_{final}-\Delta P_{tol\_high}-\Delta P_{tol\_low}-P_{min}}\right]$$

$$\acute{t}_{final} = \beta \times t_{final}$$

$$\beta = \frac{P_{final}-P_{min}}{P_{final}-\Delta P_{tol\_high}-\Delta P_{tol\_low}-P_{min}}$$

$$t_{final} = \beta \times [a \times MAT^3 + b \times MAT^2 + c \times MAT + d]$$

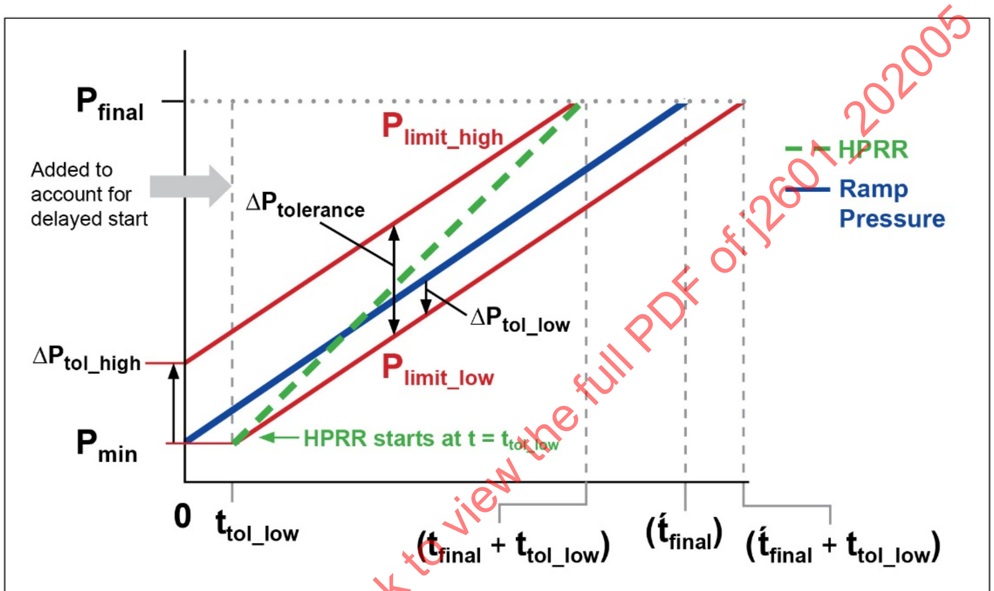

Figure H10 - Illustration of pressure corridor derivation

In Figure H10 and Equation H12, the derivation of β assumes that the rise in station pressure is delayed by the time t_{tol_low}. This is a worst-case assumption, which in most cases, does not happen. The usual case is for the station pressure to begin rising from time t = 0. The time t_{tol_low} causes the factor β to be approximately 4% larger than it would be otherwise, which means the overall fueling time will be 4% longer than it needs to be.

To eliminate or reduce the time t_{tol_low} from the overall fueling time, a method is employed to measure whether the fill has a delayed start or not. The way this is done is to measure the difference between P_{ramp} and $P_{station}$ at time t_{tol_low}. If $P_{station}$ is greater than P_{ramp} at this point, it indicates that the pressure rise has not been delayed in starting, and the time t_{tol_low} can be eliminated from the derivation of the factor β.

There are two possibilities at time t_{tol_low}: $P_{station}$ is equal to or above P_{ramp}, or $P_{station}$ is below P_{ramp}. These scenarios are illustrated in Figures H11 and H12, respectively. At time t = t_{tol_low}, $P_{station}$ is compared to P_{ramp}, and the parameter ΔP_{low} is measured. Equation H13 is utilized to calculate the time t_{tol_low}, which is a function of the pressure ramp rate PRR.

$$t_{tol\_low} = \frac{\Delta P_{tol\_low}}{PRR} = \frac{2.5}{PRR} \quad \text{(Eq. H13)}$$

The parameter ΔP_{low} is defined as the difference between P_{ramp} and $P_{station}$, as shown in Equation H14.

$$WHEN\ t = t_{tol\_low} \tag{Eq. H14}$$

$$IF\ \ P_{ramp} - P_{station} > 0$$

$$THEN\ \ \Delta P_{low} = P_{ramp} - P_{station}$$

$$ELSE\ \ \Delta P_{low} = 0$$

The equation for β is modified to utilize the measured value ΔP_{low} instead of ΔP_{tol_low}, as shown in Equation H15.

$$\beta = \frac{P_{final} - P_{min}}{P_{final} - \Delta P_{tol\_high} - \Delta P_{low} - P_{min}} \tag{Eq. H15}$$

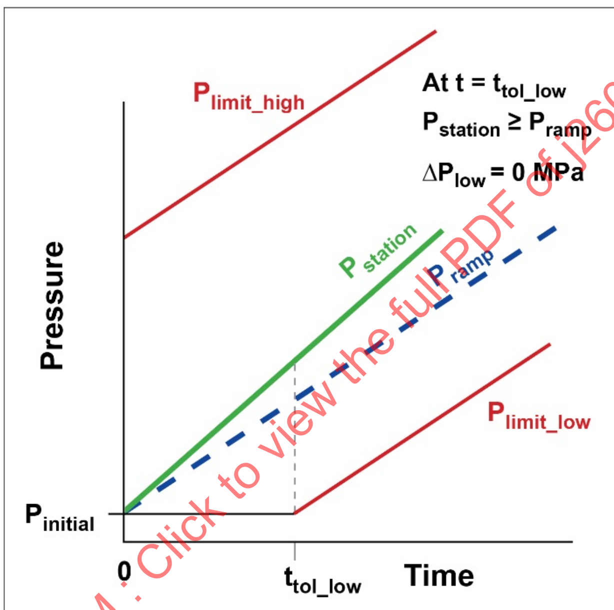

Figure H11 - Illustration of a non-delayed start of fueling

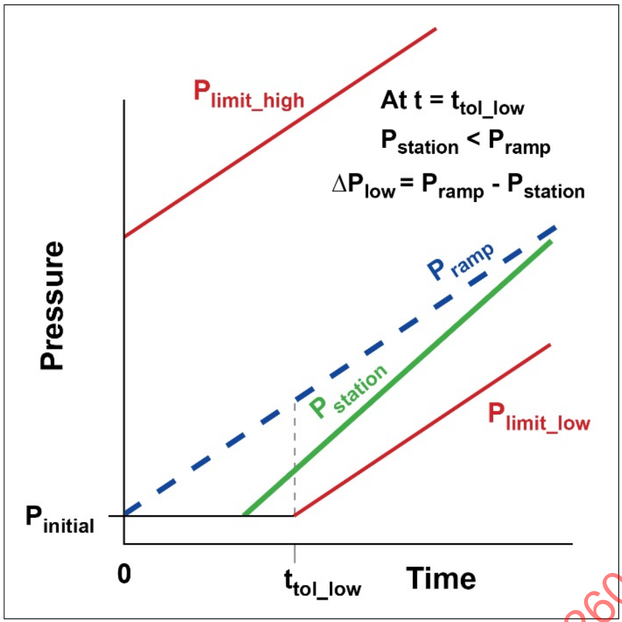

Figure H12 - Illustration of a delayed start of fueling

H.2.6.3 Combining α and β in the t_{final} Equation

In H.2.6.1, the parameter α was defined and explained. α extends t_{final} to account for the increase in enthalpy caused by variations in the pressure ramp rate. In H.2.6.2, the parameter β was defined and explained. β extends t_{final} to allow sufficient margin to apply a tolerance on pressure, such that a pressure corridor can be defined. To account for both of these cases, t_{final} is multiplied by the factor α and β respectively. Thus, the final expression for the t_{final} equation is shown in Equation H16.

$$t_{final} = \alpha \times \beta \times [a \times MAT^3 + b \times MAT^2 + c \times MAT + d] \quad \text{(Eq. H16)}$$

H.2.7 Control Pressure

In H.2.3, the equation for the pressure ramp rate PRR and the ramp pressure P_{ramp} are given. As explained in H.2.6.2.1, a pressure tolerance ΔP_{tol_high} is added to the ramp pressure P_{ramp} to form the upper pressure limit P_{limit_high}, and a pressure tolerance ΔP_{tol_low} is subtracted from the ramp pressure P_{ramp} to form the lower pressure limit P_{limit_low}. Together, P_{limit_high} and P_{limit_low} define the upper and lower boundaries of the pressure corridor, respectively.

Although the ramp pressure is utilized as an input to the pressure ramp rate equation, and to define the upper and lower boundaries of the pressure corridor, it is not necessarily utilized as the control pressure by the dispenser. The control pressure $P_{control}$ is defined as the pressure that the dispenser is targeting at any point in time. In other words, the control pressure is the control parameter that the dispenser follows in controlling the station pressure $P_{station}$. The pressure corridor is defined as the operating boundaries for the station pressure, which means that any pressure within this corridor is valid. Therefore, in setting the control pressure, the dispenser should determine how much margin is required to keep from overshooting the upper pressure limit P_{limit_high}, and how much margin is required to keep from undershooting the lower pressure limit P_{limit_low}.

If the risk to overshooting or undershooting is equal, then the middle of the pressure corridor could be chosen as the control pressure. However, it should be kept in mind that in order to ensure the best fill performance, the minimum margin needed to avoid overshooting the upper pressure limit should be utilized.

The approach utilized for defining the control pressure $P_{control}$ is to define an offset pressure ΔP_{offset}, which is added to the ramp pressure P_{ramp}, as shown in Equation H17, and as illustrated in Figure H13.

$$P_{control} = P_{ramp} + \Delta P_{offset} \quad \text{(Eq. H17)}$$

ΔP_{offset} does not have to be a constant. It can vary during the fill based on the control characteristics of the dispenser. As an example, the risk to overshooting the upper pressure limit is usually greatest after a pause in the fill due to a leak check or cascade bank switch. To mitigate this risk while still keeping the shortest fueling time possible, the dispenser manufacturer may choose to set a smaller value for ΔP_{offset} during the pause and shortly after the fill resumes, and then once the pressure control has stabilized, set a larger value for ΔP_{offset} to keep the fueling time as short as possible.

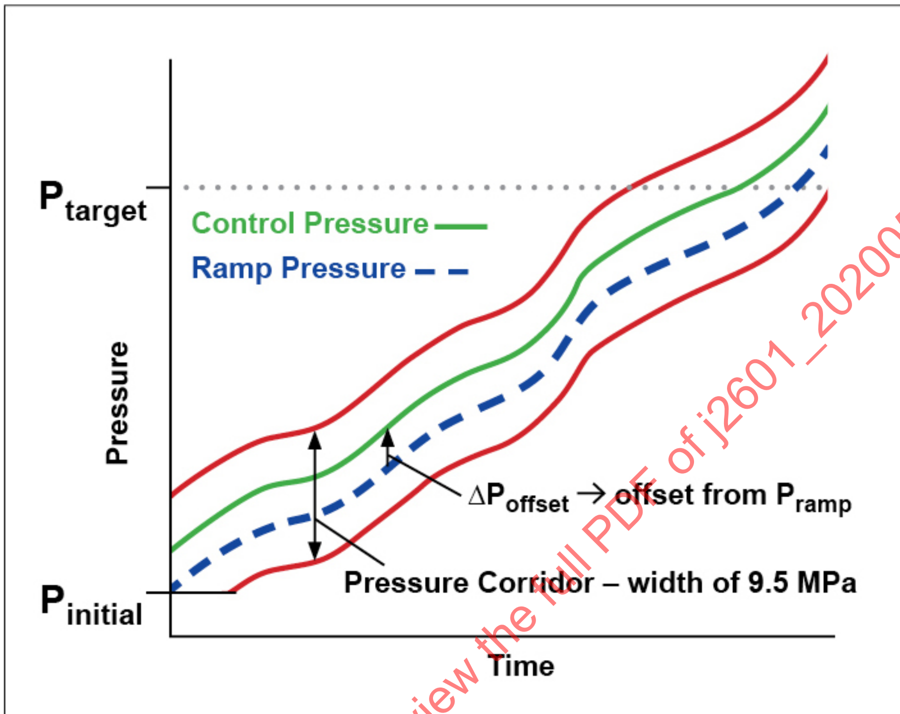

Figure H13 - Illustration of control pressure as an offset from the ramp pressure

H.2.8 Validation of MC Formula Pressure Ramp Rate Control

To demonstrate the efficacy of the MC Formula pressure ramp rate control and to validate that it is sufficiently conservative to ensure that overheating does not occur, fueling simulations and bench tests were conducted under a spectrum of worst-case boundary conditions. For the fueling simulations, the MC Formula pressure ramp rate control was programmed into the fueling model explained in A.1, so that it could operate in the same manner as a real-world hydrogen station using the MC Formula-based protocol. This allowed a much larger and broader set of conditions to be analyzed than could be done in a laboratory test or field test environment. A series of fueling simulations were conducted on the hot case CHSS, where the following parameters were varied: ambient temperature, fuel delivery temperature, fluctuating fuel delivery temperature, fuel delivery temperature cool-down time, expected mass average fuel delivery temperature, initial pressure (to test both coefficient maps), and the time step for the calculations. In total, 89 simulations were conducted, with all results showing gas temperature below the limit of 85 °C.

Additionally, bench tests were conducted on a representative hydrogen storage vessel, under as close to the worst-case boundary conditions as possible. The storage vessel and set-up conditions were identical to that used for the validation of the table-based protocol. Six fueling tests were conducted to test against overheating with the fueling conditions chosen to address the broadest set of conditions possible for the number of tests available, and, where possible, to align the test conditions with the table-based protocol validation tests. These tests successfully demonstrated that the maximum gas temperatures were below the limit of 85 °C.

The details of the simulation conditions and results, as well as the laboratory test conditions and results, can be found in Section 8 and Appendix B of SAE Paper 2014-01-1833, "Validation and Sensitivity Studies of SAE J2601, the Light Duty Vehicle Hydrogen Fueling Standard."

Field validation testing of the MC Formula-based protocol was also conducted on both a test tank and representative OEM fuel cell vehicles. Over 100 fueling tests at a real world representative fueling station were conducted, analyzed, and documented in SAE Paper 2015-01-1177, “Field Validation of the MC Default Fill Hydrogen Fueling Protocol.”

Note that in the above two referenced SAE papers, the “MC Default Fill” is synonymous with the MC Formula-based protocol. The name of the protocol was subsequently changed by the SAE Fuel Cell Standards Interface Task Force.

H.3 ENDING PRESSURE CONTROL

The MC Formula-based protocol allows for two options in determining the ending pressure control: the MC Method, or ending pressure tables. The dispenser manufacturer should choose one or the other of these two options. The MC Method is a formula-based approach to calculating the appropriate ending pressure targets and limits. The ending pressure tables provide looked-up values as a means of providing the appropriate ending pressure targets and limits. The MC Method ending pressure control requires significantly fewer stored parameters than the ending pressure targets ending pressure control, but has a higher calculation intensity.

For both ending pressure control options, a non-communication pressure target is calculated based on cold case conditions, which limits the maximum SOC to 100%, even under worst-case conditions. For communications fueling, the communications pressure target is calculated based on the communicated measured temperature from the vehicle in combination with either the vehicle communicated measured pressure or the station measured pressure. The SOC target for communications fueling is between 95 to 100% SOC, where SOC is based on the calculated density of the gas in the CHSS. The communications pressure target is used as the primary ending pressure stopping point. However, because there is a possibility that the communicated temperature and/or pressure from the vehicle could be incorrect, a pressure limit is also utilized. This pressure limit is based on a maximum SOC of 115% for the cold case, which is a worst-case condition. For the ending pressure tables, the pressure limit is calculated as described in A.7 for the hot case simulations, which in some cases results in a maximum SOC of less than 115% SOC. Figure H14 illustrates the pressure targets and pressure limits utilized for non-communication fueling and for communications fueling.

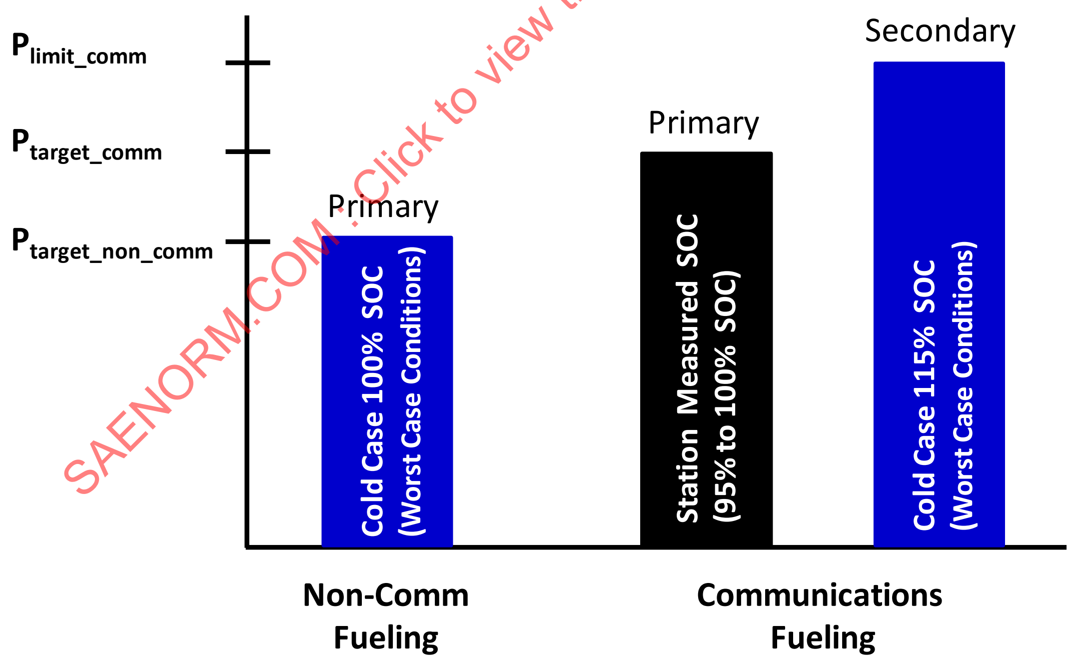

Figure H14 - Illustration of pressure targets and limits for ending pressure control

The logic and derivation of these two ending pressure control methodologies are described in H.3.1 and H.3.2, respectively.

H.3.1 The MC Method

The MC Method is an analytical method based on a lumped heat capacity model, which utilizes a thermodynamic characterization of a compressed hydrogen storage vessel. The characterization is described by MC, which is a parameter that quantifies the capability of the hydrogen storage vessel to absorb the heat generated during fueling, expressed in terms of kJ/K. MC is an equation which is a function of initial conditions, fueling conditions, and the fueling time. By calculating MC, along with initial CHSS pressure and temperature, and the measurement of enthalpy and mass flow at the dispenser outlet throughout the fill, the end of fill gas temperature in the storage vessel can be calculated, from which a target pressure can be calculated.

H.3.1.1 Theory

As shown in Figure H15, the MC Method is based on a control volume analysis of the fueling process. The energy added during fueling is defined as the mass average enthalpy of the gas entering the control volume $\int_{m_1}^{m_2} h_i dm$. As shown in Equation H18, the heat transferred from the hydrogen can be defined as the difference of the final internal energy $m_2 u_2$ and the initial internal energy $m_1 u_1$ subtracted from the enthalpy added. Because heat transfer to the environment is ignored, MC is a representation of the storage vessel's ability to absorb the heat Q.

$$Q = \int_{m_1}^{m_2} h_i dm - (m_2 u_2 - m_1 u_1) \quad \text{(Eq. H18)}$$

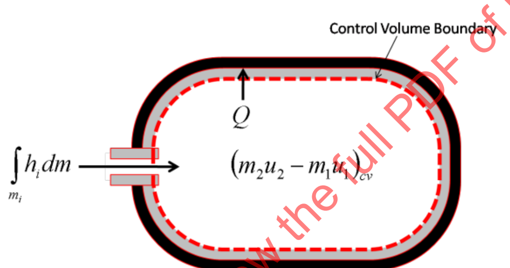

Figure H15 - Illustration of the control volume utilized in the MC Method

The heat transfer can also be defined as the difference in the adiabatic internal energy and the final internal energy, also expressed in terms of temperature in Equation H19, where m_2 represents the mass in the storage vessel at the end of the fill, m_1 represents the initial mass in the storage vessel, and C_v represents the specific heat capacity of hydrogen at constant volume. Figure H16 gives a visual illustration of this phenomenon.

$$Q = m_2(u_{adiabatic} - u_2) = m_2 C_v (T_{adiabatic} - T_{final}) \quad \text{(Eq. H19)}$$

$$Where\ u_{adiabatic} = \frac{m_1 u_1 + \int_{m_1}^{m_2} h_i dm}{m_2}$$

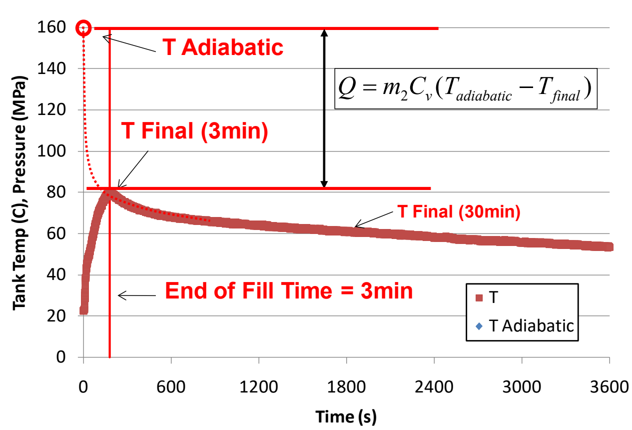

Figure H16 - Illustration of the heat Q removed quantified by $T_{adiabatic}$ and T_{final}

If a "characteristic volume" is defined, as shown in Figure H17, which is a mathematical construct with the characteristics of a thermal mass with an infinite conductive and convective heat transfer coefficient, the thermal mass being characterized as "MC," then the heat transfer can be expressed in terms of the initial and final gas temperatures as shown in Equation H20.

$$Q = MC\left(T_{final} - T_{initial}\right) \qquad \text{(Eq. H20)}$$

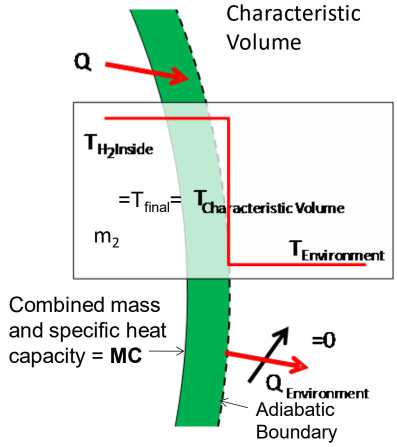

Figure H17 - Illustration of a characteristic volume

Equations H.19 and H.20 can be combined such that the final gas temperature T_{final} can be expressed in terms of the initial gas temperature, the adiabatic gas temperature and MC, as shown in Equation H21.

$$m_2 C_v\left(T_{adiabatic} - T_{final}\right) = MC\left(T_{final} - T_{initial}\right) \qquad \text{(Eq. H21)}$$

$$T_{final} = \frac{m_2 C_v T_{adiabatic} + MC \times T_{initial}}{MC + m_2 C_v}$$

MC is not a constant, but varies as a function of the fueling time t as well as the initial conditions. The equation used to represent MC was derived through analysis of hydrogen fueling tests on both Type III and Type IV storage vessels. The equation which best fits the data is shown in Equation H22, where $U_{adiabatic}$ represents the end of fill adiabatic internal energy of the hydrogen in the storage vessel, $U_{initial}$ represents the initial internal energy of the hydrogen in the storage vessel, and Δt represents the elapsed time after the first 30 seconds of the fill. The coefficients of the MC equation are unique to the storage vessel under consideration and can be derived either through a series of hydrogen fueling tests or fueling simulations.

$$MC = AC + BC \times \ln\sqrt{\frac{U_{adiabatic}}{U_{initial}}} + GC \times \left(1 - e^{-KC \times \Delta t}\right)^{JC} \qquad \text{(Eq. H22)}$$

H.3.1.2 Derivation of MC Equation Coefficients

To derive the coefficients of the MC Equation utilized for ending pressure control in the MC Formula-based protocol, a series of fueling simulations were run. The fueling model described in A.1 was utilized in combination with the 70 MPa cold case storage vessel (CHSS) specifications shown in Table A3. Heat transfer from the station and vehicle components $\dot{Q}_{sf}$ and $\dot{Q}_{vf}$ were not considered, so the enthalpy at the dispenser outlet is the same as the enthalpy entering the control volume of the storage vessel. A set of twenty-five simulations were run according to the conditions listed in Table H3. These conditions were chosen so as to provide a wide range of values for the two independent variable terms in the MC equation, $\frac{U_{adiabatic}}{U_{initial}}$ and Δt.

Table H3 - Conditions of fueling simulations on 70 MPa cold case CHSS

Sim No.	Amb Temp (°C)	Fuel Delivery Temp (°C)	Start Pressure (MPa)	CHSS Soak Temp (°C)	Approx. Fill time (s)	APRR (MPa/min)	End of Fill Condition	Record Time (minutes after fill stops)
1	0	-40	2	0	35	146.6	100% SOC	60
2	20	-40	2	20	90	57.0	100% SOC	60
3	40	-40	2	40	180	28.5	100% SOC	60
4	0	-40	20	0	35	115.7	100% SOC	60
5	20	-40	20	20	90	45.0	100% SOC	60
6	40	-40	20	40	180	22.5	100% SOC	60
7	0	-40	40	0	35	81.4	100% SOC	60
8	20	-40	40	20	90	31.7	100% SOC	60
9	40	-40	40	40	180	15.8	100% SOC	60
10	0	-40	60	0	35	47.1	100% SOC	60
11	20	-40	60	20	90	18.3	100% SOC	60
12	40	-40	60	40	180	9.2	100% SOC	60
13	0	-22.5	2	0	35	146.6	100% SOC	60
14	20	-22.5	2	20	90	57.0	100% SOC	60
15	40	-22.5	2	40	180	28.5	100% SOC	60
16	0	-22.5	20	0	35	115.7	100% SOC	60
17	20	-22.5	20	20	90	45.0	100% SOC	60
18	40	-22.5	20	40	180	22.5	100% SOC	60
19	0	-22.5	40	0	35	81.4	100% SOC	60
20	20	-22.5	40	20	90	31.7	100% SOC	60
21	40	-22.5	40	40	180	15.8	100% SOC	60
22	0	-22.5	60	0	35	47.1	100% SOC	60
23	20	-22.5	60	20	90	18.3	100% SOC	60
24	40	-22.5	60	40	180	9.2	100% SOC	60
25	15	N/A	70	15	Defuel @ 0.7 g/s until Press = 2 MPa			

From the output of the fueling simulations, the parameters listed in Table H4 were calculated for each simulation. Table H4 represents the output for fueling simulation No. 1, shown as an example.

Table H4 - Example output from fueling simulation No. 1 on 70 MPa cold case CHSS

t (s)	$U_{adiabatic}/U_{inital}$	MC (kJ/K)	Δt (s)	ΔMC(30)	T_{final} (K)
34	28.84	5.32	4	0.26	327.89
30	26.61	5.05	0	0	326.20
60	28.84	7.37	30	2.31	321.70
120	28.84	10.58	90	5.53	314.39
180	28.84	12.91	150	7.86	310.32
300	28.84	16.19	270	11.14	305.80
600	28.84	19.84	570	14.79	301.90
1200	28.84	22.42	1170	17.36	299.67
2400	28.84	26.69	2370	21.64	296.64
3600	28.84	31.35	3570	26.29	294.04

The first line in Table H4 represents the end of fill conditions of the simulation. In this case, the total fill time is 34 seconds, the ending gas temperature T_{final} is 327.9 K, and MC is 5.32 kJ/K. Note that the fueling simulations continue after the end of fill condition of 100% SOC is reached. Heat transfer from the gas to the storage vessel wall is allowed to continue for 60 minutes after the fill ended. This allows MC and T_{final} to be calculated for times up to 3600 seconds, which is necessary for deriving the coefficients of the MC equation.

With the data shown in Table H4 for each of the simulation runs, it is possible to derive the coefficients of the MC equation, Equation H22. Because MC is a function of $\frac{U_{adiabatic}}{U_{initial}}$ and Δt, it is necessary to separate these two independent parameters in deriving the MC coefficients. The first step is to utilize simulation output data where Δt is equal to zero, which isolates the first two terms of the MC equation. Since Δt is defined as the fueling time beyond the first 30 seconds, Δt is equal to zero when t is equal to 30 seconds. MC is plotted against $\frac{U_{adiabatic}}{U_{initial}}$ for simulations 1 through 24, as shown in Figure H18, and then a best fit of the data is performed using the equation $AC + BC \times \ln\sqrt{\frac{U_{adiabatic}}{U_{initial}}}$ to derive the coefficients AC and BC.

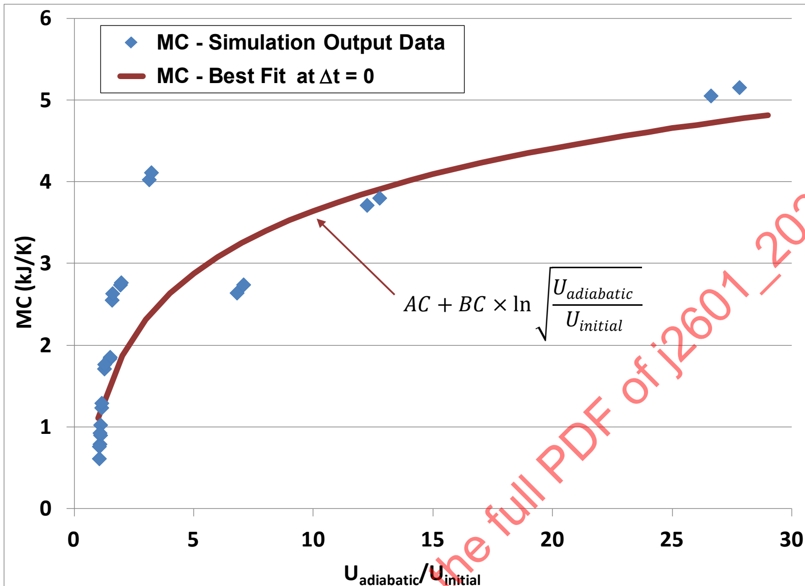

Figure H18 - Best fit of MC equation at Δt = 0

The second step in deriving the MC equation coefficients is to isolate the second part of the MC equation $GC \times (1 - e^{-KC \times \Delta t})^{JC}$. This is done by calculating a parameter ΔMC, which is the difference between MC at time t > 30 seconds and MC at time t = 30 seconds, and plotting this against time at t > 30 seconds and time at t = 30 seconds, or Δt. Thus, ΔMC is plotted against Δt, and a best fit is calculated using the equation $GC \times (1 - e^{-KC \times \Delta t})^{JC}$, as shown in Figure H19.

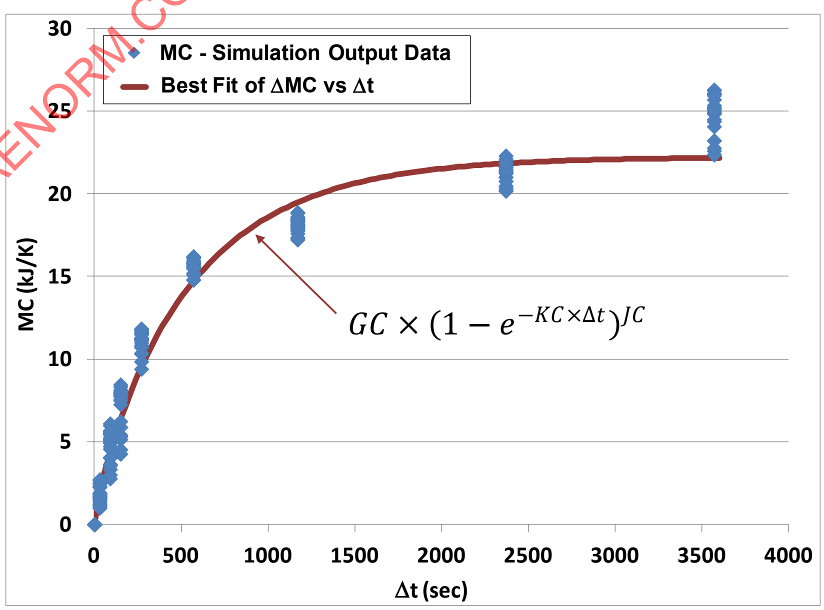

Figure H19 - Best fit of ΔMC versus Δt

From these two best fit processes, an overall best fit of the MC equation to the simulation data is obtained, resulting in the determination of the five coefficients of the MC equation, Equation H22. The final values of these coefficients is shown in Table H5.

Table H5 - Final values of MC equation coefficients

AC	1.10487E+00
BC	2.20466E+00
GC	2.22198E+01
KC	1.63097E-03
JC	8.23284E-01

H.3.1.3 Derivation of Defueling Equation

In order to utilize the MC Method to calculate the ending pressure target, an initial temperature in the cold case CHSS must be calculated. The cold soak boundary conditions from Table A4, along with the maximum defueling rate from Table A3 are utilized. The cold case initial temperature is calculated by using the MC Method, with gas exiting the control volume instead of entering it. For defueling, a unique set of MC equation coefficients were derived using the results from simulation number 25 in Table H3. To calculate the cold case initial temperature using the MC Method, an iterative solution is required, as the enthalpy exiting the control volume is a function of the gas temperature, which is also what is being solved. To eliminate the need for iteration, and to simplify this calculation, a regression equation was developed which calculates the cold case initial temperature T_{init_cold} as a function of the ambient temperature T_{amb} and the initial pressure $P_{initial}$. A lower cap on T_{init_cold} is set at -40 °C, as explained in A.6. The final regression equation is expressed in Equation H23.

$$T_{fit\_1} = 273.15 + P_{initial} \times 0.31 - 12.21 \qquad \text{(Eq. H23)}$$

$$T_{fit\_2} = 273.15 + (T_{amb} - 273.15) \times (0.89 - P_{initial} \times 6.74\text{E-}06) + (P_{initial} \times 0.31 - 43.45)$$

$$\text{IF } T_{fit\_2} > T_{fit\_1},\ THEN\ T_{init\_cold} = T_{fit\_1},\ ELSE\ T_{init\_cold} = T_{fit\_2}$$

$$\text{AND IF } T_{init\_cold} < 233.15,\ T_{init\_cold} = 233.15$$

H.3.1.4 Ending Pressure Calculation using MC Method

The ending pressure is calculated from the cold case end of fill calculated gas temperature T_{cold}. The equations utilized to calculate T_{cold} are given in J.2.2, J.2.3, and J.2.5. The nomenclature used in defining the parameters of the MC Method in J.2 is different than that utilized in H.3.1, as the denotation of these parameters is for the cold case scenario, whereas H.3.1 denotes the MC Method parameters in general terms. To relate the parameters of the general MC Method in H.3.1 to those of the cold case utilized in J.2, Table H6 is provided as a reference.

Table H6 - Relationship of general MC Method nomenclature to that of cold case nomenclature

Cold Case MC Method Nomenclature Section J.2	Cold Case Reference Equation(s)	General MC Method Nomenclature Section H.3.1	General Case Reference Equation(s)
T_{init_cold}	J.34	$T_{initial}$	H.21, H.22
m_{init_cold}	J.41	m_1	H.18
m_{final_cold}	J.40	m_2	H.18, H.19, H.21
u_{init_cold}	J.43	u_1	H.18
U_{init_cold}	J.44	$U_{initial}$	H.22
m_{add} x h_{ave}	J.64	$\int_{m_1}^{m_2} h_i dm$	H.18, H.19
$U_{adiabatic\_cold}$	J.64	$U_{adiabatic}$	H.22
$u_{adiabatic\_cold}$	J.65	$u_{adiabatic}$	H.19
$T_{adiabatic\_cold}$	J.66	$T_{adiabatic}$	H.19, H.21
c_{v_cold}	J.67	C_v	H.19, H.21
Δt_{cold}	J.35, J.68, J.69	Δt	H.22
MC_{cold}	J.69	MC	H.20, H.21, H.22
T_{cold}	J.70	T_{final}	H.19, H.20, H.21

T_{cold} is the final output of the MC Method calculations. With T_{cold} and a target density, a target end of fill pressure can be calculated. T_{cold} is used to calculate the target pressure for non-communication fueling and a limit pressure for communication fueling. The target density for non-communication fills is 40.2 g/L and 24.0 g/L for H70 and H35, respectively.

For communication fills, the target density is also based on 40.2 g/L and 24.0 g/L for H70 and H35, respectively, however, the measured CHSS temperature MT is used instead of T_{cold} as the temperature input. A discount factor SOC_{target} is applied to account for sensor accuracy in the measurement of pressure and temperature. For example, if SOC_{target} is set to 98, this discounts or reduces the target density by 2%. SOC_{target} is set by the dispenser manufacturer based on the accuracy of the sensors utilized.

A limit pressure is also calculated from T_{cold} for communication fills based on a limit of 115% SOC for the cold case scenario, which corresponds to maximum density of 46.23 g/L for the H70 pressure class and 27.6 g/L for H35 pressure class. The rationale for setting the limit at 115% SOC is that it corresponds to the maximum cold case SOC for the table-based protocol when fueling to the communication pressure targets (see A.7). Note that in A.7, 120% SOC is chosen as the target SOC for computing the cold case final pressures P_{CC}. However, in calculating the communications pressure targets for the table-based protocol, P_{CC} is never utilized (P_{HC} is always the limiting pressure). Simulations of the table-based protocol utilizing cold case conditions and fueling to the communication pressure targets result in a maximum SOC of 115%.

Equations J.82, J.83, and J.84 in J.2.7.2 are used to calculate the non-communication pressure target, the communication pressure target, and the communication pressure limit, respectively. These equations represent a curve fit of pressure versus temperature at constant density (target density).

H.3.1.5 Validation of MC Method Ending Pressure Control

The ending pressure control using the MC Method is designed to be conservative. This is because the coefficients of the MC equation were derived using a best fit approach; thus, the MC equation does have some tolerance which must be accounted for. The tolerance in the MC equation is accounted for through the calculation of the mass average enthalpy. The mass average enthalpy is measured at the dispenser outlet, and thus ignores the transfer of heat from the environment to the gas through the station and vehicle components, as well as the heat stored in these components prior to fueling. This means that the actual enthalpy entering the CHSS is higher than that being measured at the dispenser outlet. Because the calculated enthalpy is lower than the actual enthalpy entering the CHSS, the calculated ending gas temperature is colder, resulting in a lower ending pressure target. Thus, the MC Method calculated pressure target is conservative, even when considering the tolerance in the MC equation. To demonstrate and validate this, fueling simulations and bench testing were performed.

To validate the ending pressure control using the MC Method, fueling simulations were conducted on the cold case CHSS. The objective was to show that the ending SOC is always equal to or less than 100%. The MC Method ending pressure control and MC Formula pressure ramp rate control were programmed into the fueling model explained in A.1, and then a series of fueling simulations were conducted on the cold case CHSS, where first, the CHSS was defueled under cold soak starting conditions, and subsequently refueled using the MC Formula PRR control. Ambient temperature, initial pressure, and fuel delivery temperature were varied to validate the ending pressure control under a wide range of conditions. In total, 48 simulations were conducted for the H70 cold case CHSS and 45 simulations were conducted for the H35 cold case CHSS. The maximum SOC for the H70 simulations was 99.7% and the maximum SOC for the H35 simulations was 100%.

Additionally, a laboratory test was conducted using a set of two 2.3 kg Type III vessels, again under cold soak and defueling conditions with subsequent refueling. The ending SOC of this test was 97.1%.

The details of the simulation conditions and results, as well as the laboratory test conditions and result, can be found in Section 8 and Appendix B of SAE Paper 2014-01-1833, “Validation and Sensitivity Studies of SAE J2601, the Light Duty Vehicle Hydrogen Fueling Standard.”

Field validation testing of the MC Formula-based protocol was also conducted on both a test tank and representative OEM fuel cell vehicles. Over 100 fueling tests at a real world representative fueling station were conducted, analyzed, and documented in SAE Paper 2015-01-1177, “Field Validation of the MC Default Fill Hydrogen Fueling Protocol.”

Note that in the above two referenced SAE papers, the “MC Default Fill” is synonymous with the MC Formula-based protocol. The name of the protocol was subsequently changed by the SAE Fuel Cell Standards Interface Task Force.

H.3.2 Ending Pressure Tables

As an alternative to the MC Method described in H.3.1 for the ending pressure control, a set of ending pressure tables may be utilized, which function in the same manner as the pressure targets utilized in the table-based protocol.

H.3.2.1 Rationale

Ending pressure tables providing fixed pressure target and pressure limit values may be utilized for ending pressure control of the MC Formula-based protocol because the fueling time is bounded by the lower pressure limit of the pressure corridor and the mass average of the fuel delivery temperature used for control (MAT_C) is categorized by T40, T30, or T20, with a separate set of pressure targets for each fuel delivery temperature category.

The bounding of the fueling time is illustrated in Figure H20.

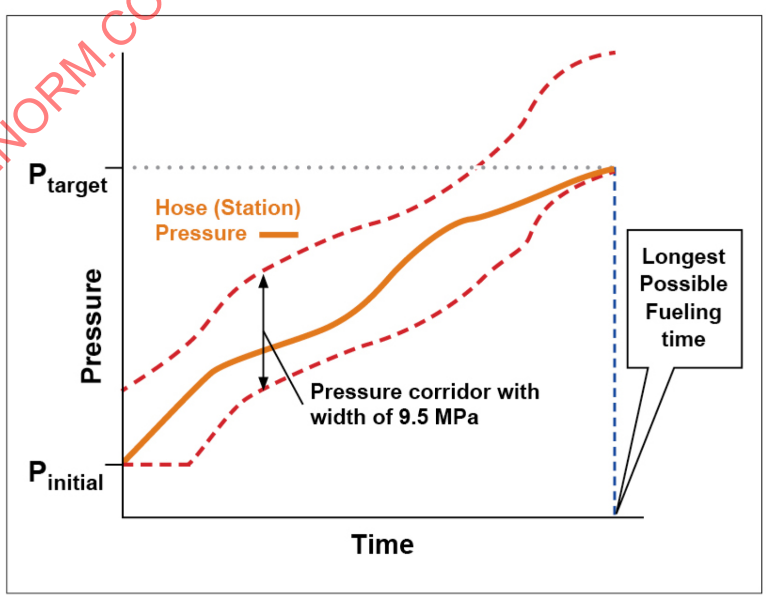

Figure H20 - Illustration of how the fueling time is bounded by the lower limit of pressure corridor

The fueling time is also bounded by the fuel delivery category. The slowest possible fueling time within a fuel delivery category is at the upper boundary of that category, as illustrated in Figure H21.

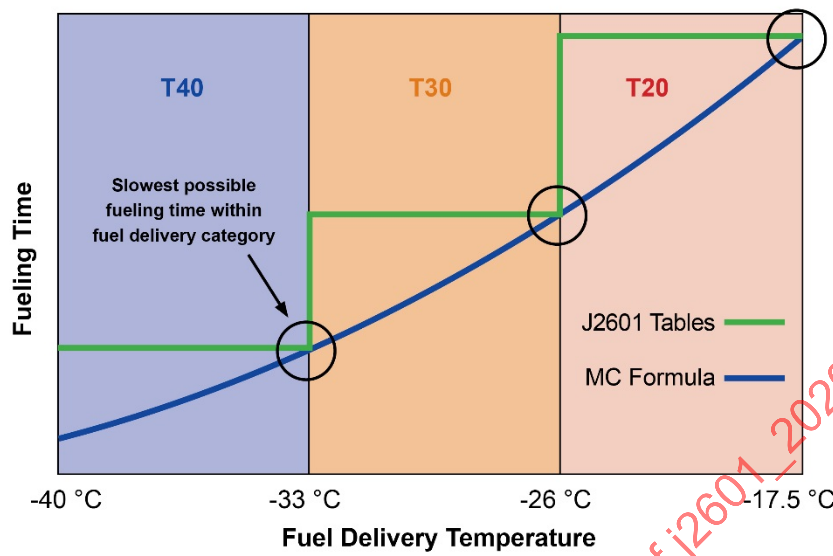

Figure H21 - Illustration of how the fueling time is bounded by the fuel delivery category

When combining the slowest possible fueling time within a fuel delivery category, along with the slowest possible fueling time within the pressure corridor, the longest possible fueling time is calculated for each ambient temperature and starting pressure. From this, a table of pressure targets is calculated in the same manner as explained in A.5 through A.7.

H.3.2.2 Application

There are two considerations in applying ending pressure tables to the MC Formula-based protocol. The first consideration is which table of pressure targets or limits to use. The second consideration is the determination of the pressure target or pressure limit from the given table.

H.3.2.2.1 Choosing the Table

Each table of ending pressure tables is classified by the following attributes: pressure class, fuel delivery temperature category, communications or non-communications, CHSS capacity category, and warm dispenser or cold dispenser (CD).

The pressure class, CHSS capacity category, and warm dispenser or cold dispenser classification can be determined prior to the fill (main fueling time) commencing. The fuel delivery temperature category, and potentially communications or non-communications classifications are updated throughout the fill. Communications versus non-communications classification will only change if communications is lost during a communications fueling and the dispenser continues the fill using non-communications. The fuel delivery temperature category classification has the highest potential for changing during the fill, although the typical case is for the dispenser to keep the fuel delivery temperature within the intended category throughout the fill.

Instead of determining which table to use during each 1 second time step calculation, non-communication pressure targets and communication pressure limits are calculated for all potential cases in the ending pressure initialization step. Nine non-communication pressure targets and nine communication pressure limits are calculated (three fuel delivery temperature categories, T40, T30, and T20, and three CHSS Capacity Categories A, B, and C). This approach facilitates rapid determination of the correct non-communication pressure target and communication pressure limit to utilize during each 1 second time step calculation.

For the purpose of determining the correct pressure target and limit value to use, the fuel delivery temperature category is based on MAT_C, which is the mass average of the fuel delivery temperature utilized as the control input for the t_{final} equation (for the purpose of determining the station designator, the fuel delivery temperature category is based on MAT_{30}; see 9.1.1).

Since MAT_C is the most likely parameter to change during the fill, the logic for choosing the correct non-communication pressure target and communication pressure limit value based on the fuel delivery temperature category is shown in Equation H24. Note that for the T20 fuel delivery temperature category, the upper boundary temperature of -17.5 °C is not utilized in making the determination of whether to use the T20 non-communication pressure target and communication pressure limit. This is because MAT_C may exceed this upper boundary temperature during the fill, especially if the initial pressure is relatively high, while the fill still stays within the process limit requirements.

$$IF\ \ -40\ ℃ \leq MAT_C \leq -33\ ℃,\ THEN\ USE\ T40\ \ Pressure\ Targets\ and\ Limits \qquad \text{(Eq. H24)}$$

$ELSE$

$$IF\ \ -33\ ℃ < MAT_C \leq -26\ ℃,\ THEN\ USE\ T30\ \ Pressure\ Targets\ and\ Limits$$

$ELSE$

$$IF\ \ -26\ ℃ < MAT_C,\ THEN\ USE\ T20\ \ Pressure\ Targets\ and\ Limits$$

H.3.2.2.2 Calculation of the Pressure Target and Limit from the Tables

For a given ending pressure table, the actual pressure value to utilize is determined by the ambient temperature T_{amb} and starting pressure $P_{initial}$. Interpolation is utilized as described by Example B in Appendix G. For cases when the initial pressure is less than 5 MPa, the table value is directly used and interpolation is only conducted on ambient temperature.

APPENDIX I - SAE J2601 MC FORMULA-BASED FLOW CHARTS

I.1 INTRODUCTION

As per 9.7, this appendix details the flow charts for MC Formula-based fueling. These flow charts provide an explanation of the control logic for MC Formula-based fueling. These flow charts are to be used in conjunction with the subroutines detailed in Appendix J. Where appropriate, a reference to the applicable section and/or equation of Appendix J is called out in the flow charts.

An overview to the subroutines flow charts is as follows:

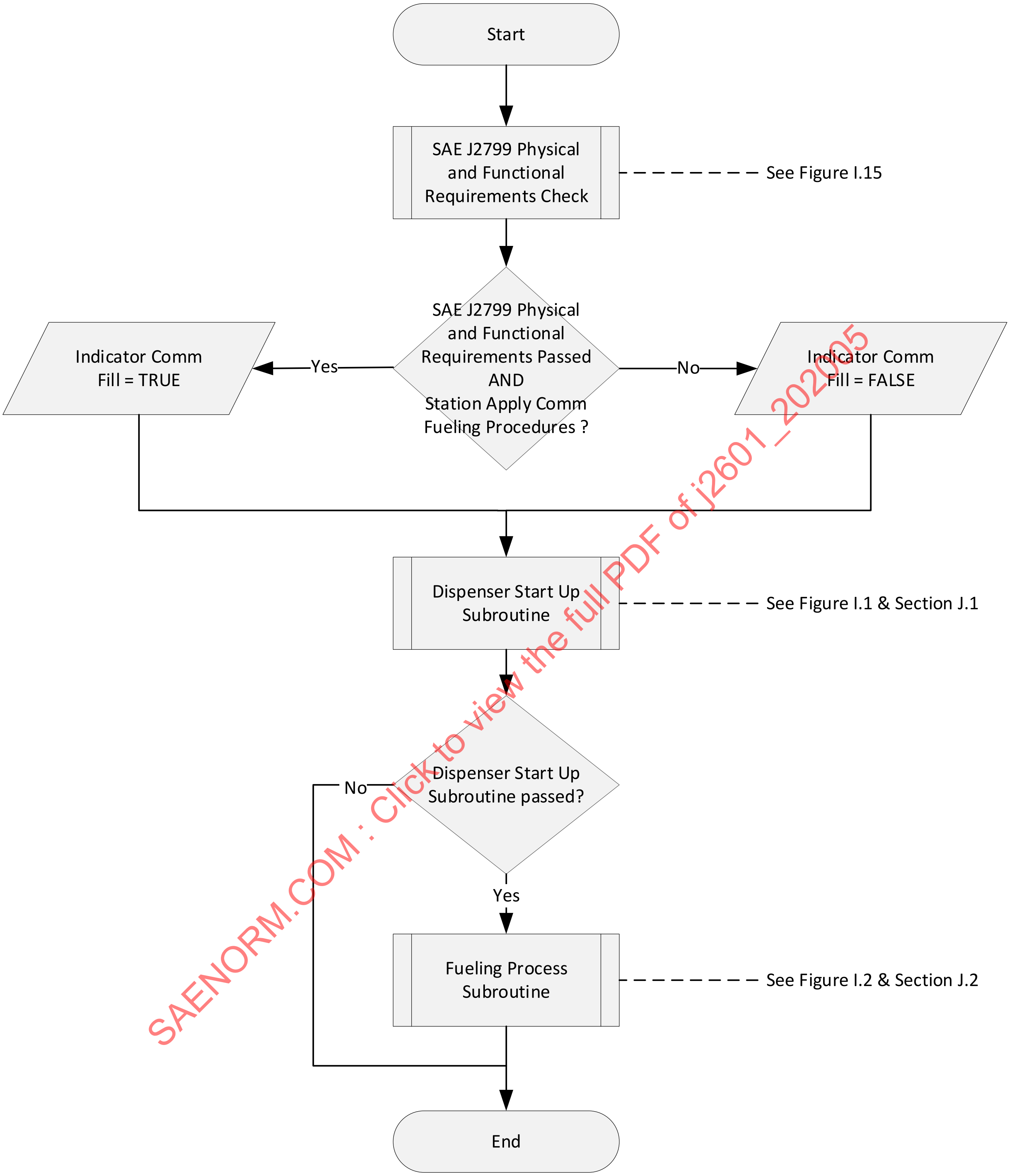

Figure I0 - SAE J2601 MC Formula-based fueling overview

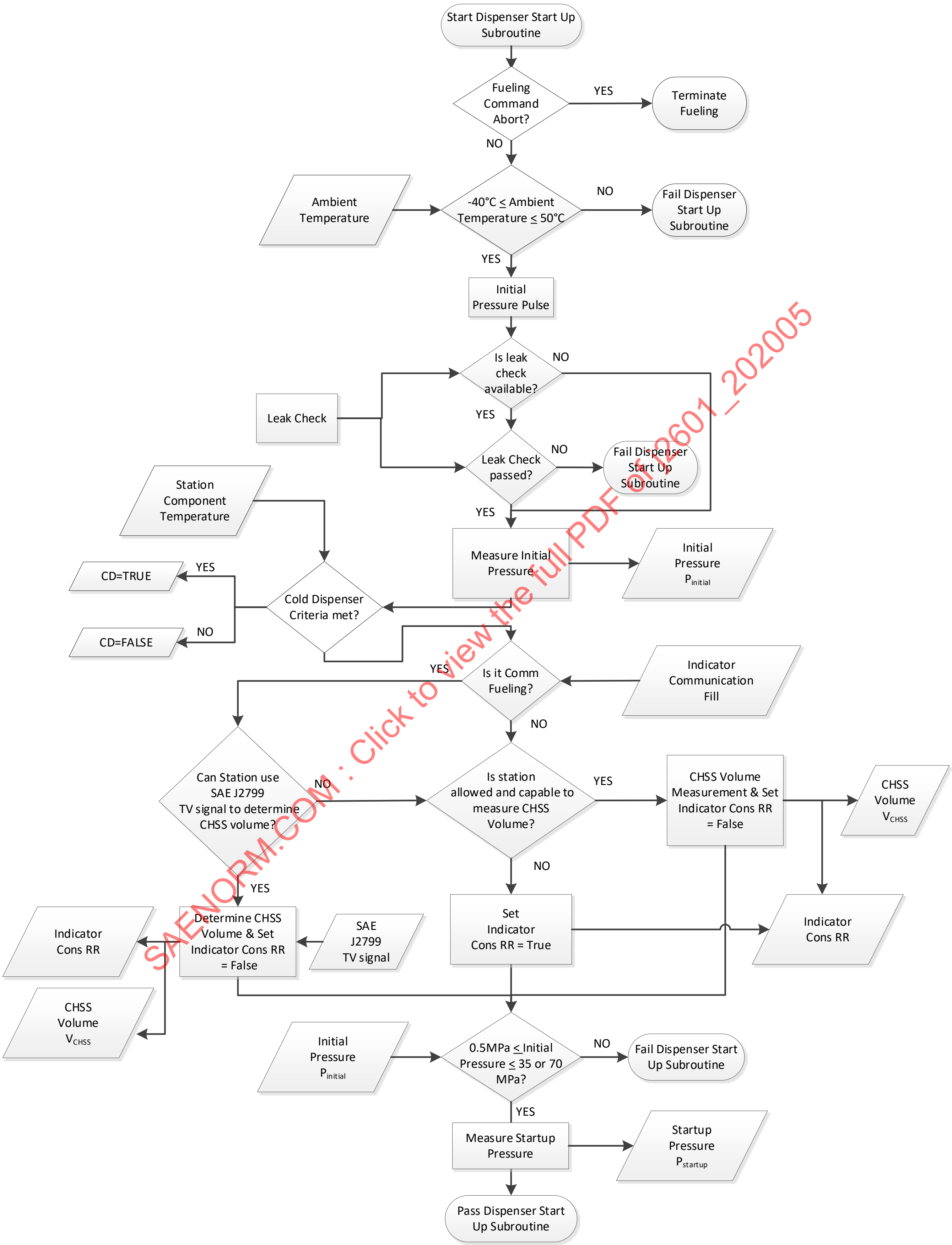

Figure I1 - SAE J2601 MC Formula-based dispenser start up subroutine

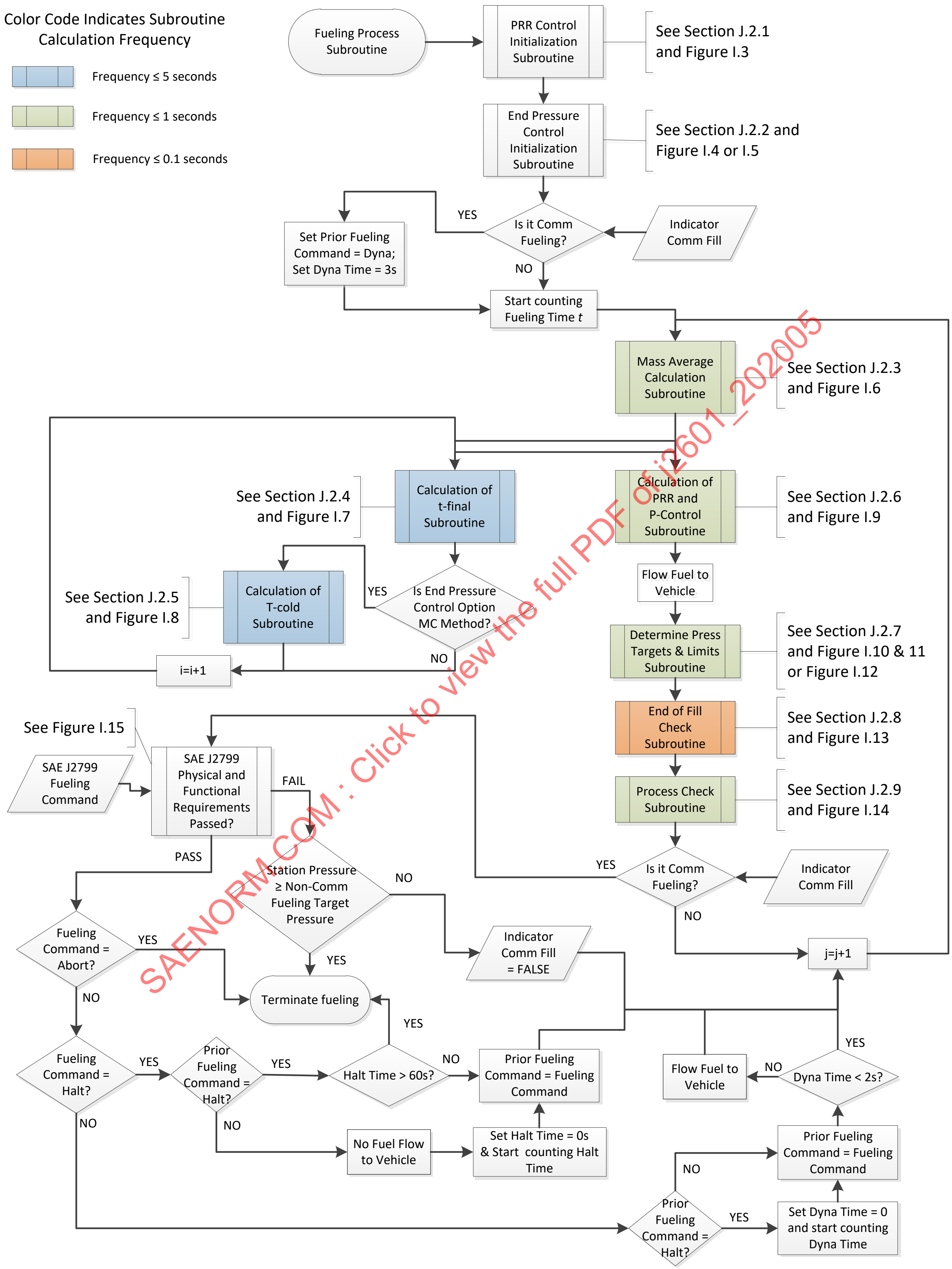

Figure I2 - SAE J2601 MC Formula-based fueling process subroutine

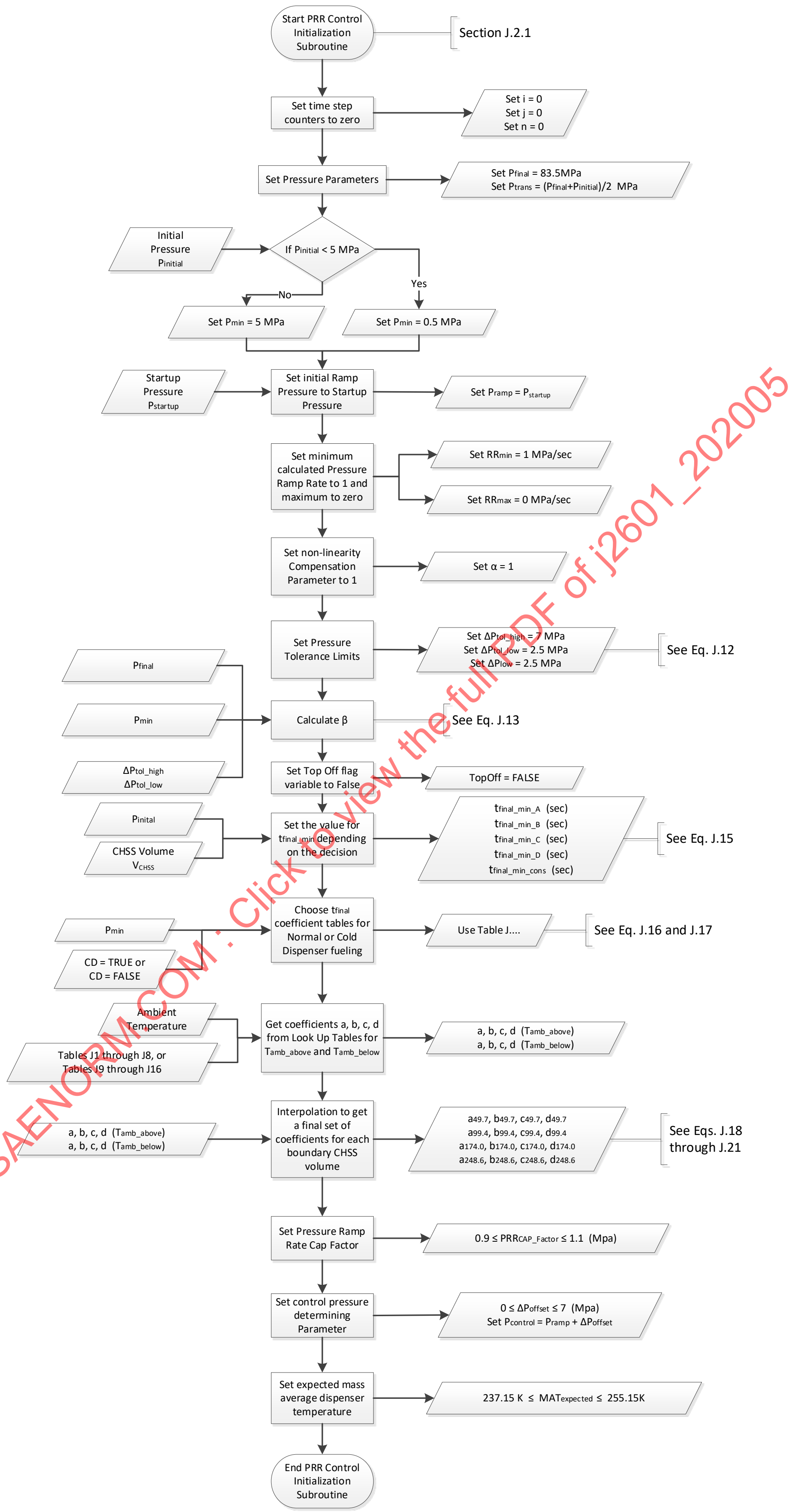

Figure I3 - SAE J2601 MC Formula-based PRR control initialization subroutine

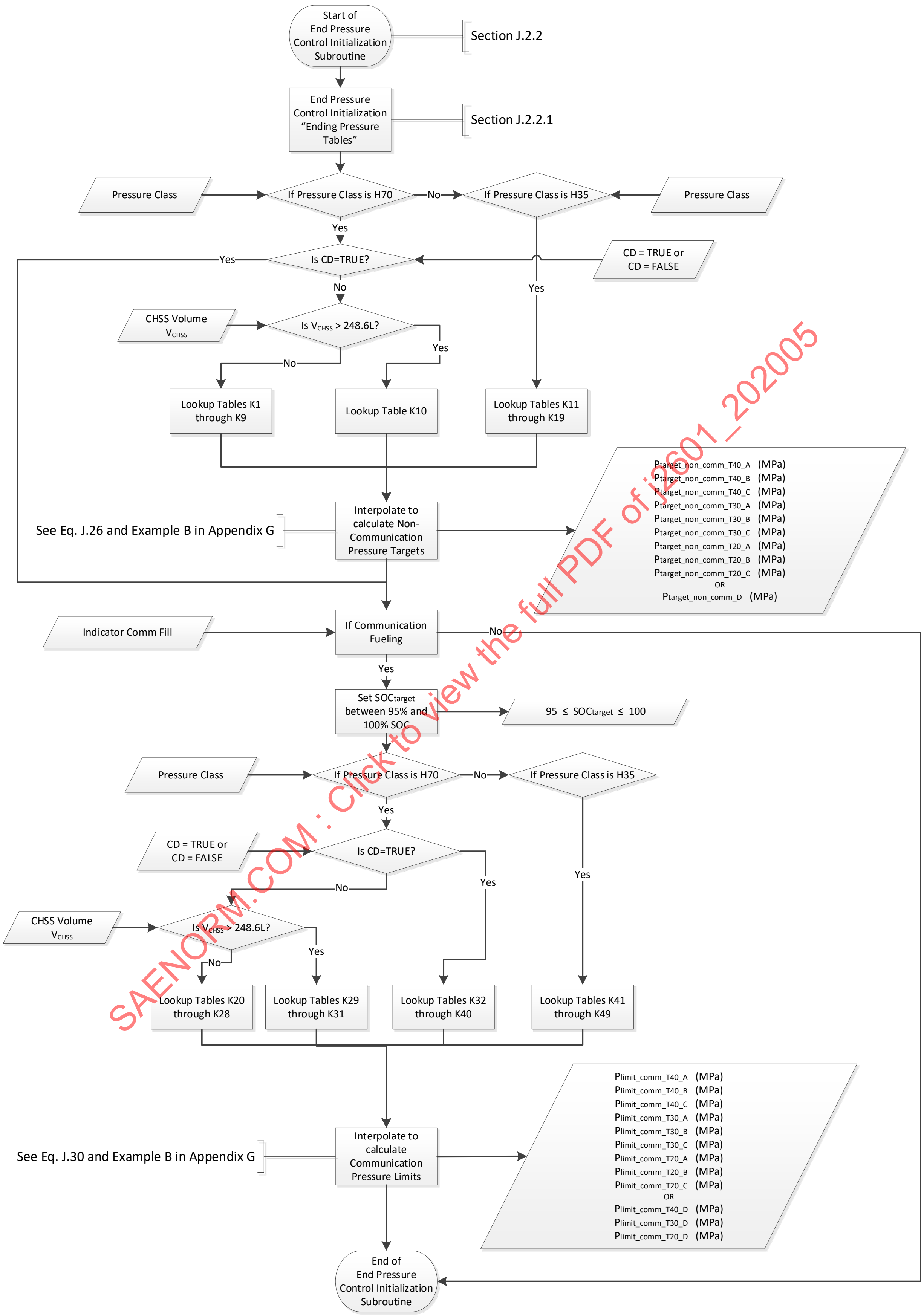

Figure I4 - SAE J2601 MC Formula-based end pressure control initialization subroutine - ending pressure tables

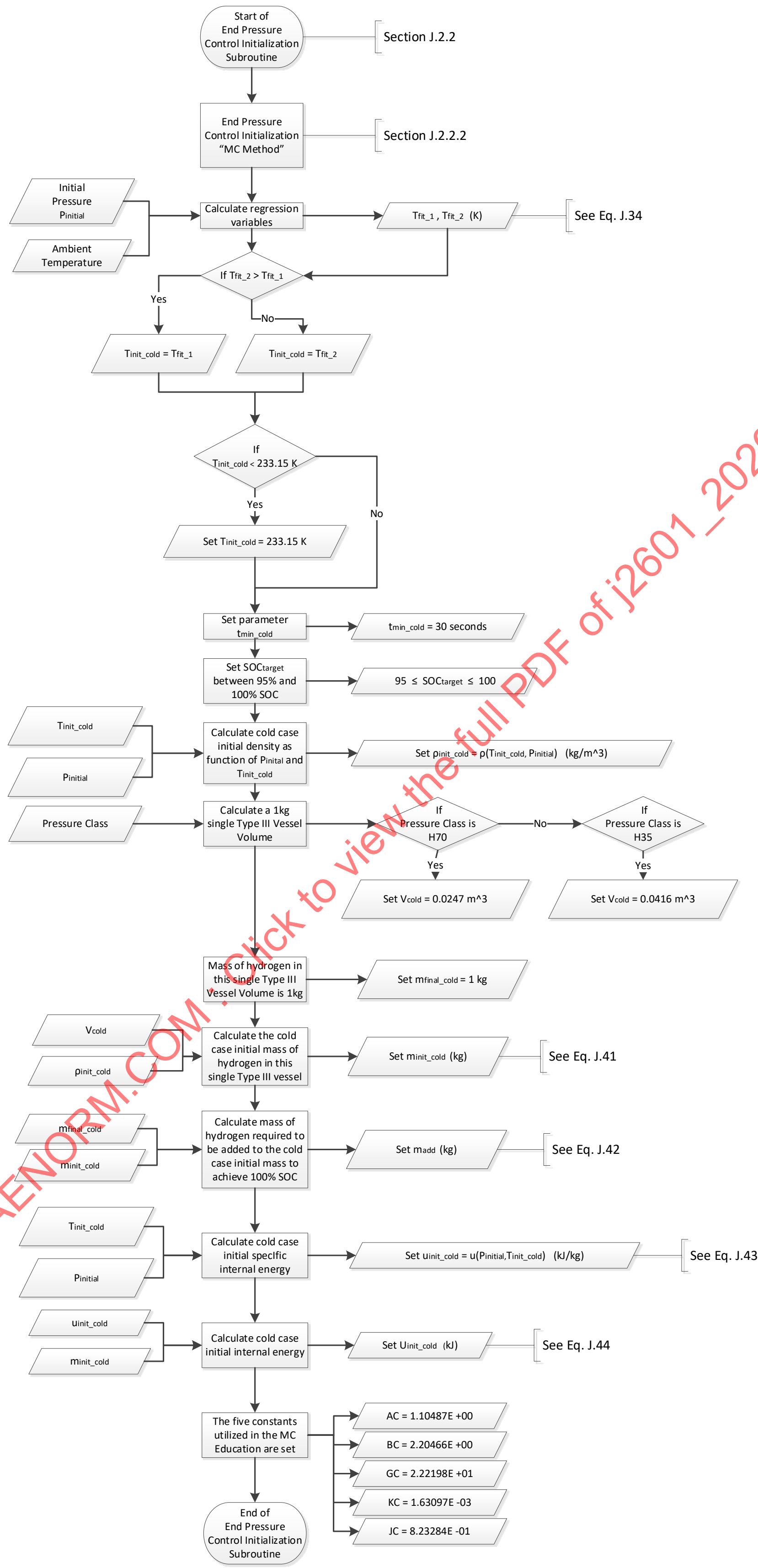

Figure I5 - SAE J2601 MC Formula-based end pressure control initialization subroutine - MC Method

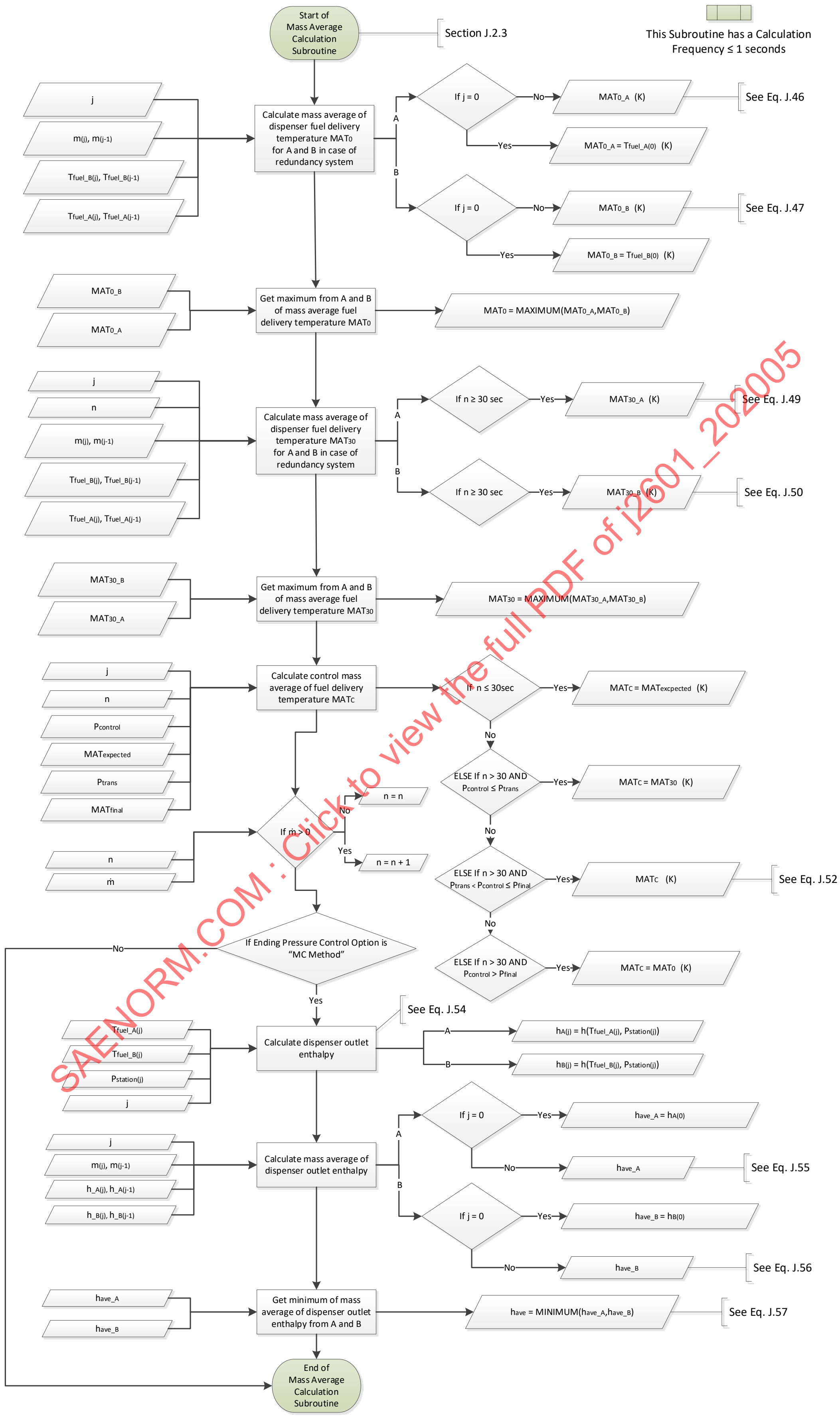

Figure I6 - SAE J2601 MC Formula-based mass average calculation subroutine

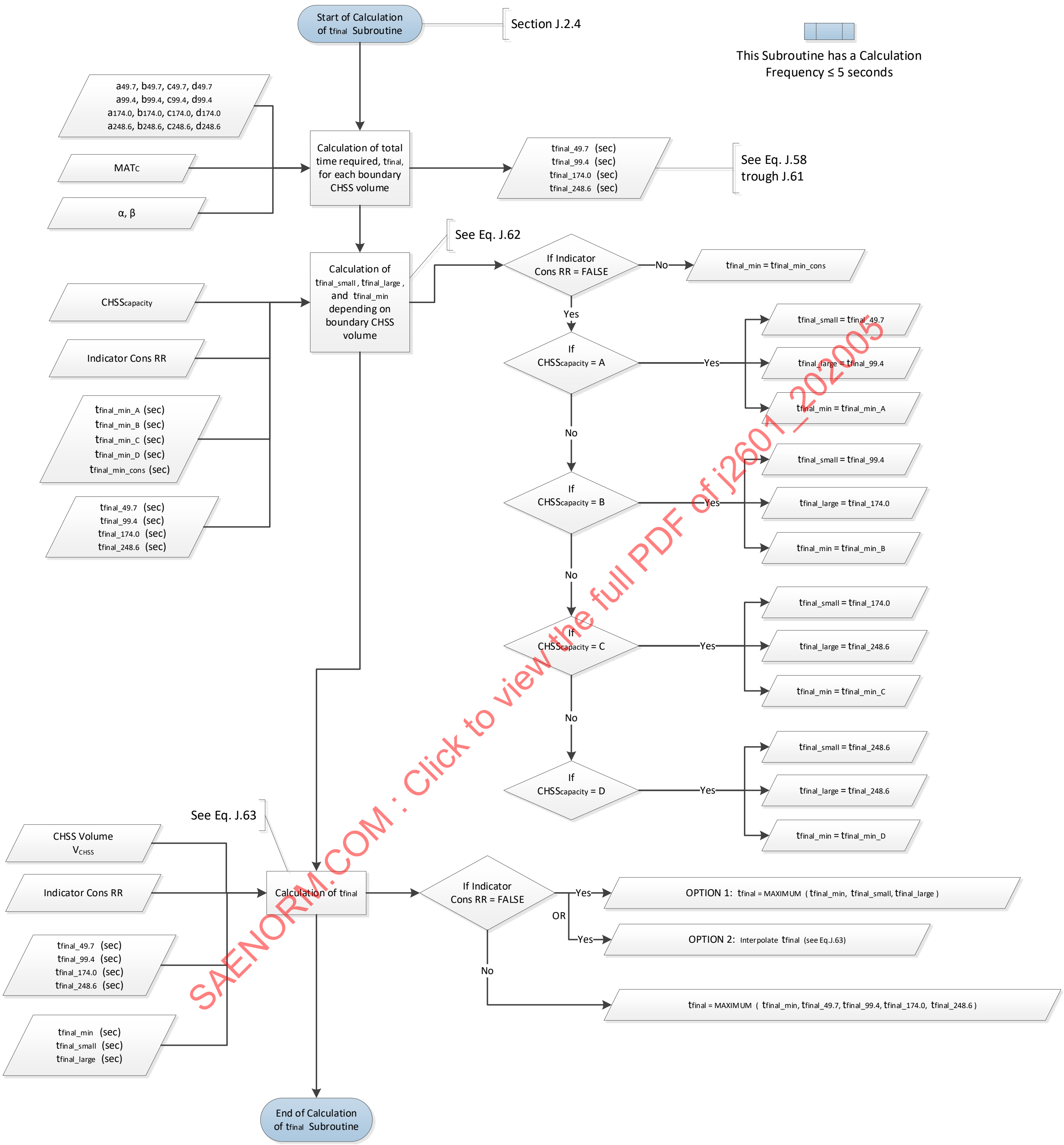

Figure I7 - SAE J2601 MC Formula-based calculation of t_{final} subroutine

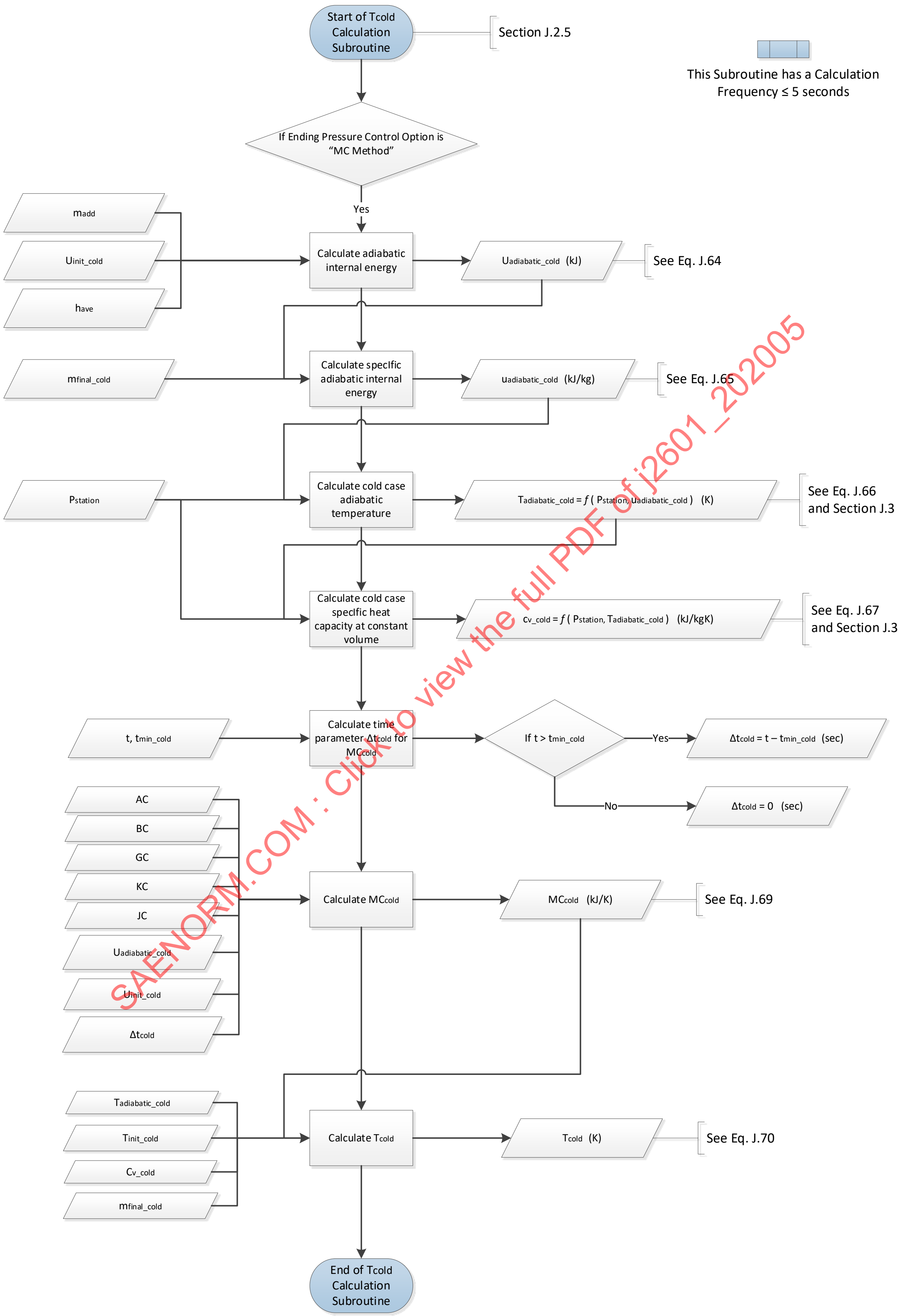

Figure I8 - SAE J2601 MC Formula-based calculation of T_{cold} subroutine

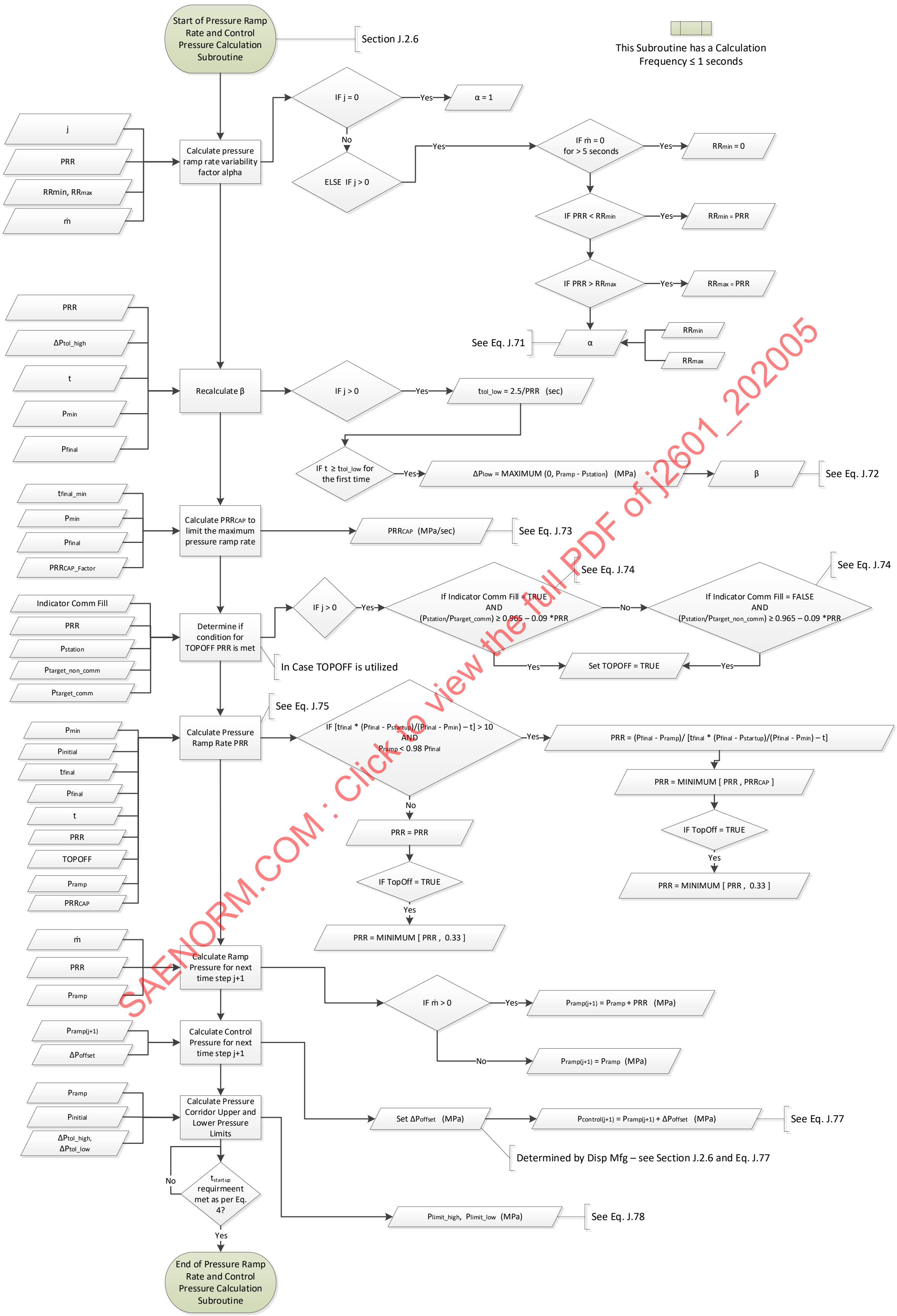

Figure I9 - SAE J2601 MC Formula-based calculation of PRR and $P_{control}$ subroutine

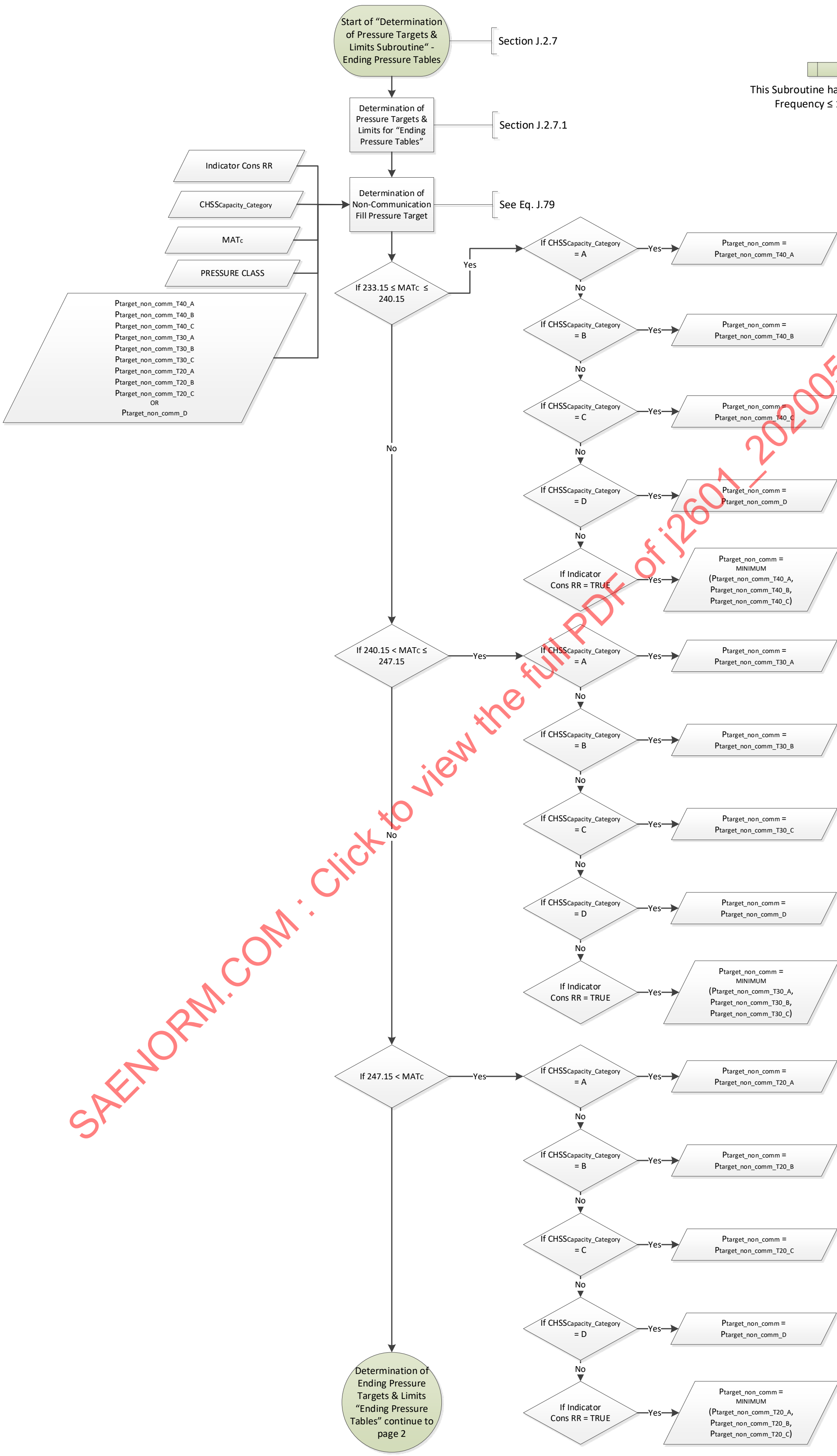

Figure I10 - SAE J2601 MC Formula-based determination of pressure targets and limits subroutine - ending pressure tables - page 1 of 2

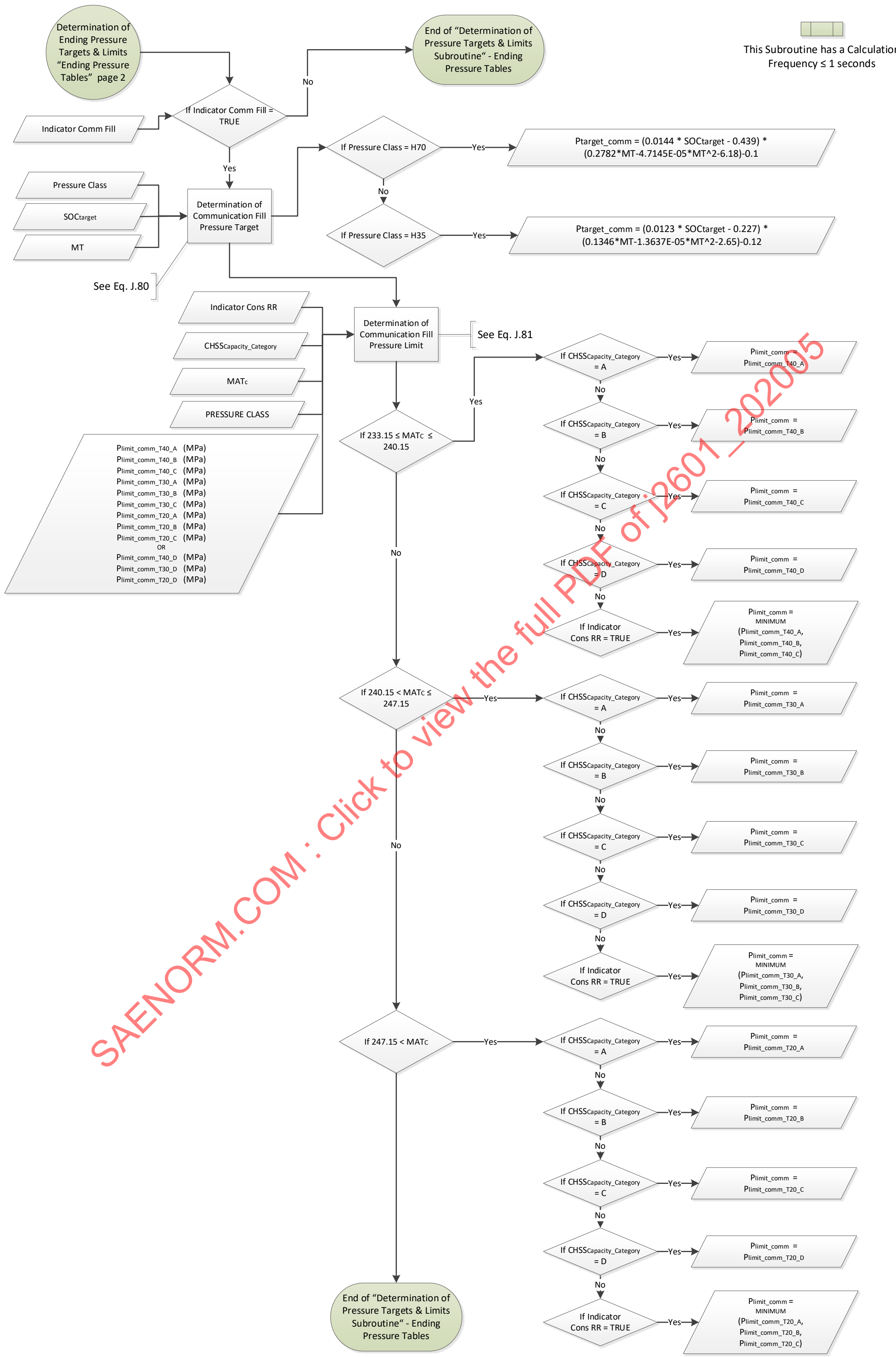

Figure I11 - SAE J2601 MC Formula-based determination of pressure targets and limits subroutine - ending pressure tables - page 2 of 2

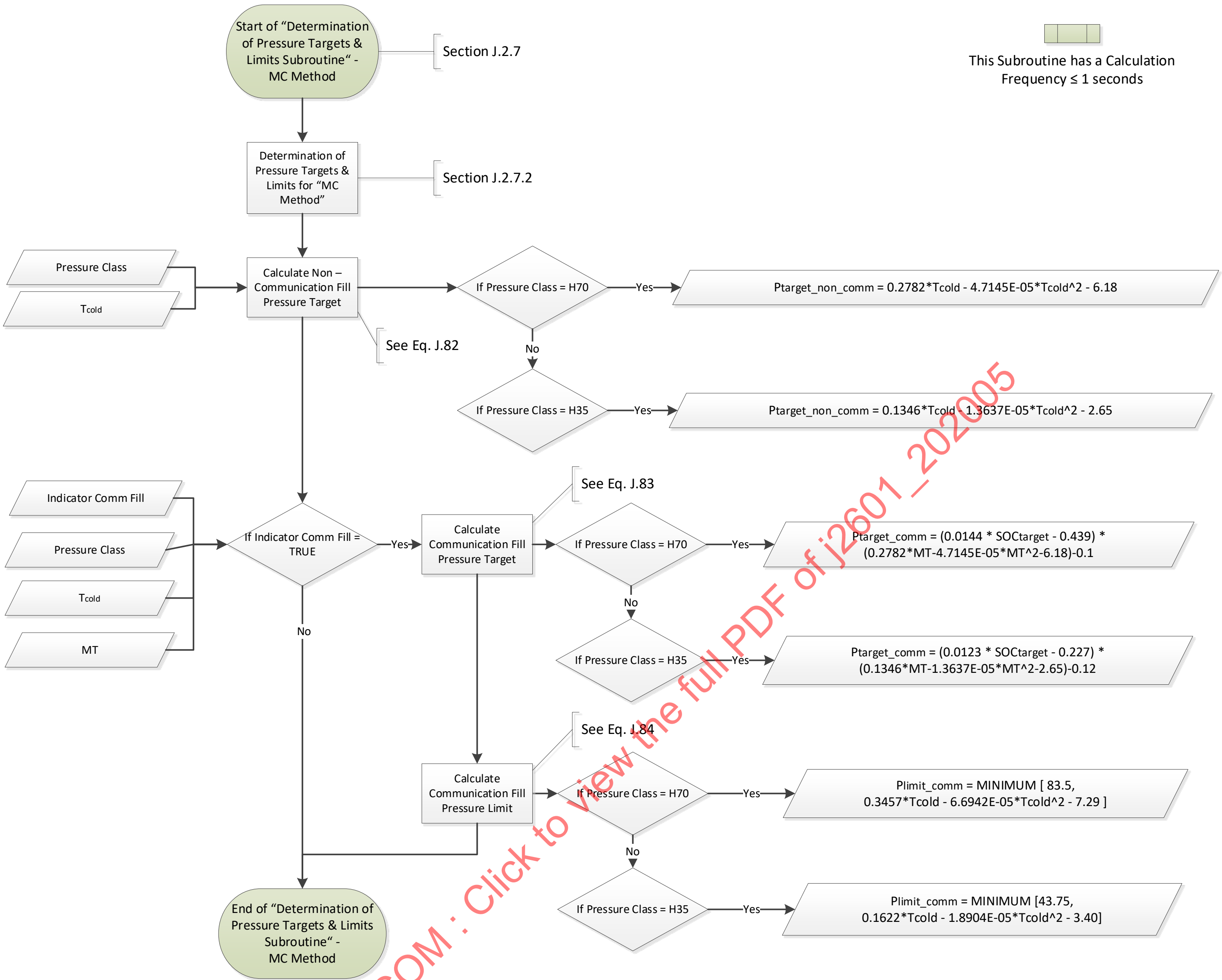

Figure I12 - SAE J2601 MC Formula-based determination of pressure targets and limits subroutine - MC Method

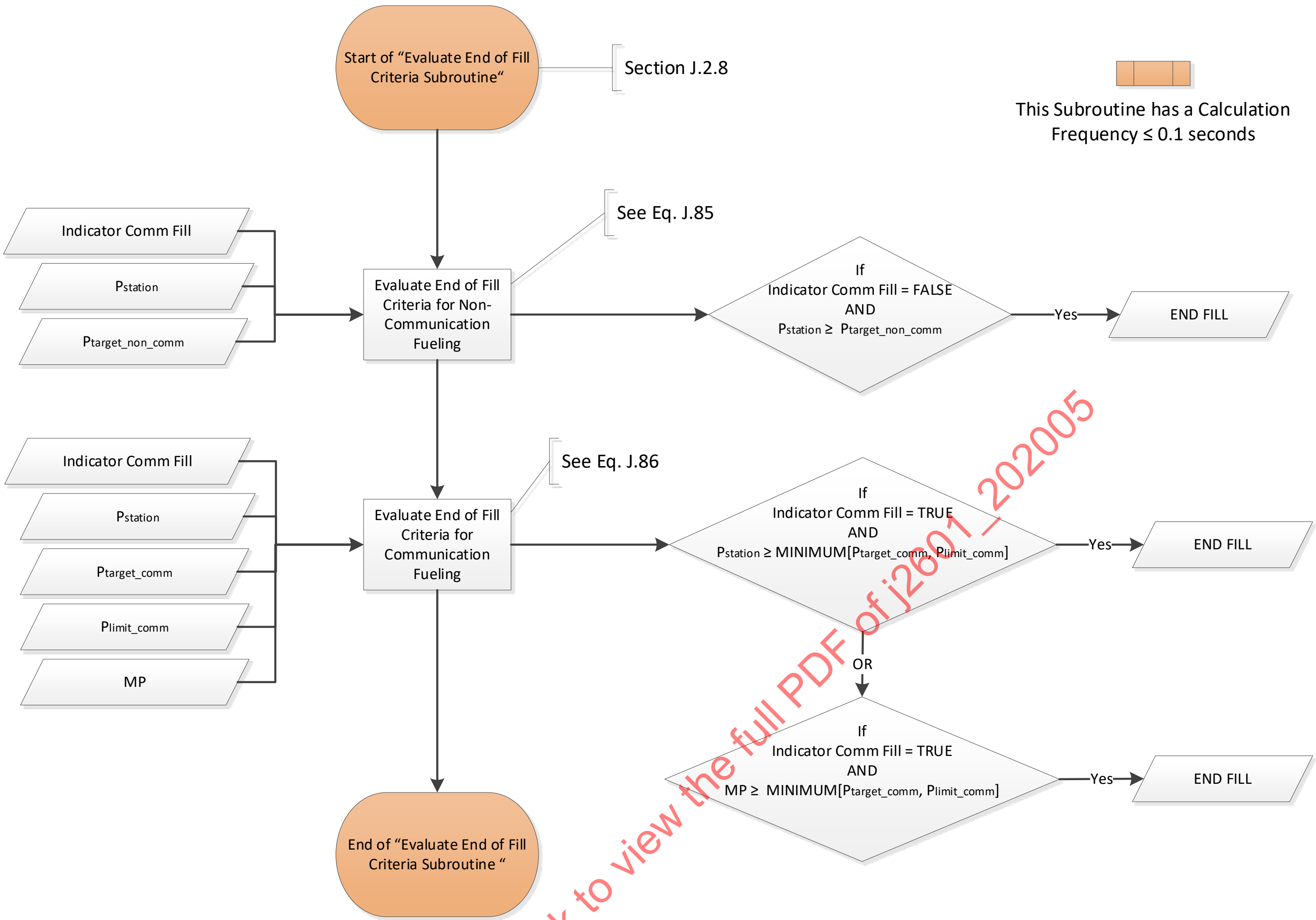

Figure I13 - SAE J2601 MC Formula-based evaluate end of fill criteria subroutine

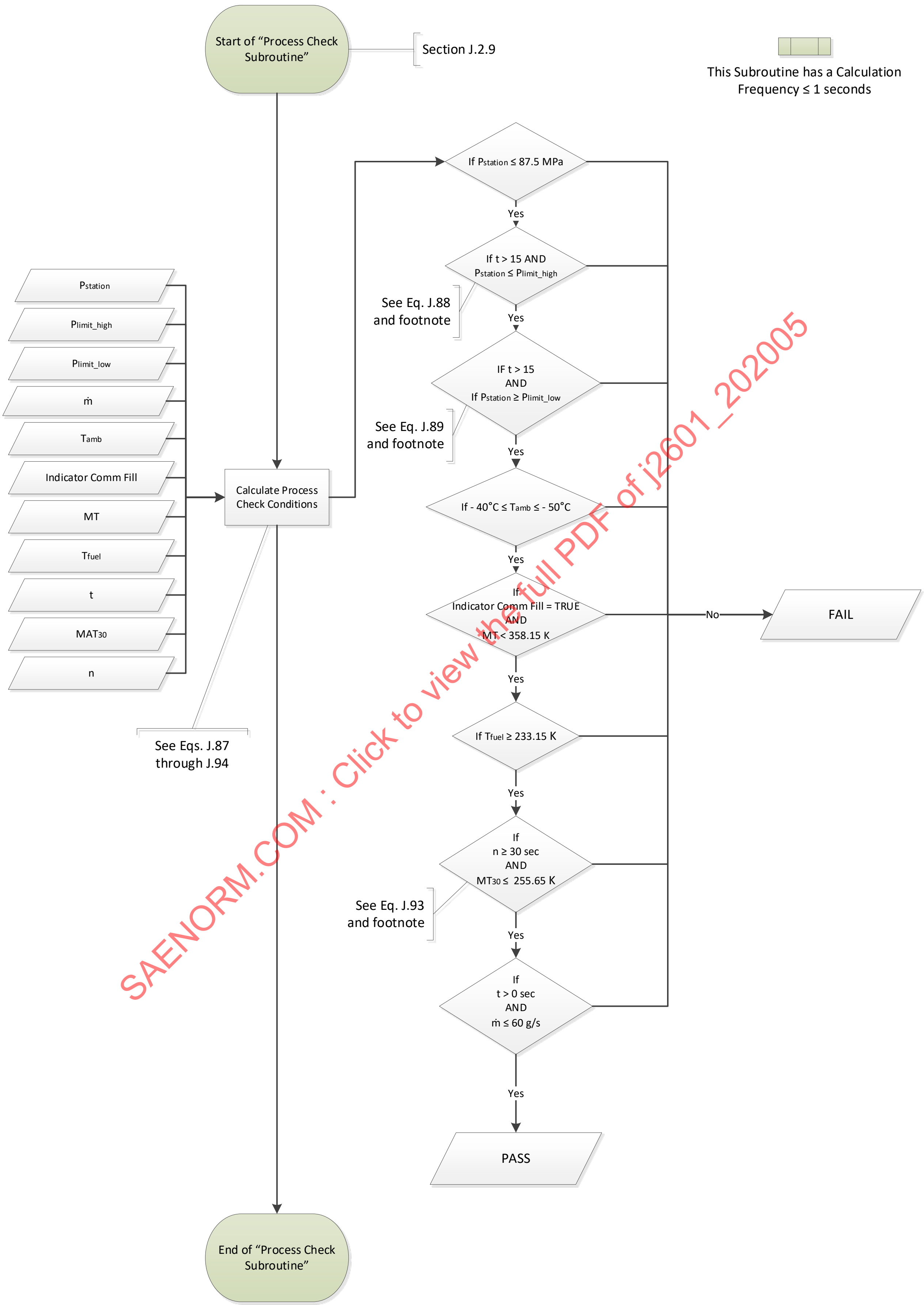

Figure I14 - SAE J2601 MC Formula-based process check subroutine

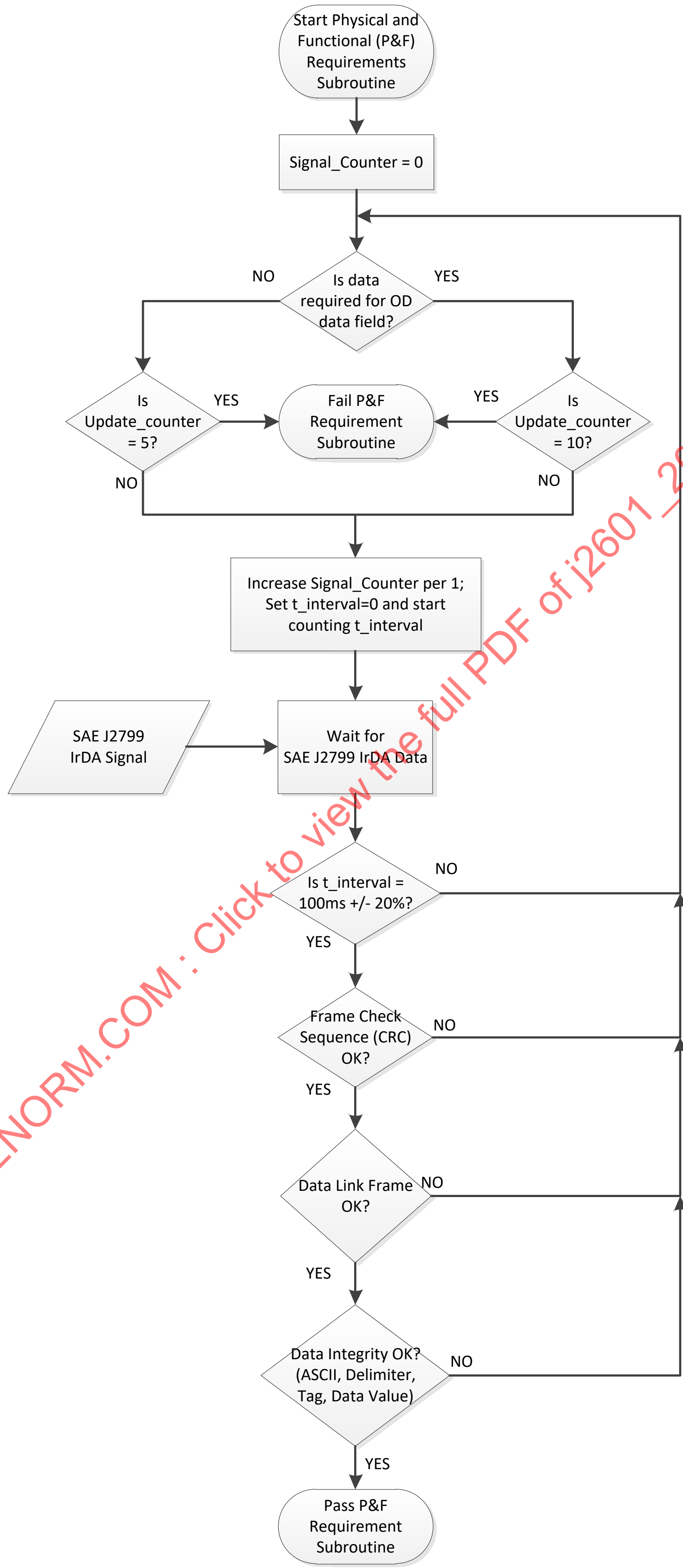

Figure I15 - Physical and functional requirements subroutine

APPENDIX J - SAE J2601 MC FORMULA-BASED EQUATIONS AND COEFFICIENTS

This appendix details the parameters, equations and formulas for implementing the MC Formula-based protocol. This appendix should be utilized in conjunction with the flow charts in Appendix I. Each subroutine in the Appendix I flow charts is directly referenced to a section of this appendix. The flow charts should be utilized as a means for understanding the order of the calculations required, whereas the subroutines detailed in this appendix should be utilized as a means for understanding the specific parameters, equations, and formulas required.

All equations in the dispenser startup subroutine and the fueling process subroutine of Appendix J shall be implemented as stated, and shall follow the order of calculation as defined in the flow charts in Appendix I.

Although an explanation for each parameter and equation, as well as guidance for their use, is provided, Section 3 should be utilized as a reference for definitions, and Section 4 as a reference for abbreviations and symbols utilized in the subroutines. Additionally, Appendix H should be referenced for a more thorough explanation of the structure and derivation of the MC Formula-based protocol.

J.1 DISPENSER STARTUP SUBROUTINE

The dispenser startup subroutine is used to determine essential initial conditions which are utilized in the fueling process subroutine. The flow chart for the dispenser startup subroutine is shown in Figure I1.

J.1.1 Check for Fueling Command Abort

The dispenser first checks if there is an abort from the IR communication data field named FC. If there is an abort, the dispenser shall terminate the startup process. If there is not an abort command, the dispenser next checks that the ambient temperature is within the defined limits.

J.1.2 Initial Pressure Pulse, Leak Check, and Determine Initial CHSS Pressure

An initial pressure pulse equilibrates the station pressure and CHSS pressure. If utilized, a leak check routine is implemented right after the initial pressure pulse. If the leak check fails, the dispenser shall terminate the startup process. If the leak check passes, or if the leak check routine is not utilized, the dispenser then measures the initial CHSS pressure, and stores this value as $P_{initial}$.

J.1.3 Cold Dispenser Fueling

If the dispenser has implemented cold dispenser fueling, as described in 9.10, the dispenser checks the station component temperature against the cold dispenser criteria to determine if the cold dispenser t_{final} coefficients can be utilized. If the cold dispenser criteria are met according to 9.10, the dispenser sets the flag variable CD to TRUE. Otherwise, if the cold dispenser criteria are not met, or if cold dispenser fueling is not utilized, the dispenser sets the flag variable CD to FALSE.

J.1.4 CHSS Volume and CHSS Capacity Category Determination

The dispenser next determines the CHSS volume and from this, the CHSS Capacity Category $CHSS_{Capacity\_Category}$. The MC Formula-based CHSS capacity category is defined in 9.2, Table 8.

$$IF\ 49.7 \leq V_{CHSS} < 99.4,\ CHSS_{Capacity\_Category} = A \qquad \text{(Eq. J1)}$$

$$IF\ 99.4 \leq V_{CHSS} \leq 174.0,\ CHSS_{Capacity\_Category} = B$$

$$IF\ 174.0 < V_{CHSS} \leq 248.6,\ CHSS_{Capacity\_Category} = C$$

$$IF\ V_{CHSS} > 248.6,\ CHSS_{Capacity\_Category} = D$$

There are two pathways for determining the CHSS volume - one for use with communication fueling, and the other for use with non-communication fueling.

J.1.4.1 CHSS Volume and CHSS Capacity Category with Communication Fueling

If the dispenser can use the SAE J2799 TV signal to determine the CHSS volume, the dispenser chooses the CHSS capacity category based on the TV signal, and sets the Indicator Cons RR flag variable to FALSE.

If the dispenser cannot use the SAE J2799 TV signal to determine the CHSS volume, and the dispenser is capable of measuring the CHSS volume, then the CHSS volume is measured, the CHSS capacity category is determined, and the Indicator Cons RR flag variable is set to FALSE.

If the dispenser cannot use the SAE J2799 TV signal to determine the CHSS volume, and the dispenser is capable of measuring the CHSS volume but the CHSS capacity category is indeterminate, the CHSS volume is not measured and the Indicator Cons RR flag variable is set to TRUE. In this case, t_{final} will be calculated for all CHSS capacity categories, and the most conservative value will be used, resulting in the most conservative pressure ramp rate.

If the dispenser cannot use the SAE J2799 TV signal to determine the CHSS volume, and the dispenser is not capable of measuring the CHSS volume, then the CHSS volume is not measured, the CHSS capacity category is considered indeterminate, and the Indicator Cons RR flag variable is set to TRUE. In this case, t_{final} will be calculated for all CHSS capacity categories, and the most conservative value will be used, resulting in the most conservative pressure ramp rate.

J.1.4.2 CHSS Volume and CHSS Capacity Category Determination Non-Communication Fueling

If the dispenser is capable of measuring the CHSS volume, then the CHSS volume is measured, the CHSS capacity category is determined, and the Indicator Cons RR flag variable is set to FALSE.

If the dispenser is not capable of measuring the CHSS volume or if the CHSS capacity category is indeterminate, the CHSS volume is not measured and the Indicator Cons RR flag variable is set to TRUE. In this case, t_{final} will be calculated for all CHSS capacity categories, and the most conservative value will be used, resulting in the most conservative pressure ramp rate.

J.1.5 Process Check for Initial CHSS Pressure

The final step in the dispenser startup subroutine is to check that the Initial CHSS pressure is within the bounds allowed for the dispenser pressure class. For an H70 pressure class, the initial CHSS pressure must be greater than or equal to 0.5 MPa, and less than or equal to 70 MPa. For an H35 pressure class, the initial CHSS pressure must be greater than or equal to 0.5 MPa, and less than or equal to 35 MPa.

J.2 FUELING PROCESS SUBROUTINE

After the dispenser startup subroutine has been completed, the dispenser moves into the fueling process subroutine, as shown in Figure I0. The beginning of the fueling process subroutine is used to initialize a number of parameters which are used throughout the fueling process. The following two sections describe the equations and processes utilized to set the initial conditions for the pressure ramp rate control (J.2.1) and for the end pressure control (J.2.2).

J.2.1 PRR Control Initialization Subroutine

J.2.1.1 Initialization of Parameters with Non-Discretionary Settings

The settings of the parameters in this subsection do not allow for discretion. The parameters shall be set and/or calculated as indicated.

The initial step is to set the time step counters to zero. j and i are two independent time steps utilized in the MC Formula-based protocol.

The time step i is used to advance the calculation of t_{final} and T_{cold}, as defined in subroutines "Calculation of t_{final}" (J.2.4) and "Calculation of T_{cold}" (J.2.5), respectively. Because these parameters do not change frequently, the magnitude of change is relatively small and the calculation intensity is relatively high, they are calculated at a lower frequency than that of the other control parameters. The time step i shall be 5 seconds, meaning that the calculations are performed every 5 seconds. A time step shorter than 5 seconds may be used, if desired, but time step i shall not be shorter than time step j.

$$Set \;\; i = 0 \quad \text{(Eq. J2)}$$

The time step j is used to calculate all other control parameters, as defined in subroutines "Mass Average Calculation" (J.2.3), "Calculation of PRR and $P_{control}$" (J.2.6), "Determination of Pressure Targets and Limits" (J.2.7), "Evaluate End of Fill Criteria " (J.2.8), and "Process Check" (J.2.9). The time step j shall be set to 1 second, meaning that the calculations are performed every second.

$$Set \;\; j = 0 \quad \text{(Eq. J3)}$$

The counter n is used to determine the point in the fill after which a total of 30 seconds of mass flow have elapsed. The counter n advances at the same frequency as time step counter j, but only advances if there is mass flow. It is utilized to determine the point in the fill at which the calculation of MAT_{30} commences.

$$Set \;\; n = 0 \quad \text{(Eq. J4)}$$

P_{final} is a parameter utilized in the variable pressure ramp rate equation. It represents the pressure at which the hot case fueling scenario will reach 85 °C when starting the fill from the minimum pressure P_{min}. The unit of measure for P_{final} is MPa.

$$Set \;\; P_{final} = 83.5 \quad \text{(Eq. J5)}$$

P_{trans} is a parameter used in the mass average fuel delivery temperature control (MAT_C) equation (Equation J52). The unit of measure for P_{trans} is MPa.

$$Set \;\; P_{trans} = \frac{P_{final} + P_{initial}}{2} \quad \text{(Eq. J6)}$$

$P_{initial}$ is a measured value from the dispenser start-up subroutine. P_{min} is the minimum starting pressure parameter under which t_{final} is derived, as explained in H.2.1 and H.2.2. If $P_{initial}$ < 5 MPa, P_{min} is 0.5 MPa, and if $P_{initial}$ ≥ 5 MPa, P_{min} is 5 MPa. The unit of measure for $P_{initial}$ and P_{min} is MPa.

$$\text{IF } P_{initial} < 5 \; MPa, \; P_{min} = 0.5, \;\; ELSE \;\; P_{min} = 5.0 \quad \text{(Eq. J7)}$$

$P_{startup}$ is used to set the initial ramp pressure P_{ramp}. The unit of measure for P_{ramp} is MPa.

$$Set \; P_{ramp} = P_{startup} \quad \text{(Eq. J8)}$$

RR_{min} is the minimum calculated pressure ramp rate throughout the fill. It is utilized in the equation for α (Equation J71). The unit of measure for RR_{min} is MPa/s.

$$Set \;\; RR_{min} = 1 \quad \text{(Eq. J9)}$$

RR_{max} is the maximum calculated pressure ramp rate throughout the fill. It is utilized in the equation for α (Equation J71). The unit of measure for RR_{max} is MPa/s.

$$Set \;\; RR_{max} = 0 \quad \text{(Eq. J10)}$$

α is a parameter which is multiplied by t_{final} to compensate for non-linearity in the pressure ramp rate during the fill (see Equations J58 through J61 and Equation J71). See H.2.6.1 for a detailed explanation of α. The higher the difference between RR_{max} and RR_{min} the higher α becomes. α is calculated for each time step j. The unit of measure for α is dimensionless.

$$Set \; \alpha = 1 \quad \text{(Eq. J11)}$$

ΔP_{tol_high} is an upper tolerance on the ramp pressure P_{ramp}. ΔP_{tol_high} is a value which is added to P_{ramp} to provide an upper limit pressure P_{limit_high} which the dispenser pressure $P_{station}$ shall not exceed (see process check subroutine in J.2.9). ΔP_{tol_low} is a lower tolerance on the ramp pressure P_{ramp}. ΔP_{tol_low} is a value which is subtracted from P_{ramp} to provide a lower limit pressure P_{limit_low} which the dispenser pressure $P_{station}$ shall not fall below (see process check subroutine in J.2.9). ΔP_{low} is a parameter that is measured at time t = t_{tol_low}, which subsequently is used to re-calculate the factor β (see Equation J72). The unit of measure for ΔP_{tol_high}, ΔP_{tol_low}, and ΔP_{low} is MPa.

$$Set\ \Delta P_{tol\_high} = 7 \quad \text{(Eq. J12)}$$

$$Set\ \Delta P_{tol\_low} = 2.5$$

$$Set\ \Delta P_{low} = 2.5$$

β is a parameter which is multiplied by t_{final} to allow for the pressure tolerance ΔP_{tol_high} and ΔP_{tol_low} (see Equations J58 through J61). See H.2.6.2 for a detailed explanation of β. β is calculated during initialization, and again at time t = t_{tol_low} (see Equation J72). The unit of measure for β is dimensionless.

$$Set\ \beta = \frac{P_{final} - P_{min}}{P_{final} - P_{min} - \Delta P_{tol\_high} \ \ - \Delta P_{tol\_low}} \quad \text{(Eq. J13)}$$

TopOff is a logical flag variable that is set to either TRUE or FALSE. When TopOff is TRUE, the pressure ramp rate is reduced near the end of the fill to lower the pressure drop between the dispenser pressure and the CHSS pressure in order to increase the ending SOC in the CHSS. The condition which activates TopOff to be TRUE is Equation J74.

Note that TopOff is “optional”; the dispenser may choose to implement it or not.

$$\text{Set } TopOff = FALSE \quad \text{(Eq. J14)}$$

t_{final_min} is the minimum value for t_{final}. t_{final} is inversely proportional to the pressure ramp rate PRR. Therefore, t_{final_min} also dictates the maximum overall (or average) pressure ramp rate which is possible. t_{final_min} is a function of the CHSS capacity category and initial pressure $P_{initial}$. A t_{final_min} is calculated for each CHSS capacity category, A ($t_{final\_min\_A}$), B ($t_{final\_min\_B}$), C ($t_{final\_min\_C}$), and D ($t_{final\_min\_D}$). A conservative value $t_{final\_min\_cons}$ is also calculated for use in cases where the CHSS capacity category is indeterminate. See H.2.5.1 for a more detailed explanation of t_{final_min}. The unit of measure for t_{final} and t_{final_min} is seconds.

$$\text{Set } t_{final\_min} \quad \text{(Eq. J15)}$$

$$\text{IF } P_{initial} < 5\ MPa$$

$THEN$

$$Set\ t_{final\_min\ \_A} = 155$$

$$Set\ t_{final\_min\ \_B} = 155$$

$$Set\ t_{final\_min\ \_C} = 222$$

$$Set\ t_{final\_min\ \_D} = 222 \times \left(\frac{V_{CHSS}}{248.6}\right)$$

$$Set\ t_{final\_min\ \_cons} = 222$$

$ELSE$

$$\text{IF } P_{initial} \geq 5\ MPa$$

$THEN$

$$Set\ t_{final\_min\ \_A} = 147$$

$$Set\ t_{final\_min\ \_B} = 147$$

$$Set\ t_{final\_min\ \_C} = 210$$

$$Set\ t_{final\_min\ \_D} = 210 \times \left(\frac{V_{CHSS}}{248.6}\right)$$

$$Set\ t_{final\_min\ \_cons} = 210$$

There are four coefficients (a, b, c, and d), which are utilized in the t_{final} equation. Each coefficient is a discrete value for a given ambient temperature T_{amb}, boundary CHSS volume, and minimum pressure P_{min}. See H.2.1 and H.2.2 for a more detailed explanation of the t_{final} equation and coefficients a, b, c, and d.

The coefficients a, b, c, and d are provided in a set of lookup Tables J1 through J16. Tables J1 through J8 are the "normal" tables, for use with a warm dispenser or when a cold dispenser is not integrated or does not meet the requisite criteria. Tables J9 through J16 are for use with a "cold dispenser" and shall only be used if the dispenser meets the criteria of 9.10. If the criteria of 9.10 are met, the cold dispenser flag variable CD is set to TRUE in the dispenser startup subroutine.

All of the digits in the coefficient Tables J1 through J16 are significant.

Table J1 - Table of coefficients for 49.7 L boundary CHSS with $CD = FALSE$ ***and*** $Pmin = 0.5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	-0.7732152	585.8593	-147183.73	12270144
45/318.15	0.0927714	-63.41554	14463.47	-1100136
40/313.15	0.020384	-14.097	3277.2	-255773.3
35/308.15	0.009682	-6.43912	1447.971	-109965
30/303.15	0.00256616	-1.43936	270.86	-17181
25/298.15	-0.00018982	0.4843	-181.015	18490
20/293.15	0.00020773	0.12289	-79.69	9440
15/288.15	0.0011237	-0.594127	103.997	-6043
10/283.15	0.00132477	-0.7799	156.73	-10807
5/278.15	0.0019454	-1.29693	295.944	-23050
0/273.15	0.00077381	-0.463295	96.814	-7106
-10/263.15	0.00077591	-0.4807	104.18	-7919
-20/253.15	-0.00067296	0.60984	-170.165	15124
-30/243.15	0.00021984	-0.077138	5.172	255.7
-40/233.15	0.000232478	-0.0722243	-0.4924	1149

Table J2 - Table of coefficients for 99.4 L boundary CHSS with $CD = FALSE$ ***and*** $Pmin = 0.5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	1.1462427	-805.95758	188923.82	-14763290
45/318.15	0.12728894	-88.669728	20627.75	-1602334
40/313.15	0.01362863	-8.260816	1651.2	-108438
35/308.15	0.00459226	-1.80716	112.064	14112
30/303.15	0.000043	1.14407	-526.8	60268
25/298.15	0.00023559	0.7645	-383.873	45116.8
20/293.15	0.00202084	-0.72322	17.42	9783
15/288.15	0.00431385	-2.519	480.38	-29613.4
10/283.15	0.0023259	-1.12621	152.89	-3780
5/278.15	-0.00146812	1.58788	-497.62	48436
0/273.15	0.00411881	-2.69214	590.798	-43511
-10/263.15	0.00337783	-2.15258	458.639	-32638.6
-20/253.15	-0.0035514	3.035924	-837.335	75323
-30/243.15	0.0055517	-3.842547	893.505	-69736
-40/233.15	0.0035207	-2.346046	525.1	-39448

Table J3 - Table of coefficients for 174.0 L boundary CHSS with $CD = FALSE$ ***and*** $Pmin = 0.5$

T_{amb} (°C/K)	a	b	d	d
50/323.15	0.9268339	-657.517	155528.3	-12265725
45/318.15	0.07921025	-53.348011	11978.32	-896503
40/313.15	0.0249784	-15.523	3175.39	-212923
35/308.15	0.02517224	-15.823577	3283.684	-224295
30/303.15	0.02413323	-15.64356	3368.772	-240766
25/298.15	0.025086	-16.7493	3729.139	-276767.5
20/293.15	0.0242024	-16.408	3713.878	-280575
15/288.15	0.00934463	-5.7358	1156.276	-76093
10/283.15	0.0069356	-4.069	769.682	-46032
5/278.15	0.00551525	-3.2227	605.9843	-35875.5
0/273.15	0.00976311	-6.567066	1476.306	-110857
-10/263.15	0.0104087	-7.07709	1608.83	-122217
-20/253.15	0.0080489	-5.32725	1175.232	-86326.7
-30/243.15	0.0065696	-4.25041	912.935	-64955.7
-40/233.15	0.00257318	-1.289612	180.796	-4540.2

Table J4 - Table of coefficients for 248.6 L boundary CHSS with $CD = FALSE$ and $Pmin = 0.5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.2662904	-182.73827	41776.75	-3181410
45/318.15	0.0584734	-38.19249	8278.407	-594895
40/313.15	0.00617452	-1.37227	-374.704	83913
35/308.15	0.0019644	1.5696	-1061.016	137370
30/303.15	-0.0080091	8.39276	-2620.55	256485
25/298.15	-0.0033995	4.540487	-1572.302	163049
20/293.15	-0.0027867	3.79686	-1325.566	138178
15/288.15	-0.0049967	5.31436	-1676.392	165514.8
10/283.15	-0.00343584	4.01186	-1323.242	134198
5/278.15	0.0016587	-0.0973	-231.264	38359.8
0/273.15	0.006548	-3.9771	786.21	-49965
-10/263.15	-0.0016567	2.24234	-786.47	82675
-20/253.15	0.00326382	-1.4996	160.73	2851
-30/243.15	0.0031083	-1.41579	146.895	3490.2
-40/233.15	0.0027597	-1.1819	94.19	7484.3

Table J5 - Table of coefficients for 49.7 L boundary CHSS with $CD = FALSE$ and $Pmin = 5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.5412013	-379.1329	88600.8	-6906304
45/318.15	0.0514442	-36.2126	8535.106	-673023
40/313.15	0.00706393	-4.66896	1048.03	-79773
35/308.15	0.0039647	-2.471	526.2	-38342.9
30/303.15	0.00006517	0.2768	-124.63	13392
25/298.15	-0.000478	0.61478	-197.145	18768.7
20/293.15	0.00088071	-0.43825	70.601	-3667.7
15/288.15	0.0011843	-0.69919	141.59	-9904
10/283.15	0.0018624	-1.237747	281.67	-21903
5/278.15	0.00186084	-1.29269	307.125	-24858
0/273.15	0.00008452	0.01345	-14.392	1605
-10/263.15	0.0001608	-0.0477	1.0987	340.2
-20/253.15	0.0001541	-0.04517	0.4927	419
-30/243.15	0.000157	-0.05101	2.169	303.34
-40/233.15	0.00002187	-0.00238	1.133	-365.2

Table J6 - Table of coefficients for 99.4 L boundary CHSS with $CD = FALSE$ and $Pmin = 5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.4522741	-318.7519	74944.26	-5877949
45/318.15	0.0416164	-28.22393	6406.944	-486773
40/313.15	0.0008569	0.6705	-436.37	54608
35/308.15	-0.00120471	2.096348	-767.206	80352.9
30/303.15	0.0004433	0.61375	-347.6567	42215
25/298.15	0.00260556	-1.1645	127.14	756
20/293.15	0.00135946	-0.366034	-44.804	13224.7
15/288.15	0.00347128	-2.03413	389.029	-24028.4
10/283.15	0.00439055	-2.7963	594.36	-42132.7
5/278.15	-0.00780848	6.28166	-1661.04	144902
0/273.15	0.00408545	-2.78004	636.37	-48976
-10/263.15	-0.00087722	0.95603	-302.221	29691.8
-20/253.15	0.00056196	-0.1596	-15.1666	5153
-30/243.15	0.00059066	-0.198721	-1.922	3825.4
-40/233.15	0.0006335	-0.23966	9.6234	2816

Table J7 - Table of coefficients for 174.0 L boundary CHSS with $CD = FALSE$ and $Pmin = 5$

T_{amb} (°C/K)	a	B	C	d
50/323.15	0.44703053	-319.4646	76166.61	-6057967
45/318.15	0.0243003	-14.3591	2740.5	-166210
40/313.15	0.02419946	-15.509441	3293.4	-231338.6
35/308.15	0.02431024	-15.70205	3364.745	-238911.2
30/303.15	0.0210368	-13.8062	3013.98	-218715
25/298.15	0.02611283	-17.860686	4078.3	-310812
20/293.15	0.00590649	-3.22952	542.579	-25683.4
15/288.15	0.01086815	-7.097156	1540.516	-111017.8
10/283.15	0.019704	-13.7608	3211.4	-250363.6
5/278.15	0.00069773	0.23241	-226.89	31553
0/273.15	0.01021522	-7.11209	1656.445	-129000
-10/263.15	0.0106218	-7.448146	1747.1	-137025.6
-20/253.15	0.00934097	-6.515163	1519.8187	-118515
-30/243.15	-0.00115032	1.418468	-480.926	49735
-40/233.15	-0.0008313	1.1738	-419.7	44726.6

Table J8 - Table of coefficients for 248.6 Lboundary CHSS with $CD = FALSE$ and $Pmin = 5$

T_{amb} (°C/K)	a	B	C	d
50/323.15	0.17459569	-120.800282	27872.643	-2144558
45/318.15	0.0128136	-5.564232	492.34	25487
40/313.15	0.0020037	1.14502	-873.35	116180
35/308.15	-0.00153372	3.66264	-1471.974	163728.8
30/303.15	0.0044367	-1.258945	-146.17	46458
25/298.15	-0.000686	2.2684	-960.344	109488.2
20/293.15	-0.0022991	3.2481	-1156.191	122351
15/288.15	0.000566	0.9	-524.75	66435.6
10/283.15	0.00919033	-5.756565	1181.764	-78949
5/278.15	0.00288917	-1.1815	69.4	11606
0/273.15	0.0025998	-1.1628	110.06	4757
-10/263.15	0.00247675	-1.11031	106.038	4395.6
-20/253.15	0.0024533	-1.12972	119.393	2628
-30/243.15	0.00261086	-1.19564	120.97	3886.8
-40/233.15	0.0074823	-4.800655	1007.894	-68651

Table J9 - (Cold dispenser) table of coefficients for 49.7 L boundary CHSS with $CD = TRUE$ and $Pmin = 0.5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.5003696	-353.4108	83238.994	-6537335
45/318.15	0.042544	-29.73507	6955.086	-544154
40/313.15	0.00554388	-3.37733	686.56	-46538
35/308.15	0.00355474	-1.9946	365.366	-21613
30/303.15	0.00152269	-0.66906	75.946	-460
25/298.15	0.00125052	-0.574657	74.7	-1871.6
20/293.15	0.00143918	-0.7887	142.724	-8504
15/288.15	0.00210174	-1.32335	283.553	-20684.6
10/283.15	0.0021646	-1.4102	313.411	-23733
5/278.15	0.00191225	-1.27565	291.134	-22670.5
0/273.15	0.00077381	-0.463295	96.814	-7106
-10/263.15	0.00077591	-0.4807	104.18	-7919
-20/253.15	0.00020697	-0.05851	-0.972	848.7
-30/243.15	0.00021984	-0.077138	5.172	255.7
-40/233.15	0.00023248	-0.0722243	-0.4924	1149

Table J10 - (Cold dispenser) table of coefficients for 99.4 L boundary CHSS with $CD = TRUE$ and $Pmin = 0.5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.9687701	-690.801	164236.563	-13018382.8
45/318.15	0.0566422	-38.515	8742.2	-662298
40/313.15	0.01060865	-6.09423	1122.283	-64669.1
35/308.15	0.00587212	-2.75385	336.242	-2956
30/303.15	0.00420311	-1.90616	212.224	1018.3
25/298.15	0.00442132	-2.31857	368.586	-15797
20/293.15	0.00510249	-3.00313	576.603	-35728.4
15/288.15	0.00469629	-2.8143	554.4147	-35679
10/283.15	0.00193625	-0.834954	79.237	2496
5/278.15	0.0039197	-2.448	509.32	-35250.8
0/273.15	0.00411665	-2.69058	590.425	-43481.4
-10/263.15	0.00338305	-2.156543	459.642	-32723.2
-20/253.15	-0.0046816	3.8971	-1055.91	93801.8
-30/243.15	0.0055517	-3.84255	893.506	-69736
-40/233.15	0.0035207	-2.346046	525.1	-39448

Table J11 - (Cold dispenser) table of coefficients for 174.0 L boundary CHSS with $CD = TRUE$ and $Pmin = 0.5$

T_{amb} (°C/K)	a	b	d	d
50/323.15	0.6662714	-475.11105	112976.363	-8957980
45/318.15	0.06999041	-46.99349	10507.25	-782122
40/313.15	0.04451	-29.9278	6705.56	-500516
35/308.15	0.0350106	-23.108694	5073.096	-370192.5
30/303.15	0.03142684	-21.0506	4698.94	-349426
25/298.15	0.02840683	-19.237836	4346.643	-327562.5
20/293.15	0.025896	-17.6966	4037.7	-307499.2
15/288.15	0.01302785	-8.47722	1834.54	-131901
10/283.15	0.00974828	-6.17516	1294.175	-89485
5/278.15	0.0051173	-2.92573	531.74	-29664
0/273.15	0.0087316	-5.79951	1286	-95135.2
-10/263.15	0.0098242	-6.642391	1501.12	-113325
-20/253.15	0.01035215	-7.06227	1610.78	-122763
-30/243.15	0.0065708	-4.2513	913.16	-64975
-40/233.15	0.00257318	-1.27955	175.8	-3921

Table J12 - (Cold dispenser) table of coefficients for 248.6 L boundary CHSS with $CD = TRUE$ and $Pmin = 0.5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.224659	-155.053	35663.1	-2733398.6
45/318.15	0.0424084	-26.38949	5375.542	-356045
40/313.15	0.00767545	-2.48003	-109.735	63339
35/308.15	-0.0060228	7.57232	-2569.99	264147
30/303.15	-0.0031548	4.8039	-1740.749	184922
25/298.15	0.000358	1.75584	-887.716	107185
20/293.15	-0.0062946	6.48235	-2012.528	196854
15/288.15	-0.00883637	8.21091	-2405.888	226828
10/283.15	-0.00368842	4.17696	-1359.133	136786
5/278.15	0.0021689	-0.481	-135.46	30413
0/273.15	0.006548	-3.9771	786.21	-49965
-10/263.15	-0.0016567	2.24234	-786.47	82675
-20/253.15	0.00326382	-1.4996	160.73	2851
-30/243.15	0.0031083	-1.41579	146.895	3490.2
-40/233.15	0.0027597	-1.1819	94.19	7484.3

Table J13 - (Cold dispenser) table of coefficients for 49.7 L boundary CHSS with $CD = TRUE$ ***and*** $Pmin = 5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.308322	-222.299	53466.2	-4289070
45/318.15	0.0131114	-8.729216	1952.33	-146631
40/313.15	0.0009067	-0.16645	-57.85	11214.8
35/308.15	0.00083135	-0.15323	-52.138	10112
30/303.15	0.0011923	-0.538035	66.706	-1278
25/298.15	0.00179313	-1.06327	212.61	-14379
20/293.15	0.00189269	-1.194744	256.796	-18812.2
15/288.15	0.0018112	-1.17689	261.384	-19832.66
10/283.15	0.00155155	-1.014717	227.605	-17492.4
5/278.15	0.0018946	-1.322	315.15	-25569
0/273.15	0.00008452	0.01345	-14.392	1605
-10/263.15	0.0001608	-0.0477	1.0987	340.2
-20/253.15	0.0001541	-0.04517	0.4927	419
-30/243.15	0.000157	-0.05101	2.169	303.34
-40/233.15	0.00002187	-0.00238	1.133	-365.2

Table J14 - (Cold dispenser) table of coefficients for 99.4 L boundary CHSS with $CD = TRUE$ ***and*** $Pmin = 5$

T_{amb} (°C/K)	a	b	c	d
50/323.15	0.24854436	-176.1897	41674.45	-3288765
45/318.15	0.0177394	-10.85412	2178.823	-142643
40/313.15	0.0051423	-2.46973	320.1	-5418
35/308.15	0.003695	-1.490055	99.04	11208
30/303.15	0.0054339	-3.064446	549.824	-30364
25/298.15	0.00387363	-2.096993	351.604	-16971
20/293.15	0.00451234	-2.71847	537.32	-34594
15/288.15	0.00518451	-3.3236	710.6	-50631
10/283.15	0.0052048	-3.4158	750.332	-55148
5/278.15	-0.00591136	4.8539	-1303.33	115059
0/273.15	0.00411386	-2.8016	641.824	-49435.9
-10/263.15	-0.00086939	0.9501	-300.729	29567
-20/253.15	0.0007818	-0.326638	27.1244	1585
-30/243.15	0.00071957	-0.296622	22.858	1735
-40/233.15	0.0007854	-0.35504	38.83	352.2

Table J15 - (Cold dispenser) table of coefficients for 174.0 L boundary CHSS with $CD = TRUE$ ***and*** $Pmin = 5$

T_{amb} (°C/K)	a	B	C	d
50/323.15	0.16079266	-111.07096	25580.75	-1964148
45/318.15	0.09771	-67.88782	15733.43	-1216166
40/313.15	0.0401005	-27.2827	6188.9	-467989.8
35/308.15	0.0376002	-25.5509	5789.08	-437223.6
30/303.15	0.03626885	-25.04764	5773.3	-444042
25/298.15	0.007091	-3.8635	642.12	-29429
20/293.15	0.01050209	-6.67089	1398.784	-96493
15/288.15	0.01252871	-8.349878	1853.77	-137006.5
10/283.15	0.0126522	-8.5783	1941.24	-146558.4
5/278.15	0.01155257	-7.953264	1829.8477	-140639
0/273.15	0.01025578	-7.1429	1664.24	-129657
-10/263.15	0.0106099	-7.43914	1744.83	-136835
-20/253.15	0.00935027	-6.52224	1521.61	-118666
-30/243.15	0.0015371	-0.62249	35.674	6154
-40/233.15	0.001586	-0.7024	65.626	2886.6

Table J16 - (Cold dispenser) table of coefficients for 248.6 L boundary CHSS with $CD = TRUE$ and $Pmin = 5$

T_{amb} (°C/K)	a	B	C	d
50/323.15	0.13039754	-89.40084	20422.852	-1554315.5
45/318.15	0.02685119	-16.04746	3089.05	-187994
40/313.15	0.00108558	1.8785	-1074.64	134902.5
35/308.15	-0.0001017	2.6552	-1242.473	146855
30/303.15	0.00356175	-0.55124	-340.15	64331.6
25/298.15	-0.00362681	4.5323	-1543.93	159800
20/293.15	0.0037787	-1.32835	-9.997	26839
15/288.15	0.0056244	-2.909158	429.72	-13164
10/283.15	0.01180977	-7.73242	1677.6	-120356
5/278.15	0.00307266	-1.32414	105.95	8512.9
0/273.15	0.0025998	-1.1628	110.06	4757
-10/263.15	0.00247675	-1.11031	106.038	4395.6
-20/253.15	0.0024533	-1.12972	119.393	2628
-30/243.15	0.00022912	-0.037312	-4.279	1.4
-40/233.15	0.00022921	-0.04172	-3.18	-6

A set of t_{final} coefficients is calculated for each boundary CHSS - 49.7, 99.4, 174.0, and 248.6 L based on the measured ambient temperature T_{amb} and minimum pressure P_{min}. The first step in this calculation process is to choose the appropriate coefficients a, b, c, and d from the table of coefficients (Tables J1 through J8, or Tables J9 through J16). For each boundary CHSS, there are two coefficient tables: one for P_{min} = 0.5 MPa, and one for P_{min} = 5 MPa.

Choose t_{final} Coefficients Tables for "Normal" Fueling, CD = FALSE (Eq. J16)

$$49.7\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J1,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J5$$

$$99.4\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J2,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J6$$

$$174.0\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J3,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J7$$

$$248.6\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J4,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J8$$

Choose t_{final} Coefficients Tables for "Cold Dispenser" Fueling, CD = TRUE (Eq. J17)

$$49.7\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J9,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J13$$

$$99.4\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J10,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J14$$

$$174.0\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J11,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J15$$

$$248.6\ liter\ boundary\ CHSS\ \rightarrow \text{IF}\ P_{min} = 0.5\ MPa\ \text{Use}\ Table\ J12,\ ELSE\ \text{IF}\ P_{min} = 5\ MPa\ Use\ Table\ J16$$

Once the correct table has been determined, two sets of coefficients are looked up for each boundary CHSS based on the ambient temperature T_{amb}: one set for the temperature value directly above the T_{amb}, and one set for the temperature value directly below the T_{amb}. For each coefficient table, choose the coefficients a, b, c, and d directly above and directly below the measured ambient temperature T_{amb}.

The next step is to interpolate the coefficients based on the actual ambient temperature T_{amb} to arrive at a final set of coefficients for each boundary CHSS. For example, if the actual measured ambient temperature is 32 °C, interpolation is performed between the coefficients at 35 °C and 30 °C. The interpolation equations are shown in Equations J18 through J21.

Interpolation for 49.7 L boundary CHSS (Eq. J18)

$$a_{49.7} = a(T_{amb\_below}) + \frac{[a(T_{amb\_above}) - a(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$b_{49.7} = b(T_{amb\_below}) + \frac{[b(T_{amb\_above}) - b(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$c_{49.7} = c(T_{amb\_below}) + \frac{[c(T_{amb\_above}) - c(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$d_{49.7} = d(T_{amb\_below}) + \frac{[d(T_{amb\_above}) - d(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

Interpolation for 99.4 L boundary CHSS (Eq. J19)

$$a_{99.4} = a(T_{amb\_below}) + \frac{[a(T_{amb\_above}) - a(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$b_{99.4} = b(T_{amb\_below}) + \frac{[b(T_{amb\_above}) - b(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$c_{99.4} = c(T_{amb\_below}) + \frac{[c(T_{amb\_above}) - c(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$d_{99.4} = d(T_{amb\_below}) + \frac{[d(T_{amb\_above}) - d(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

Interpolation for 174.0 L boundary CHSS (Eq. J20)

$$a_{174.0} = a(T_{amb\_below}) + \frac{[a(T_{amb\_above}) - a(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$b_{174.0} = b(T_{amb\_below}) + \frac{[b(T_{amb\_above}) - b(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$c_{174.0} = c(T_{amb\_below}) + \frac{[c(T_{amb\_above}) - c(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$d_{174.0} = d(T_{amb\_below}) + \frac{[d(T_{amb\_above}) - d(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

Interpolation for 248.6 L boundary CHSS (Eq. J21)

$$a_{248.6} = a(T_{amb\_below}) + \frac{[a(T_{amb\_above}) - a(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$b_{248.6} = b(T_{amb\_below}) + \frac{[b(T_{amb\_above}) - b(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$c_{248.6} = c(T_{amb\_below}) + \frac{[c(T_{amb\_above}) - c(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$d_{248.6} = d(T_{amb\_below}) + \frac{[d(T_{amb\_above}) - d(T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

J.2.1.2 Initialization of Parameters with Discretionary Settings

The settings for the parameters in this subsection shall be determined by the discretion of the dispenser manufacturer within the acceptable range provided. The discretion allowed in setting these parameters is so the dispenser manufacturer may tune or optimize some aspects of the MC Formula to the dispenser design and performance characteristics. These characteristics may include the precision of pressure control, the ability of the dispenser to keep the highest pressure ramp rates, the pre-cooling system characteristics and their effect on the rate of change and stability of the fuel delivery temperature, etc.

PRR_{CAP_Factor} is a settable parameter used in the calculation of PRR_{CAP}, which enforces a limit on the maximum instantaneous pressure ramp rate during the fill. PRR_{CAP_Factor} is utilized in the "Calculation of PRR and $P_{control}$ Subroutine," Equation J73. A limit is placed on PRR to ensure that the maximum flow rate is not exceeded and to prevent α from becoming too large, which can actually cause the overall fill time to be longer. PRR_{CAP} is a function of PRR_{CAP_Factor}, P_{final}, P_{min} and t_{final_min}. See H.2.5.2 for a detailed explanation of PRR_{CAP}.

PRR_{CAP_Factor} may be set to any value between 0.9 and 1.1. The dispenser manufacturer should choose a setting for PRR_{CAP_Factor} based on the capability of the dispenser to keep the station pressure within the pressure corridor under the maximum PRR. To achieve the best possible fueling performance, the dispenser manufacturer should utilize the highest value for PRR_{CAP_Factor} which still allows the dispenser to keep the station pressure within the pressure corridor under the maximum PRR and expected vehicle CHSS capacities. Table J17 shows the effect the setting of PRR_{CAP_Factor} has on the value of PRR_{CAP} for the CHSS Capacity Categories A, B, C, and the case where the CHSS Capacity Category is indeterminate.

Table J17 - Effect of the setting of PRR_{CAP_Factor} on the maximum pressure ramp rate PRR_{CAP}

PRR_{CAP_Factor}	**PRR_{CAP}**							
	CHSS Capacity A		CHSS Capacity B		CHSS Capacity C		CHSS Capacity Indeterminate	
	MPa/s	MPa/min	MPa/s	MPa/min	MPa/s	MPa/min	MPa/s	MPa/min
0.9	0.48	28.8	0.48	28.8	0.34	20.2	0.34	20.2
1.0	0.53	32	0.53	32	0.37	22.4	0.37	22.4
1.1	0.59	35.2	0.59	35.2	0.41	24.7	0.41	24.7

$$0.9 \leq PRR_{CAP\_Factor} \leq 1.1 \quad \text{(Eq. J22)}$$

$$Set\ PRR_{CAP\_Factor}$$

ΔP_{offset} is a parameter used to determine the dispenser control pressure $P_{control}$. The control pressure $P_{control}$ is defined as the pressure that the dispenser is targeting at any point in time. In other words, the control pressure is the control parameter that the dispenser follows in controlling the station pressure $P_{station}$. $P_{control}$ is determined as an offset from P_{ramp}. ΔP_{offset} is initialized in this subroutine, however, it does not need to be a constant, and therefore may change during the fill. The dispenser manufacturer should determine the appropriate offset value based on the characteristics of the dispenser control. A larger offset results in shorter fueling times, but provides a smaller margin between $P_{control}$ and P_{limit_high}. See H.2.7 for a detailed explanation. ΔP_{offset} may be set to any value between 0 and 7. The unit of measure for $P_{control}$, P_{ramp}, and ΔP_{offset} is MPa.

$$0 \leq \Delta P_{offset} \leq 7 \quad \text{(Eq. J23)}$$

$$Set\ \Delta P_{offset}$$

$$Set\ P_{control} = P_{ramp} + \Delta P_{offset} \quad \text{(Eq. J24)}$$

$MAT_{expected}$ is the expected mass average fuel delivery temperature at the end of the fill. $MAT_{expected}$ is determined by the dispenser manufacturer based on the characteristics of the pre-cooling system utilized. For example, $MAT_{expected}$ may be a function of the pre-cooling system set point temperature and the ambient temperature. Alternatively, $MAT_{expected}$ may be set to the midpoint of the fuel delivery temperature category (e.g., for a T30 station, $MAT_{expected}$ may be set to 243.65 K). $MAT_{expected}$ is only utilized for the first 30 seconds of mass flow where it is the input to the MAT_C equation (Equation J53).

The dispenser manufacturer may choose any value for $MAT_{expected}$ between 237.15 K and 255.65 K. See H.2.4 for a more detailed explanation of $MAT_{expected}$. The units for $MAT_{expected}$ is Kelvin (K).

$$237.15 \leq MAT_{expected} \leq 255.65 \qquad \text{(Eq. J25)}$$

$$\text{Set } MAT_{expected}$$

J.2.2 End Pressure Control Initialization Subroutine

This subroutine is divided into two sections, J.2.2.1 and J.2.2.2, based on the ending pressure control method chosen by the dispenser manufacturer. Section J.2.2.1 is only applicable to the use of ending pressure tables for ending pressure control. Section J.2.2.2 is only applicable to the MC Method for ending pressure control.

J.2.2.1 End Pressure Control Initialization - Ending Pressure Tables

Ending pressure tables are provided in Appendix K. These tables are utilized to calculate non-communication pressure target values and communication pressure limit values. A communication pressure target is also calculated based on the CHSS measured temperature MT. The communication pressure limit value is used as a secondary means of protection to limit over filling in the event of a fault in the CHSS measured temperature MT, which causes the communication pressure target to be incorrect.

J.2.2.1.1 Non-Communication Pressure Targets

Non-communication pressure target values are calculated for the three fuel delivery temperature categories, T40, T30, and T20, as well as for the three CHSS capacity categories A, B, and C (nine non-communication pressure target values), except when the CHSS capacity category is D (in which case pressure targets for CHSS capacity categories A, B, and C are not needed). A pressure target is calculated for each of these categories during the end pressure control initialization subroutine for use later in the evaluate end of fill criteria subroutine (J.2.8). The reason that a pressure target is calculated for each of these categories is that the fuel delivery temperature category, and potentially the CHSS capacity category, may change as the fill progresses. Thus, it is necessary to pre-determine the pressure target for each of these categories so it is available and can be utilized in the evaluate end of fill criteria subroutine based on the real-time determination of the fuel delivery temperature category and CHSS capacity category.

Non-communication pressure targets are calculated using interpolation on the non-communication pressure target lookup tables, Tables K1 through K19. For a visual representation of the interpolation process, see Example B in Appendix G. The interpolation calculations are shown mathematically in Equation J26.

Equation J26 is utilized to conduct the interpolation required to calculate the actual non-communication pressure targets using inputs of ambient temperature T_{amb}, and initial pressure, $P_{initial}$. In Equation J26, $P_{initial\_below}$ represents the $P_{initial}$ value in the table directly below the actual initial pressure $P_{initial}$, and $P_{initial\_above}$ represents the $P_{initial}$ value in the table directly above the initial pressure $P_{initial}$. In Equation J26, T_{amb_below} represents the T_{amb} value in the table directly below the actual ambient temperature T_{amb}, and T_{amb_above} represents the T_{amb} value in the table directly above the actual ambient temperature T_{amb}. P_{table} represents the actual table pressure target value at $P_{initial\_above}$ or $P_{initial\_below}$ and at T_{amb_above} or T_{amb_below}. Note that if $P_{initial}$ <5 MPa, interpolation is conducted only on ambient temperature using the table value for P <5 (i.e., P_{below} and P_{above} are not calculated).

As an example, in Table K1, P_{table} (20,30) = 74.6 MPa, where 20 represents $P_{initial\_above}$ or $P_{initial\_below}$, and 30 represents T_{amb_above} or T_{amb_below}. In Equation J26, P_{below} is an intermediate calculation representing the below pressure target value after interpolating on T_{amb}, and P_{above} is an intermediate calculation representing the above pressure target value after interpolating on T_{amb}. The final $P_{target\_non\_comm}$ value is a result of interpolating P_{below} and P_{above} on $P_{initial}$.

Interpolation for Non-Communication Pressure Target (Eq. J26)

$$IF\ P_{intial} \geq 5\ MPa$$

$THEN$

$$P_{below} = P_{table}(P_{initial\_below}, T_{amb\_below}) + \frac{[P_{table}(P_{initial\_below}, T_{amb\_above}) - P_{table}(P_{initial\_below}, T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$P_{above} = P_{table}(P_{initial\_above}, T_{amb\_below}) + \frac{[P_{table}(P_{initial\_above}, T_{amb\_above}) - P_{table}(P_{initial\_above}, T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$P_{target\_non\_comm} = P_{below} + \frac{[P_{above} - P_{below}] \times [P_{intial} - P_{initial\_below}]}{[P_{initial\_above} - P_{initial\_below}]}$$

$ELSE$

$$IF\ P_{intial} < 5\ MPa$$

$THEN$

$$P_{target\_non\_comm} = P_{table}(P < 5, T_{amb\_below}) + \frac{[P_{table}(P<5, T_{amb\_above}) - P_{table}(P<5, T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

As an example, consider Table K1, with $P_{initial}$ = 23 MPa and T_{amb} = 32 °C. In this case, $P_{initial\_below}$ = 20, $P_{initial\_above}$ = 30, T_{amb_below} = 30, and T_{amb_above} = 35. $P_{target\_non\_comm}$ is calculated as follows:

$$P_{below} = 74.6 + \frac{[75.4 - 74.6] \times [32 - 30]}{[35 - 30]} = 74.9$$

$$P_{above} = 73.9 + \frac{[74.9 - 73.9] \times [32 - 30]}{[35 - 30]} = 74.3$$

$$P_{target\_non\_comm} = 74.9 + \frac{[74.3 - 74.9] \times [23 - 20]}{[30 - 20]} = 74.7$$

Equation J26 is utilized to calculate a non-communication pressure target for each fuel delivery temperature category and for each CHSS capacity category. Equations J.27 and J.28 are used for determining the appropriate non-communication pressure target table to utilize for calculating each of these pressure targets. The pressure target tables are designated based on the CHSS capacity category (A, B, C) and fuel delivery temperature category (T40, T30, T20).

Note that for the H35 pressure class, and for H70 non-communications, cold dispenser fueling is not applicable.

Note that if the CHSS capacity category is D, it is not necessary to calculate the non-communication pressure targets for CHSS capacity categories A, B, and C. Also note that in the case of CHSS Capacity Category D, there is only one non-communication pressure target table, which is applicable to all fuel delivery temperature categories.

Determination of Non-Communication Target Pressure Tables - H70 (Eq. J27)

For CHSS capacity categories A, B, and C

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K1\ \ to\ calculate\ P_{target\_non\_comm\_T40\_A}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K2\ \ to\ calculate\ P_{target\_non\_comm\_T40\_B}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K3\ \ to\ calculate\ P_{target\_non\_comm\_T40\_C}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K4\ \ to\ calculate\ P_{target\_non\_comm\_T30\_A}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K5\ \ to\ calculate\ P_{target\_non\_comm\_T30\_B}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K6\ \ to\ calculate\ P_{target\_non\_comm\_T30\_C}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K7\ \ to\ calculate\ P_{target\_non\_comm\_T20\_A}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K8\ \ to\ calculate\ P_{target\_non\_comm\_T20\_B}$$

$$IF\ Pressure\ Class = H70,\ USE\ TABLE\ \ K9\ \ to\ calculate\ P_{target\_non\_comm\_T20\_C}$$

For CHSS Capacity Category D

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K10\ \ to\ calculate\ P_{target\_non\_comm\_D}$$

Determination of Non-Communication Target Pressure Tables - H35 (Eq. J28)

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K11\ \ to\ calculate\ P_{target\_non\_comm\_T40\_A}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K12\ \ to\ calculate\ P_{target\_non\_comm\_T40\_B}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K13\ \ to\ calculate\ P_{target\_non\_comm\_T40\_C}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K14\ \ to\ calculate\ P_{target\_non\_comm\_T30\_A}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K15\ \ to\ calculate\ P_{target\_non\_comm\_T30\_B}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K16\ \ to\ calculate\ P_{target\_non\_comm\_T30\_C}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K17\ \ to\ calculate\ P_{target\_non\_comm\_T20\_A}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K18\ \ to\ calculate\ P_{target\_non\_comm\_T20\_B}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K19\ \ to\ calculate\ P_{target\_non\_comm\_T20\_C}$$

J.2.2.1.2 Communication Pressure Target

A communication pressure target is calculated continuously during the fill. The pressure target is calculated based on an end of fill target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for H35 pressure class. However, the pressure target may be reduced to account for sensor tolerance. The amount the SOC target is reduced for sensor tolerance is determined by the dispenser manufacturer. A parameter SOC_{target} is used to define the target SOC, where SOC_{target} = 100 represents a target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for H35 pressure class. Communication fills should achieve a final SOC in the CHSS of ≥95% and ≤100%. Thus, SOC_{target} shall be set between 95 and 100, where the value 95 represents 95% SOC and the value 100 represents 100% SOC. The unit of measure for SOC_{target} is percent (%).

$$Set\ SOC_{target} \quad \text{(Eq. J29)}$$

J.2.2.1.3 Communication Pressure Limits

A pressure limit is determined for communication fueling, P_{limit_comm}. This pressure limit value is used as a secondary means of protection to limit over filling in the event of a fault in the CHSS measured temperature MT, which causes the communication pressure target to be incorrect. Pressure limit values are calculated for the three fuel delivery temperature categories, T40, T30, and T20, as well as for the three CHSS capacity categories A, B, and C, for a total of nine communication pressure limit values, except when the CHSS capacity category is D (in which case pressure targets for CHSS capacity categories A, B, and C are not needed). A pressure limit is calculated for each of these categories during the end pressure control initialization subroutine for use later in the evaluate end of fill criteria subroutine (J.2.8). The reason that a pressure limit is calculated for each of these categories is that the fuel delivery temperature category, and potentially the CHSS capacity category, may change as the fill progresses. Thus, it is necessary to pre-determine the pressure limit for each of these categories so it is available and can be utilized in the evaluate end of fill criteria subroutine based on the real-time determination of the fuel delivery temperature category and CHSS capacity category.

Communication pressure limits are calculated using interpolation on the communication pressure limit lookup tables, Tables K20 through K49. For a visual representation of the interpolation process, see Example B in Appendix G. The interpolation calculations are shown mathematically in Equation J30.

Equation J30 is utilized to conduct the interpolation required to calculate the actual communication pressure limits using inputs of ambient temperature T_{amb}, and initial pressure, $P_{initial}$. In Equation J30, $P_{initial\_below}$ represents the $P_{initial}$ value in the table directly below the actual initial pressure $P_{initial}$, and $P_{initial\_above}$ represents the $P_{initial}$ value in the table directly above the initial pressure $P_{initial}$. In Equation J30, T_{amb_below} represents the T_{amb} value in the table directly below the actual ambient temperature T_{amb}, and T_{amb_above} represents the T_{amb} value in the table directly above the actual ambient temperature T_{amb}. P_{table} represents the actual table pressure limit value at $P_{initial\_above}$ or $P_{initial\_below}$ and at T_{amb_above} or T_{amb_below}. Note that if $P_{initial}$ <5 MPa, interpolation is conducted only on ambient temperature using the table value for P <5 (i.e., P_{below} and P_{above} are not calculated).

As an example, in Table K20, P_{table} (20,30) = 85.7 MPa, where 20 represents $P_{initial\_above}$ or $P_{initial\_below}$, and 30 represents T_{amb_above} or T_{amb_below}. P_{below} is an intermediate calculation representing the below pressure limit value after interpolating on T_{amb}, and P_{above} is an intermediate calculation representing the above pressure limit value after interpolating on T_{amb}. The final P_{limit_comm} value is a result of interpolating P_{below} and P_{above} on $P_{initial}$.

Interpolation for Communication Pressure Limit (Eq. J30)

$$IF\ P_{intial} \geq 5\ MPa$$

$THEN$

$$P_{below} = P_{table}(P_{initial\_below},\ T_{amb\_below}) + \frac{[P_{table}(P_{initial\_below}, T_{amb\_above}) - P_{table}(P_{initial\_below}, T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$P_{above} = P_{table}(P_{initial\_above},\ T_{amb\_below}) + \frac{[P_{table}(P_{initial\_above}, T_{amb\_above}) - P_{table}(P_{initial\_above}, T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

$$P_{limit\_comm} = P_{below} + \frac{[P_{above} - P_{below}] \times [P_{intial} - P_{initial\_below}]}{[P_{initial\_above} - P_{initial\_below}]}$$

$$ELSE\ IF\ P_{intial} < 5\ MPa$$

$THEN$

$$P_{limit\_comm} = P_{table}(P < 5,\ T_{amb\_below}) + \frac{[P_{table}(P{<}5, T_{amb\_above}) - P_{table}(P{<}5, T_{amb\_below})] \times [T_{amb} - T_{amb\_below}]}{[T_{amb\_above} - T_{amb\_below}]}$$

As an example, consider Table K20, with $P_{initial}$ = 23 MPa and T_{amb} = 32 °C. In this case, $P_{initial\_below}$ = 20, $P_{initial\_above}$ = 30, T_{amb_below} = 30, and T_{amb_above} = 35. P_{limit_comm} is calculated as follows:

$$P_{below} = 85.7 + \frac{[86.0 - 85.7] \times [32 - 30]}{[35 - 30]} = 85.8$$

$$P_{above} = 84.5 + \frac{[84.9 - 84.5] \times [32 - 30]}{[35 - 30]} = 84.7$$

$$P_{limit\_comm} = 85.8 + \frac{[84.7 - 85.8] \times [23 - 20]}{[30 - 20]} = 85.5$$

Equation J30 is utilized to calculate a communication pressure limit for each fuel delivery temperature category and for each CHSS capacity category. Equations J31 through J33 are used for determining the appropriate communication pressure limit table to utilize for calculating each of these pressure limits. The pressure limit tables are designated based on the CHSS capacity category (A, B, C) and fuel delivery temperature category (T40, T30, T20).

Note that for the H35 pressure class, cold dispenser fueling is not applicable.

Note that if the CHSS capacity category is D, it is not necessary to calculate the communication pressure limits for CHSS capacity categories A, B, and C.

Determination of Communication Pressure Limit Tables - H70, “Normal” Fueling, CD = FALSE (Eq. J31)

For CHSS capacity categories A, B, and C

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K20\ \ to\ calculate\ P_{limit\_comm\_T40\_A}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K21\ \ to\ calculate\ P_{limit\_comm\_T40\_B}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K22\ \ to\ calculate\ P_{limit\_comm\_T40\_C}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K23\ \ to\ calculate\ P_{limit\_comm\_T30\_A}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K24\ \ to\ calculate\ P_{limit\_comm\_T30\_B}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K25\ \ to\ calculate\ P_{limit\_comm\_T30\_C}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K26\ \ to\ calculate\ P_{limit\_comm\_T20\_A}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K27\ \ to\ calculate\ P_{limit\_comm\_T20\_B}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K28\ \ to\ calculate\ P_{limit\_comm\_T20\_C}$$

For CHSS Capacity Category D

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K29\ \ to\ calculate\ P_{limit\_comm\_T40\_D}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K30\ \ to\ calculate\ P_{limit\_comm\_T30\_D}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = FALSE,\ USE\ TABLE\ \ K31\ \ to\ calculate\ P_{limit\_comm\_T20\_D}$$

Determination of Communication Pressure Limit Tables - H70, “Cold Disp,” CD = TRUE (Eq. J32)

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K32\ \ to\ calculate\ P_{limit\_comm\_T40\_A}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K33\ \ to\ calculate\ P_{limit\_comm\_T40\_B}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K34\ \ to\ calculate\ P_{limit\_comm\_T40\_C}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K35\ \ to\ calculate\ P_{limit\_comm\_T30\_A}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K36\ \ to\ calculate\ P_{limit\_comm\_T30\_B}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K37\ \ to\ calculate\ P_{limit\_comm\_T30\_C}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K38\ \ to\ calculate\ P_{limit\_comm\_T20\_A}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K39\ \ to\ calculate\ P_{limit\_comm\_T20\_B}$$

$$IF\ Pressure\ Class = H70\ AND\ CD = TRUE,\ USE\ TABLE\ \ K40\ \ to\ calculate\ P_{limit\_comm\_T20\_C}$$

Determination of Communication Pressure Limit Tables - H35 (Eq. J33)

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K41\ \ to\ calculate\ P_{limit\_comm\_T40\_A}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K42\ \ to\ calculate\ P_{limit\_comm\_T40\_B}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K43\ \ to\ calculate\ P_{limit\_comm\_T40\_C}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K44\ \ to\ calculate\ P_{limit\_comm\_T30\_A}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K45\ \ to\ calculate\ P_{limit\_comm\_T30\_B}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K46\ \ to\ calculate\ P_{limit\_comm\_T30\_C}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K47\ \ to\ calculate\ P_{limit\_comm\_T20\_A}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K48\ \ to\ calculate\ P_{limit\_comm\_T20\_B}$$

$$IF\ Pressure\ Class = H35,\ USE\ TABLE\ \ K49\ \ to\ calculate\ P_{limit\_comm\_T20\_C}$$

J.2.2.2 End Pressure Control Initialization - MC Method

Equation J34 is used to calculate the initial CHSS temperature T_{init_cold} with cold case assumptions, meaning the CHSS began at the cold soak temperature and 100% SOC, and then was defueled at the maximum flow rate, as explained in A.3.8 and A.3.9. T_{fit_1} and T_{fit_2} represent a regression fit to the defueling data generated using simulations, and are temporary variables used in calculating T_{init_cold}. The unit of measure for T_{amb} and T_{init_cold} in Equation J34 is Kelvin (K).

$$T_{fit\_1} = 273.15 + P_{initial} \times 0.31 - 12.21$$ (Eq. J34)

$$T_{fit\_2} = 273.15 + (T_{amb} - 273.15) \times (0.89 - P_{initial} \times 6.74\text{E-}06) + (P_{initial} \times 0.31 - 43.45)$$

$$IF\ T_{fit\_2} > T_{fit\_1},\ THEN\ T_{init\_cold} = T_{fit\_1},\ ELSE\ \ T_{init\_cold} = T_{fit\_2}$$

$$AND\ \ IF\ T_{init\_cold} < 233.15,\ THEN\ T_{init\_cold} = 233.15$$

Equation J35 is used to set the parameter t_{min_cold} to 30 seconds. This parameter is used in the MC equation and represents the time elapsed after which the parameter Δt_{cold} is calculated. Δt_{cold} is the difference between the fueling time t and t_{min_cold}. The unit of measure for t and t_{min_cold} is seconds.

$$Set\ t_{\min\_cold} = 30$$ (Eq. J35)

A pressure target is calculated for communication fueling based on an end of fill target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for H35 pressure class. However, the pressure target may be reduced to account for sensor tolerance. The amount the SOC target is reduced for sensor tolerance is determined by the dispenser manufacturer. A parameter SOC_{target} is used to define the target SOC, where SOC_{target} = 100 represents a target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for H35 pressure class. Communication fills should achieve a final SOC in the CHSS of ≥95% and ≤100%. Thus, SOC_{target} shall be set between 95 and 100, where the value 95 represents 95% SOC and the value 100 represents 100% SOC. The unit of measure for SOC_{target} is percentage (%).

$$Set\ SOC_{target}$$ (Eq. J36)

The cold case initial density ρ_{init_cold} is calculated based on $P_{initial}$ and T_{init_cold}. The equation to calculate density is not given here, as the dispenser should have this capability. If desired, a reference equation for density is given in J.3.4, Equation J98. The unit of measure for ρ_{init_cold} is kg/m^3.

$$Set\ \rho_{init\_cold} = \rho(P_{initial}, T_{init\_cold})$$ (Eq. J37)

A 1 kg Type III vessel is used in the calculation of the ending pressure, as detailed in A.3.7. The volume of this vessel is set for either H70 or H35 fueling. Units are in m^3.

$$IF\ Pressure\ Class = H70,\ \ THEN\ Set\ V_{cold} = 0.0247 \qquad \text{(Eq. J38)}$$

$$IF\ Pressure\ Class = H35,\ THEN\ Set\ V_{cold} = 0.0416 \qquad \text{(Eq. J39)}$$

The mass of hydrogen in the Type III vessel at 100% SOC is 1 kg. The unit of measure for m_{final_cold} is kg.

$$Set\ m_{final\_cold} = 1 \qquad \text{(Eq. J40)}$$

The cold case initial mass of hydrogen in this single Type III vessel is calculated based on the initial density ρ_{init_cold} and the volume V_{cold}. The unit of measure for m_{init_cold} is kg.

$$Set\ m_{init\_cold} = V_{cold}\ \times \rho_{init\_cold} \qquad \text{(Eq. J41)}$$

The mass of hydrogen required to be added to the cold case initial mass to achieve 100% SOC is calculated. The unit of measure for m_{add} is kg.

$$Set\ m_{add} = m_{final\_cold} - m_{init\_cold} \qquad \text{(Eq. J42)}$$

The cold case initial specific internal energy is calculated based on the initial pressure $P_{initial}$ and the cold case initial temperature T_{init_cold}. The equation to calculate specific internal energy is not given here, but guidance for the calculation of specific internal energy is given in J.3.2, and if desired, a reference equation for specific internal energy is also provided, Equation J96. The unit of measure for u_{init_cold} is kJ/kg.

$$Set\ u_{init\_cold} = u(P_{initial}, T_{init\_cold}) \qquad \text{(Eq. J43)}$$

The cold case initial internal energy U_{init_cold} is calculated based on the cold case initial specific internal energy u_{init_cold} and the cold case initial mass m_{init_cold}. The unit of measure for U_{init_cold} is kJ.

$$Set\ U_{init\_cold} = u_{init\_cold} \times m_{init\_cold} \qquad \text{(Eq. J44)}$$

There are five constants utilized in the MC Equation. See H.3.1 for a detailed explanation of the MC equation and how it is used in calculating the end of fill pressure target and limit. The five constants utilized in the MC equation are set. The unit of measure for AC, BC, and GC are kJ/K. KC and JC are dimensionless.

$$AC = 1.10487E + 00 \qquad \text{(Eq. J45)}$$

$$BC = 2.20466E + 00$$

$$GC = 2.22198E + 01$$

$$KC = 1.63097E - 03$$

$$JC = 8.23284E - 01$$

J.2.3 Mass Average Calculation Subroutine

This subroutine is used to calculate the mass average of the fuel delivery temperature measured at the dispenser outlet and the mass average of enthalpy measured at the dispenser outlet. The mass average of enthalpy is only calculated if the MC Method is used as the ending pressure control option. These mass average calculations shall be conducted using the time step j, which means they are calculated once every second.

The mass average calculations in this subroutine utilize inputs from the station pressure sensor and the fuel delivery temperature sensor. The location, accuracy and reliability requirements for these sensors are listed in 6.2.

A method of fault detection (sensor drift or failure) of the fuel delivery temperature measurement should be utilized. Although this Standard does not prescribe a methodology for ensuring the integrity of this measurement, the requirements of 6.2.4 should be adhered to. As an example of a potential methodology, redundancy may be applied, so that the mass average of two temperature measurements is compared, and if the absolute value of their difference is greater than a limit criteria, the dispenser faults and stops the fill. The limit criteria should be determined by the dispenser manufacturer based on sensor type used and its standard error. An example of a limit criteria is the standard error of the sensor. It should be noted that the mass average calculation is inherently more accurate the more mass that is dispensed. Thus, the dispenser manufacturer may decide to implement the limit criteria after a certain amount of time has passed or mass has been dispensed. Alternatively, the limit criteria can be progressive in nature, such that it decreases with increasing elapsed time or mass dispensed.

In addition to implementing a fault detection methodology, the error of the temperature measurement should also be considered and the requirements of 6.2.2 adhered to. Typically, a temperature sensor will employ a standard measurement error of ±X, where X is expressed in the units of measurement. In this case, to ensure that the most conservative measurement is utilized as the control input, for the fuel delivery temperature utilized in the mass average fuel delivery temperature calculation, the + measurement error should be added to the measured value, and for the fuel delivery temperature utilized in the mass average enthalpy calculation, the + measurement error should be subtracted from the measured value. Alternatively, if the sensor has been calibrated by an accredited laboratory, the measured value can be corrected by the calibrated error for both the mass average temperature and enthalpy calculations.

If redundancy is employed and two fuel delivery temperatures are measured, then two mass average values (represented as A and B) should be calculated and the most conservative value utilized as the control input.

J.2.3.1 Mass Average Calculation of the Fuel Delivery Temperature Subroutine

A key control input for determining the pressure ramp rate is the mass average of the fuel delivery temperature measured at the dispenser outlet. There are two mass average calculations, MAT_0 and MAT_{30}. MAT_0 begins the calculation at the beginning of the main fueling time from t = 0 seconds. MAT_{30} begins the calculation after a total of 30 seconds of mass flow have elapsed. See H.2.4 for a detailed explanation of how the mass average of the fuel delivery temperature is used in the pressure ramp rate control. The unit of measure for MAT_0 and MAT_{30} is Kelvin (K).

In the equations in this subroutine, T_{fuel_inst} is the fuel delivery temperature measured at the dispenser outlet, and m represents the total mass dispensed from the beginning of the main fueling time. $T_{fue\_instl(j)}$ represents the temperature measured at the current time step j. $T_{fuel\_inst(j-1)}$ represents the temperature measured at the previous time step j-1. $T_{fuel\_inst\_A}$ and $T_{fuel\_inst\_B}$ represent two separate measurements when redundancy is employed. $m_{(j)}$ represents the total mass dispensed up to the current time step j. $m_{(j-1)}$ represents the total mass dispensed up to the previous time step j-1. Thus, $m_{(j)}$ - $m_{(j-1)}$ represents the change in mass over the last time step j. It is important that the denominator in Equations J46 and J47 be calculated as the sum of $m_{(j)}$ - $m_{(j-1)}$, rather than just using the value m. This is because the mass average is a weighting function, and thus the change in mass for the numerator and denominator must be summed in the same way. The unit of measure for T_{fuel_inst} is Kelvin (K). The unit of measure for m is grams.

$$IF\ j=0,\ THEN\ MAT_{0\_A}=T_{fuel\_inst\_A(0)},\ ELSE\ \ MAT_{0\_A}=\frac{\sum_0^j[(m_{(j)}-m_{(j-1)})\times 0.5(T_{fuel\_inst\_A(j)}+T_{fuel\_inst\_A(j-1)})]}{\sum_0^j(m_{(j)}-m_{(j-1)})} \quad \text{(Eq. J46)}$$

$$IF\ j=0,\ THEN\ MAT_{0\_B}=T_{fuel\_inst\_B(0)},\ ELSE\ \ MAT_{0\_B}=\frac{\sum_0^j[(m_{(j)}-m_{(j-1)})\times 0.5(T_{fuel\_inst\_B(j)}+T_{fuel\_inst\_B(j-1)})]}{\sum_0^j(m_{(j)}-m_{(j-1)})} \quad \text{(Eq. J47)}$$

$$MAT_0 = MAXIMUM\left[MAT_{0\_A}, MAT_{0\_B}\right] \quad \text{(Eq. J48)}$$

In Equations J49 and J50 for MAT_{30}, and Equation J52, which utilizes $MAT_{30,}$ a parameter named n (a counter), is utilized for determining the point in the fill at which these calculations shall commence. The calculation of MAT_{30} begins after a total of 30 seconds of mass flow have elapsed. Because the time step counter j advances every second, regardless of whether there is mass flow or not, a separate counter n, which updates at the same frequency as j, is utilized. The difference between n and j is that n only updates when there is mass flow during the calculation cycle, which means that n does not advance during an intended non-fueling event such as a leak check or bank switch. Since, by definition, the calculation of MAT_{30} begins after a total of 30 seconds of mass flow, the calculation of MAT_{30} begins when n=30. Since the summation terms in the numerator and denominator of Equations J49 and J50 utilize the time step j, the time at which the calculation begins is denoted by j at n=30, which represents the value of j when the counter n reaches 30. If there are no intended non-fueling events during the first 30 seconds of the fill, then j and n will reach 30 at the same time.

If an intended non-fueling event occurs when $20 \leq n \leq 30$, then subtract 10 seconds from n. In this case, a total of 40 seconds of mass flow are allowed prior to the MAT_{30} cacluation beginning. The purpose of subtracting 10 seconds is to allow the fuel delivery temperature T_{fuel_inst} to get cold again after the warming which occurs during the intended non-fueling event.

It is important that the denominator in Equations J49 and J50 be calculated as the sum of $m_{(j)} - m_{(j-1)}$, rather than just using the value $m - m_{(j@n=30)}$. This is because the mass average is a weighting function, and thus the change in mass for the numerator and denominator must be summed in the same way.

$$IF\ n \geq 30,\ THEN\ MAT_{30\_A} = \frac{\sum_{j@n=30}^{j}\left[\left(m_{(j)}-m_{(j-1)}\right)\times 0.5\left(T_{fuel\_inst\_A(j)}+T_{fuel\_inst\_A(j-1)}\right)\right]}{\sum_{j@n=30}^{j}\left(m_{(j)}-m_{(j-1)}\right)} \qquad \text{(Eq. J49)}$$

$$IF\ n \geq 30,\ THEN\ MAT_{30\_B} = \frac{\sum_{j@n=30}^{j}\left[\left(m_{(j)}-m_{(j-1)}\right)\times 0.5\left(T_{fuel\_inst\_B(j)}+T_{fuel\_inst\_B(j-1)}\right)\right]}{\sum_{j@n=30}^{j}\left(m_{(j)}-m_{(j-1)}\right)} \qquad \text{(Eq. J50)}$$

$$MAT_{30} = MAXIMUM\left[MAT_{30\_A}, MAT_{30\_B}\right] \qquad \text{(Eq. J51)}$$

The mass average of the fuel delivery temperature which is utilized as the control input for the t_{final} equation is labeled as MAT_C. MAT_C is calculated from either $MAT_{expected}$, MAT_{30}, or a combination of MAT_{30} and MAT_0. The logic for making this determination is explained in H.2.4. Equation J52 is utilized to calculate MAT_C.

IF

$$n \leq 30 \quad \text{(Eq. J52)}$$

$THEN$

$$MAT_C = MAT_{expected}$$

$ELSE$

$$IF\ P_{control} \leq P_{trans}$$

$THEN$

$$MAT_C = MAT_{30}$$

$ELSE$

$$IF\ P_{trans} < P_{control} \leq P_{final}$$

$THEN$

$$MAT_C = MAT_{30} \times \left(\frac{P_{final} - P_{control}}{P_{final} - P_{trans}}\right) + MAT_0 \times \left(1 - \frac{P_{final} - P_{control}}{P_{final} - P_{trans}}\right)$$

$ELSE$

$$IF\ P_{control} > P_{final}$$

$THEN$

$$MAT_C = MAT_0$$

The counter n is only advanced if mass is flowing, as represented in Equation J53. During an intended non-fueling event, the counter n does not advance.

$$IF\ \dot{m} > 0,\ \ n = n + 1 \quad \text{(Eq. J53)}$$

J.2.3.2 Mass Average Calculation of Enthalpy Subroutine

This subroutine is only applicable if the MC Method is utilized as the ending pressure control option. If ending pressure tables are the ending pressure control option, this subroutine is not applicable.

In the equations in this subroutine, T_{fuel_inst} is the temperature measured at the dispenser outlet, $P_{station}$ is the station pressure measured at the dispenser outlet, h represents the enthalpy measured at the dispenser outlet, and m represents the total mass dispensed from the beginning of the main fueling time. $h_{(j)}$ represents the enthalpy measured at the current time step j. $h_{(j-1)}$ represents the enthalpy measured at the previous time step j-1. $T_{fuel\_inst\_A}$ and $T_{fuel\_inst\_B}$, and h_A and h_B, represent two separate measurements when redundancy is employed. $m_{(j)}$ represents the total mass dispensed up to the current time step j. $m_{(j-1)}$ represents the total mass dispensed up to the previous time step j-1. Thus, $m_{(j)}$ - $m_{(j-1)}$ represents the change in mass over the last time step j. The unit of measure for T_{fuel_inst} is Kelvin (K). The unit of measure for $P_{station}$ is MPa. The unit of measure for m is grams.

Equations J54 through J57 are used to calculate the mass average of the dispenser outlet enthalpy h_{ave}. The equation for enthalpy as a function of temperature and pressure is not given here, but guidance for the calculation of enthalpy is given in J.3, and if desired, a reference equation for enthalpy is provided by Equation J95. The unit of measure for h and h_{ave} is kJ/kg.

It is important that the denominator in Equations J55 and J56 be calculated as the sum of $m_{(j)}$ - $m_{(j-1)}$, rather than just using the value m. This is because the mass average is a weighting function, and thus the change in mass for the numerator and denominator must be summed in the same way.

$$h_{A(j)} = h\left(T_{fuel\_inst\_A(j)}, P_{station(j)}\right),\ \ h_{B(j)} = h\left(T_{fuel\_inst\_B(j)}, P_{station(j)}\right) \quad \text{(Eq. J54)}$$

$$IF\ j = 0,\ h_{ave\_A} = h_{A(0)}\ \ ELSE\ \ h_{ave\_A} = \frac{\sum_0^j\left[\left(m_{(j)} - m_{(j-1)}\right)\times 0.5\left(h_{A(j)} + h_{A(j-1)}\right)\right]}{\sum_0^j\left(m_{(j)} - m_{(j-1)}\right)} \quad \text{(Eq. J55)}$$

$$IF\ j = 0,\ h_{ave\_B} = h_{B(0)}\ \ ELSE\ \ h_{ave\_B} = \frac{\sum_0^j\left[\left(m_{(j)} - m_{(j-1)}\right)\times 0.5\left(h_{B(j)} + h_{B(j-1)}\right)\right]}{\sum_0^j\left(m_{(j)} - m_{(j-1)}\right)} \quad \text{(Eq. J56)}$$

$$h_{ave} = MINIMUM\left[h_{ave\_A}, h_{ave\_B}\right] \quad \text{(Eq. J57)}$$

J.2.4 Calculation of t_{final} Subroutine

This subroutine is used to calculate t_{final}, which is defined as the total time required to fill from P_{min} to P_{final}. t_{final} is the key control input to the pressure ramp rate equation. For a detailed explanation of t_{final} and the pressure ramp rate equation, see H.2.2 and H.2.3, respectively. The unit of measure for t_{final} is seconds.

The calculations in this subroutine shall be conducted using the time step i, which means they are calculated once every 5 seconds. A time step shorter than 5 seconds may be used, if desired, but time step i shall not be shorter than time step j.

t_{final} is calculated for each boundary CHSS: 49.7 L, 99.4 L, 174.0 L, and 248.6 L. These form the boundaries of the CHSS capacity categories A, B, and C, listed in Table 8 of 9.2. As described in J.1.4, when the CHSS capacity category can be determined by the dispenser, the flag variable “Indicator Cons RR” is set to FALSE. In this case, there are two options for calculating t_{final}. The dispenser manufacturer may choose either option. When Option1 is utilized, t_{final} is chosen based on the more conservative t_{final} of the lower boundary CHSS and upper boundary CHSS, or the minimum value t_{final_min}, whichever is higher. When Option 2 is utilized (only applicable to CHSS Capacity Categories A, B and C), t_{final} is determined by interpolating between t_{final} of the upper and lower boundary CHSS based on the measured CHSS volume, or the minimum value t_{final_min}, whichever is higher.

When the CHSS capacity category cannot be determined by the dispenser, the flag variable “Indicator Cons RR” is set to TRUE and t_{final} is chosen based on the most conservative t_{final} of all of the boundary CHSS, or the minimum value $t_{final\_min\_cons}$.

Although Equations J58 through J61 calculate t_{final} for every boundary CHSS, if the CHSS capacity category is determined, and “Indicator Cons RR” is FALSE, it is only necessary to calculate t_{final} for the boundary CHSS of the CHSS capacity category (e.g., $t_{final\_99.4}$ and t_{final_174} for CHSS capaicty Category B). The equations are written this way to provide a logical and consistent approach that is applicable under all cases, and regardless of whether “Indicator Con RR” is FALSE or TRUE.

Calculation of t_{final} for 49.7 L boundary CHSS (Eq. J58)

$$t_{final\_49.7} = \alpha \times \beta \times \left(a_{49.7} \times MAT_C^3 + b_{49.7} \times MAT_C^2 + c_{49.7} \times MAT_C + d_{49.7}\right)$$

Calculation of t_{final} for 99.4 L boundary CHSS (Eq. J59)

$$t_{final\_99.4} = \alpha \times \beta \times \left(a_{99.4} \times MAT_C^3 + b_{99.4} \times MAT_C^2 + c_{99.4} \times MAT_C + d_{99.4}\right)$$

Calculation of t_{final} for 174.0 L boundary CHSS (Eq. J60)

$$t_{final\_174.0} = \alpha \times \beta \times \left(a_{174.0} \times MAT_C^3 + b_{174.0} \times MAT_C^2 + c_{174.0} \times MAT_C + d_{174.0}\right)$$

Calculation of t_{final} for 248.6 L boundary CHSS (Eq. J61)

$$t_{final\_248.6} = \alpha \times \beta \times (a_{248.6} \times MAT_C^3 + b_{248.6} \times MAT_C^2 + c_{248.6} \times MAT_C + d_{248.6})$$

Calculation of t_{final_small}, t_{final_large}, and t_{final_min} (Eq. J62)

$$IF\ Indicator\ Cons\ RR = FALSE$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ t_{final\_small} = t_{final\_49.7},\ t_{final\_large} = t_{final\_99.4},\ t_{final\_min} = t_{final\_min\ \_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ t_{final\_small} = t_{final\_99.4},\ t_{final\_large} = t_{final\_174.0},\ t_{final\_min} = t_{final\_min\ \_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ t_{final\_small} = t_{final\_174.0},\ t_{final\_large} = t_{final\_248.6},\ t_{final\_min} = t_{final\_min\ \_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ t_{final\_small} = t_{final\_248.6},\ t_{final\_large} = t_{final\_248.6},\ t_{final\_min} = t_{final\_min\ \_D}$$

$ELSE$

$$t_{final\_min} = t_{final\_min\ \_cons}$$

Calculation of t_{final} (Eq. J63)

$$IF\ Indicator\ Cons\ RR = FALSE$$

$THEN$

OPTION 1:

$$t_{final} = MAXIMUM(t_{final\_min}, t_{final\_small}, t_{final\_large})$$

OPTION 2: Interpolate t_{final} (Only Applicable to CHSS Capacity Categories A, B and C)

$$IF\ CHSS_{Capacity\_Category} = A,\ t_{final\_interp} = t_{final\_49.7} + (t_{final\_99.4} - t_{final\_49.7}) \times \frac{(V_{CHSS} - 49.7)}{(99.4 - 49.7)}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ t_{final\_interp} = t_{final\_99.4} + (t_{final\_174.0} - t_{final\_99.4}) \times \frac{(V_{CHSS} - 99.4)}{(174.0 - 99.4)}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ t_{final\_interp} = t_{final\_174.0} + (t_{final\_248.6} - t_{final\_174.0}) \times \frac{(V_{CHSS} - 174.0)}{(248.6 - 174.0)}$$

$$t_{final} = MAXIMUM(t_{final\_interp}, t_{final\_min})$$

$ELSE$

$$t_{final} = MAXIMUM(t_{final\_min}, t_{final\_49.7}, t_{final\_99.4}, t_{final\_174.0}, t_{final\_248.6})$$

J.2.5 Calculation of T_{cold} Subroutine

This subroutine is only applicable if the MC Method is utilized as the ending pressure control option. If ending pressure tables are the ending pressure control option, this subroutine is not applicable.

This subroutine is used to calculate the cold case CHSS gas temperature using the MC Method equations. See H.3.1 for a detailed explanation of the MC Method and how it is used to calculate the end of fill pressure target. T_{cold} represents the cold case gas temperature and is used to calculate the pressure target for non-communication fills and the pressure limit for communication fills.

The calculations in this subroutine shall be conducted using the time step i, which means they are calculated once every 5 seconds. A time step shorter than 5 seconds may be used, if desired, but time step i shall not be shorter than time step j.

Equation J64 calculates the adiabatic internal energy. The unit of measure for $U_{adiabatic\_cold}$ is kJ.

$$U_{adiabatic\_cold} = U_{init\_cold} + m_{add} \times h_{ave} \quad \text{(Eq. J64)}$$

Equation J65 calculates the specific adiabatic internal energy. The unit of measure for $u_{adiabatic\_cold}$ is kJ/kg.

$$u_{adiabatic\_cold} = \frac{U_{adiabatic\_cold}}{m_{final\_cold}} \quad \text{(Eq. J65)}$$

Equation J66 calculates the cold case adiabatic temperature $T_{adiabatic\_cold}$. The equation for temperature as a function of pressure and specific internal energy is not given here, but guidance for this calculation is given in J.3, and if desired, a reference equation for temperature is provided by Equation J97. The unit of measure for $T_{adiabatic\_cold}$ is Kelvin (K).

$$T_{adiabatic\_cold} = f\left(P_{station}, u_{adiabatic\_cold}\right) \quad \text{(Eq. J66)}$$

Equation J67 calculates the cold case specific heat capacity at constant volume c_{v_cold}. The equation for specific heat capacity as a function of pressure and temperature is not given here, but guidance for this calculation is given in J.3, and if desired, a reference equation for specific heat capacity is provided by Equation J99. The unit of measure for c_{v_cold} is kJ/kgK.

$$c_{v\_cold} = f\left(P_{station}, T_{adiabatic\_cold}\right) \quad \text{(Eq. J67)}$$

Equations J68 and J69 are used to calculate MC_{cold}. For a detailed explanation of MC_{cold} and how it is used (see H.3.1). The unit of measure for MC_{cold} is kJ/K.

$$IF\ t > t_{\min\_cold},\ \Delta t_{cold} = t - t_{\min\_cold},\ ELSE\ \Delta t_{cold} = 0 \quad \text{(Eq. J68)}$$

$$MC_{cold} = AC + BC \times \ln\sqrt{\frac{U_{adiabatic\_cold}}{U_{init\_cold}}} + GC \times \left(1 - e^{-KC \times \Delta t_{cold}}\right)^{JC} \quad \text{(Eq. J69)}$$

The final step in this subroutine is to calculate T_{cold}. T_{cold} represents the cold case gas temperature in the cold case CHSS and is used in the Determination of pressure targets and limits subroutine in J.2.7.2 to calculate the pressure target for non-communication fills and the pressure limit for communication fills. For a detailed explanation of T_{cold} (see H.3.1). The unit of measure for T_{cold} is Kelvin (K).

$$T_{cold} = \frac{m_{final\_cold} \times c_{v\_cold} \times T_{adiabatic\_cold} + MC_{cold} \times T_{init\_cold}}{MC_{cold} + m_{final\_cold} \times c_{v\_cold}} \quad \text{(Eq. J70)}$$

J.2.6 Calculation of PRR and $P_{control}$ Subroutine

This subroutine is used to calculate the pressure ramp rate PRR, ramp pressure P_{ramp}, control pressure $P_{control}$, limit pressures P_{limit_high} and P_{limit_low}, and the factors, α and β, used in the t_{final} equation. The ramp pressure is the pressure upon which the pressure ramp rate is based. The control pressure is the pressure that the dispenser control is targeting at any point in time during the fill. The upper and lower limit pressures define the pressure corridor and are limits on the station pressure that are not to be breached. See H.2.3 and H.2.5 for a detailed explanation of the variable pressure ramp rate PRR, H.2.6 for a detailed explanation of α, β, P_{limit_high}, and P_{limit_low}, and H.2.7 for a detailed explanation of $P_{control}$.

The calculations in this subroutine shall be conducted based on a time step j, which is advanced every 1 second. Thus, each calculation in this subroutine is conducted once every second.

Equation J71 is used to calculate α. α is a factor which accounts for variability in the pressure ramp rate during the fill. α is multiplied by the t_{final} equation to extend the fueling time based on the amount of variability in the pressure ramp rate. The unit of measure for α is dimensionless. The unit of measure for RR_{min} and RR_{max} is MPa/s.

Note that in Equation J71, for the first calculation cycle when j = 0, α is not calculated and the initialization value of 1 is utilized. Also note that if the mass flow rate is zero for longer than 5 seconds (for example, during an intended non-fueling event), the minimum pressure ramp rate RR_{min} is set to zero.

$$IF\ j > 0 \qquad \text{(Eq. J71)}$$

$THEN$

$$IF\ \ PRR < RR_{min},\ THEN\ RR_{min} = PRR$$

$$IF\ \ PRR > RR_{max},\ THEN\ RR_{max} = PRR$$

$$IF\ \dot{m} = 0\ for\ greater\ than\ 5\ seconds,\ THEN\ RR_{min} = 0$$

$$\alpha\ = \left[\frac{100+18.5(RR_{max}-RR_{min})}{100}\right]$$

Equation J72 is used to re-calculate β. The factor β is initialized in the PRR control initialization subroutine, J.2.1, Equation J13. However, the inclusion of parameter ΔP_{tol_low} in the β equation (see Equation J13) provides excess margin that causes the fueling time to be longer than it may need to be. A detailed explanation of the β factor and how it is derived, is given in H.2.6.2.1. To eliminate this excess margin and optimize the fueling time, a measurement of the ramp pressure minus the station pressure is made shortly after fueling commences at time $t = t_{tol\_low}$. This measurement then allows the factor β to be recalculated. β is only recalculated once during the fill. The re-calculation of β is optional. The dispenser manufacturer may choose to utilize the β factor initially calculated in J.2.1, Equation J13, throughout the fill, although this will cause the fueling time to be up to 4% longer.

Note that in Equation J72, for the first calculation cycle when j = 0, because the PRR is not yet known, t_{tol_low} cannot be calculated, and therefore, this step is skipped, and the initialized value of β is utilized. The initialized value of β is used until the criteria of $t \geq t_{tol\_low}$ satisfied. Also note that the measurement of $P_{ramp} - P_{station}$ in the calculation of ΔP_{low} is only conducted once, exactly at the first time that the criteria of $t \geq t_{tol\_low}$ is satisfied. If $P_{station}$ is greater than or equal to P_{ramp}, then $\Delta P_{tol\_low} = 0$.

$$IF\ j > 0 \qquad \text{(Eq. J72)}$$

$THEN$

$$t_{tol\_low} = \frac{2.5}{PRR}$$

$$IF\ \ t \geq t_{tol\_low}\ for\ the\ first\ time$$

$THEN$

$$\Delta P_{low} = MAXIMUM\left(\ 0,\ P_{ramp} - P_{station}\right)$$

AND

$$\beta = \frac{P_{final}-P_{min}}{P_{final}-P_{min}-\ \Delta P_{tol\_high}-\ \Delta P_{low}}$$

A cap PRR_{CAP} is placed on the pressure ramp rate PRR to limit the maximum flow rate and to prevent α from becoming too large, which can actually cause the overall fill time to be longer. The highest average pressure ramp rate that can occur is if t_{final} is calculated to be t_{final_min}. In this case, the highest average pressure ramp rate over the whole fill would be $\frac{P_{final}-P_{min}}{t_{final\_min}}$. The cap on PRR is set so that it can never be higher than 110% of the highest average pressure ramp rate. This approach allows the PRR to vary sufficiently, while ensuring that the flow rate and α do not become too large. The factor PRR_{CAP_Factor}, which determines the magnitude of PRR_{CAP}, is set in the PRR control initialization subroutine, J.2.1.2, Equation J22. The unit of measure for PRR_{CAP_Factor} is dimensionless and the unit of measure for PRR_{CAP} is MPa/s.

$$PRR_{CAP} = PRR_{CAP\_Factor} \times \frac{P_{final}-P_{min}}{t_{final\_min}} \qquad \text{(Eq. J73)}$$

TopOff is an optional logical flag variable that is set to either TRUE or FALSE. When TopOff is TRUE, the pressure ramp rate is limited to 0.33 MPa/s (20 MPa/min) near the end of the fill to lower the pressure drop between the dispenser pressure and the CHSS pressure in order to increase the ending SOC in the CHSS. The limiting value of 0.33 MPa/s is utilized because at this pressure ramp rate, the pressure drop between dispenser and CHSS is typically <1 MPa. Using a lower (i.e., less than 0.33 MPa/s) limiting value may reduce the pressure drop even further, but at the cost of increasing the overall fueling time.

If the TopOff pressure ramp rate is utilized, the criteria to determine when the TopOff flag variable is activated is provided in Equation J74. Equation J74 is not utilized during the first calculation cycle when j = 0, because the necessary inputs of pressure target and the PRR have not yet been determined. The unit of measure for $P_{station}$, $P_{target\_non\_comm}$, and P_{target_comm} is MPa, and the unit of measure for PRR is MPa/s.

The use of the TopOff pressure ramp rate is optional.

Conditions for Activation of TopOff Flag Variable (Eq. J74)

$$IF\ \ j > 0$$

$THEN$

$$IF\ \ Indicator\ Comm\ Fill\ = TRUE$$

$THEN$

$$IF\ \ \frac{P_{station}}{P_{target\_comm}} \geq 0.965 - 0.09 \times PRR$$

$THEN$

$$TOPOFF = TRUE$$

$ELSE$

$$IF\ \ Indicator\ Comm\ Fill\ = FALSE$$

$$IF\ \ \frac{P_{station}}{P_{target\_non\_comm}} \geq 0.965 - 0.09 \times PRR$$

$THEN$

$$TOPOFF = TRUE$$

Equation J75 is used to calculate the pressure ramp rate PRR. See H.2.3 and H.2.5 for a detailed explanation of pressure ramp rate control and equations. Note that the incorporation of a TopOff pressure ramp rate is optional. If TopOff is not utilized, then ignore the condition in Equation J75 where TopOff = TRUE. The unit of measure for PRR is MPa/s.

Pressure Ramp Rate Equation (Eq. J75)

$$IF \quad t_{final} \times \left(\frac{P_{final} - P_{startup}}{P_{final} - P_{min}}\right) - t > 10 \quad AND \; P_{ramp} < 0.98 \times P_{final}$$

$THEN$

$$PRR = \frac{P_{final} - P_{ramp}}{t_{final} \times \left(\frac{P_{final} - P_{startup}}{P_{final} - P_{min}}\right) - t}$$

$$PRR = MINIMUM\ [PRR, PRR_{CAP}]$$

$$IF\ TopOff = TRUE$$

$$THEN\ PRR = MINIMUM\ [PRR, 0.33]$$

$ELSE$

$$PRR = PRR$$

$$IF\ TopOff = TRUE$$

$THEN$

$$PRR = MINIMUM\ [PRR, 0.33]$$

The ramp pressure P_{ramp} advances throughout the fill based on the PRR calculated in Equation J75. Since P_{ramp} is used to advance the pressure during the fill, it is always calculated for the next time step j + 1, i.e., 1 second in advance. If there is an intended non-fueling event where the flow rate drops to zero, such as during a leak check or a bank switch, then P_{ramp} may be held constant during this pause (if P_{ramp} is not held constant, then the lower pressure limit P_{limit_low} process requirement Eq. J89 still applies). P_{ramp} begins advancing again once gas flow resumes. The unit of measure for P_{ramp} is MPa.

Ramp Pressure Equation (Eq. J76)

$$IF\ \dot{m} > 0$$

$THEN$

$$P_{ramp(j+1)} = P_{ramp} + PRR$$

$ELSE$

$$IF\ \dot{m} = 0$$

$THEN$

$$P_{ramp(j+1)} = P_{ramp}$$

OR

$$P_{ramp(j+1)} = P_{ramp} + PRR$$

The control pressure $P_{control}$ is defined as the pressure that the dispenser is targeting at any point in time. In other words, the control pressure is the control parameter that the dispenser follows in controlling the station pressure $P_{station}$. $P_{control}$ is determined as an offset ΔP_{offset} from P_{ramp}. ΔP_{offset} is initialized in the PRR control initialization subroutine, J.2.1.2, Equation J23; however, it does not need to be a constant, and therefore may change during the fill. To provide the option for ΔP_{offset} to change, the value of ΔP_{offset} is set each loop through this subroutine. The dispenser manufacturer should determine the appropriate offset value based on the characteristics of the dispenser control. A larger offset results in shorter fueling times, but provides a smaller margin between $P_{control}$ and P_{limit_high}. See H.2.7 for a detailed explanation, and for an example of how ΔP_{offset} may be varied. ΔP_{offset} may be set to any value between 0 and 7. The unit of measure for $P_{control}$ and ΔP_{offset} is MPa.

Control Pressure Equation (Eq. J77)

$$Set\ \Delta P_{offset} \text{ (determined by dispenser mfg)}$$

$$P_{control(j+1)} = P_{ramp(j+1)} + \Delta P_{offset}$$

The upper and lower limit pressures P_{limit_high} and P_{limit_low}, respectively, are utilized to set the upper and lower boundaries of a pressure corridor which the station pressure $P_{station}$ shall not penetrate during the main fueling time, with the exception of the first 15 seconds (as well as additional conditions as per 9.3.2). The process check subroutine, J.2.9, performs a check on $P_{station}$ against P_{limit_high} and P_{limit_low} to ensure that the station pressure stays within the pressure corridor. The unit of measure for P_{limit_high} and P_{limit_low} is MPa.

Upper and Lower Pressure Limit Equation (Eq. J78)

$$P_{limit\_high} = P_{ramp} + \Delta P_{tol\_high}$$

$$IF\ CHSS\ Capacity\ Category = A, B, or\ C$$

$THEN$

$$P_{limit\_low} = MAXIMUM\left(P_{startup}\ , P_{ramp} - \Delta P_{tol\_low}\right)$$

$ELSE$

$$IF\ CHSS\ Capacity\ Category = D$$

$$P_{limit\_low} = MAXIMUM\left(P_{startup}, P_{startup} + 0.0167 \times t - \Delta P_{tol\_low}\right)$$

J.2.7 Determination of Pressure Targets and Limits Subroutine

This subroutine is used to determine and set the end of fill pressure targets and limits. There are two independent and exclusive sub-sections, the use of which is determined by the ending pressure control option utilized. Section J.2.7.1 describes the determination of pressure targets and limits for “ending pressure tables” as the ending pressure control option. Section J.2.7.2 describes the determination of pressure targets and limits for the “MC Method” as the ending pressure control option.

The calculations in this subroutine shall be conducted based on a time step j, which is advanced every 1 second. Thus, each calculation in this subroutine is conducted once every second.

J.2.7.1 Determination of Pressure Targets and Limits - Ending Pressure Tables

For end of fill determination, there are two pressure targets utilized, one for non-communication fueling $P_{target\_non\_comm}$, and one for communication fueling P_{target_comm}. Additionally, there is a pressure limit utilized for communication fueling, P_{limit_comm}, used as a secondary protection in case of a fault condition in the MT signal. The non-communication pressure targets and the communication pressure limits were calculated in the end pressure control initialization subroutine, J.2.2.1. In J.2.7.1, a determination is made for which one of these pre-calculated non-communication pressure targets and communication pressure limits is applicable to current conditions, and the communication pressure target is calculated as a function of the CHSS measured temperature MT.

J.2.7.1.1 Determine Non-Communication Pressure Target

If the CHSS Capacity Category is A, B, C, or indeterminate, then nine non-communication pressure targets were calculated in the end pressure control initialization subroutine, based on the fuel delivery temperature categories T40, T30, T20, and the CHSS capacity categories A, B, and C. If the CHSS Capacity Category is D, then a single non-communication pressure target was calculated in the end pressure control initialization subroutine.

Equation J79 is utilized to determine which of these pre-calculated non-communication pressure targets is applicable based on the known mass average fuel delivery temperature and the known CHSS capacity category in the current time step. This determination is made each time step, as these parameters may change during the fill. Note that for the T20 fuel delivery temperature category, the upper boundary temperature of 255.65 K is not utilized in making the determination of whether to use the T20 non-communication pressure target. This is because MAT_C may exceed this upper boundary temperature during the fill, especially if the initial pressure is relatively high, while the fill still stays within the process limit requirements.

Determination of Non-Communication Pressure Target (Eq. J79)

$$IF\ \ 233.15 \le MAT_c \le 240.15$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_T40\_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_T40\_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_T40\_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_D}$$

$$IF\ Indicator\ Cons\ RR = TRUE$$

$THEN$

$$P_{target\_non\_comm} = MINIMUM\left[P_{target\_non\_comm\_T40\_A},\ P_{target\_non\_comm\_T40\_B},\ P_{target\_non\_comm\_T40\_C}\right]$$

$$IF\ \ 240.15 < MAT_c \le 247.15$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ \ THEN\ P_{target\_non\_comm} = P_{target\_non\_comm\_T30\_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ \ THEN\ P_{target\_non\_comm} = P_{target\_non\_comm\_T30\_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ \ THEN\ P_{target\_non\_comm} = P_{target\_non\_comm\_T30\_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_D}$$

$$IF\ Indicator\ Cons\ RR = TRUE$$

$THEN$

$$P_{target\_non\_comm} = MINIMUM\left[P_{target\_non\_comm\_T30\_A},\ P_{target\_non\_comm\_T30\_B},\ P_{target\_non\_comm\_T30\_C}\right]$$

$$IF\ \ 247.15\ < MAT_c$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ \ THEN\ P_{target\_non\_comm} = P_{target\_non\_comm\_T20\_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_T20\_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ \ THEN\ \ P_{target\_non\_comm} = P_{target\_non\_comm\_T20\_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ \ THEN\ P_{target\_non\_comm} = P_{target\_non\_comm\_D}$$

$$IF\ Indicator\ Cons\ RR = TRUE$$

$THEN$

$$P_{target\_non\_comm} = MINIMUM\left[P_{target\_non\_comm\_T20\_A},\ P_{target\_non\_comm\_T20\_B},\ P_{target\_non\_comm\_T20\_C}\right]$$

J.2.7.1.2 Determine Communication Pressure Target

A pressure target is calculated for communication fills based on an end of fill target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for the H35 pressure class, which has been discounted by SOC_{target}. SOC_{target} is set in the end pressure control initialization subroutine, J.2.2.1. The unit of measure for P_{target_comm} is MPa, the unit of measure for MT is Kelvin (K), and the unit of measure for SOC_{target} is percent (e.g., 100% is expressed as 100). Equation J80 has an accuracy of +0/-0.08 MPa over the range of temperatures 233.15 K ≤ MT ≤ 358.15 K and range of target SOC 95 ≤ SOC_{target} ≤ 100, referencing data from the National Institute of Standards and Technology (NIST).

Calculate Communication Fill Pressure Target (Eq. J80)

$$IF\ \ Press\ Class = H70, P_{target\_comm} = \left(0.0144 \times SOC_{target} - 0.439\right) \times (0.2782 \times MT - 4.7145E - 05 \times MT^2 - 6.18) - 0.1$$

$$IF\ \ Press\ Class = H35, P_{target\_comm} = \left(0.0123 \times SOC_{target} - 0.227\right) \times (0.1346 \times MT - 1.3637E - 05 \times MT^2 - 2.65) - 0.12$$

J.2.7.1.3 Determine Communication Pressure Limit

A pressure limit is determined for communication fueling, P_{limit_comm}. This pressure limit value is used as a secondary means of protection to limit over filling in the event of a fault in the CHSS measured temperature MT, which causes the communication pressure target to be incorrect.

If the CHSS Capacity Category is A, B, C, then nine communication pressure limits were calculated in the end pressure control initialization subroutine, based on the fuel delivery temperature categories T40, T30, T20, and the CHSS capacity categories A, B, and C. If the CHSS Capacity Category is D, then three communication pressure limits were calculated in the end pressure control initialization subroutine, based on the fuel delivery temperature categories T40, T30, T20.

Equation J81 is utilized to determine which of these pre-calculated communication pressure limits is applicable based on the known mass average fuel delivery temperature and the known CHSS capacity category in the current time step. This determination is made each time step, as these parameters may change during the fill. Note that for the T20 fuel delivery temperature category, the upper boundary temperature of 255.65 K is not utilized in making the determination of whether to use the T20 communication pressure limit. This is because MAT_C may exceed this upper boundary temperature during the fill, especially if the initial pressure is relatively high, while the fill still stays within the process limit requirements.

Determination of Communication Pressure Limit (Eq. J81)

$$IF\ \ 233.15 \leq MAT_c \leq 240.15$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T40\_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T40\_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T40\_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T40\_D}$$

$$IF\ Indicator\ Cons\ RR = TRUE$$

$THEN$

$$P_{limit\_comm} = MINIMUM\left[P_{limit\_comm\_T40\_A}, P_{limit\_comm\_T40\_B}, P_{limit\_comm\_T40\_C}\right]$$

$$IF\ \ 240.15 < MAT_c \leq 247.15$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T30\_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T30\_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T30\_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T30\_D}$$

$$IF\ Indicator\ Cons\ RR = TRUE$$

$THEN$

$$P_{limit\_comm} = MINIMUM\left[P_{limit\_comm\_T30\_A}, P_{limit\_comm\_T30\_B}, P_{limit\_comm\_T30\_C}\right]$$

$$IF\ \ 247.15 < MAT_c$$

$THEN$

$$IF\ CHSS_{Capacity\_Category} = A,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T20\_A}$$

$$IF\ CHSS_{Capacity\_Category} = B,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T20\_B}$$

$$IF\ CHSS_{Capacity\_Category} = C,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T20\_C}$$

$$IF\ CHSS_{Capacity\_Category} = D,\ \ THEN\ P_{limit\_comm} = P_{limit\_comm\_T20\_D}$$

$$IF\ Indicator\ Cons\ RR = TRUE$$

$THEN$

$$P_{limit\_comm} = MINIMUM\left[P_{limit\_comm\_T20\_A}, P_{limit\_comm\_T20\_B}, P_{limit\_comm\_T20\_C}\right]$$

J.2.7.2 Determination of Pressure Targets and Limits - MC Method

For end of fill determination, there are two pressure targets calculated, one for non-communication fueling $P_{target\_non\_comm}$, and one for communication fueling P_{target_comm}. Additionally, there is a pressure limit calculated for communication fueling, P_{limit_comm}, used as a secondary protection in case of a fault condition in the MT signal. The communication pressure target is calculated as a function of the CHSS measured temperature MT. The non-communication pressure target and the communication pressure limit are calculated as functions of the parameter T_{cold}, which represents the minimum end of fill gas temperature under cold case conditions.

A pressure target is calculated for non-communication fills based on an end of fill target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for the H35 pressure class. The unit of measure for $P_{target\_non\_comm}$ is MPa and the unit of measure for T_{cold} is Kelvin (K). Equation J82 has an accuracy of ±0.01 MPa over the range of temperatures 233.15 K ≤ T_{cold} ≤ 358.15 K, referencing data from the National Institute of Standards and Technology (NIST).

Calculate Non-Communication Fill Pressure Target (Eq. J82)

$$IF\ \ Pressure\ Class = H70,\ P_{target\_non\_comm} = 0.2782 \times T_{cold} - 4.7145E - 05 \times {T_{cold}}^2 - 6.18$$

$$IF\ \ Pressure\ Class = H35,\ P_{target\_non\_comm} = 0.1346 \times T_{cold} - 1.3637E - 05 \times {T_{cold}}^2 - 2.65$$

A pressure target is calculated for communication fills based on an end of fill target density of 40.2 g/L for the H70 pressure class and 24.0 g/L for the H35 pressure class, which has been discounted by SOC_{target}. SOC_{target} is set in the end pressure control initialization subroutine, J.2.2.2. The unit of measure for P_{target_comm} is MPa, the unit of measure for MT is Kelvin (K), and the unit of measure for SOC_{target} is % (e.g., 100% is expressed as 100). Equation J83 has an accuracy of +0/-0.08 MPa over the range of temperatures 233.15 K ≤ MT ≤ 358.15 K and range of target SOC 95 ≤ SOC_{target} ≤ 100, referencing data from the National Institute of Standards and Technology (NIST).

Calculate Communication Fill Pressure Target (Eq. J83)

$$IF\ \ Press\ Class = H70, P_{target\_comm} = \left(0.0144 \times SOC_{target} - 0.439\right) \times (0.2782 \times MT - 4.7145E - 05 \times MT^2 - 6.18) - 0.1$$

$$IF\ \ Press\ Class = H35, P_{target\_comm} = \left(0.0123 \times SOC_{target} - 0.227\right) \times (0.1346 \times MT - 1.3637E - 05 \times MT^2 - 2.65) - 0.12$$

A pressure limit is calculated for communication fills based on a limit of 115% SOC, which corresponds to maximum density of 46.23 g/L for the H70 pressure class and 27.6 g/L for the H35 pressure class. See H.3.1.4 for an explanation and rationale for this density limit. The pressure limit P_{limit_comm} is used as secondary protection in case of a fault condition in the MT signal. The unit of measure for P_{limit_comm} is MPa and the unit of measure for T_{cold} is Kelvin (K). Equation J84 has an accuracy of ±0.01 MPa over the range of temperatures 233.15 K ≤ T_{cold} ≤ 358.15 K, referencing data from the National Institute of Standards and Technology (NIST).

Calculate Communication Fill Pressure Limit (Eq. J84)

$$IF\ \ Pressure\ Class = H70,\ \ P_{limit\_comm} = MINIMUM\left[83.5,\ \ \left(0.3457 \times T_{cold} - 6.6942E - 05 \times T_{cold}{}^{2} - 7.29\right)\right]$$

$$IF\ \ Pressure\ Class = H35,\ \ P_{limit\_comm} = MINIMUM\left[43.75,\ \ \left(0.1622 \times T_{cold} - 1.8904E - 05 \times T_{cold}{}^{2} - 3.40\right)\right]$$

J.2.8 Evaluate End of Fill Criteria Subroutine

This subroutine is utilized to determine if the end of fill criteria are met, which will then end the fill. The calculations in this subroutine shall be conducted at a frequency of no less than 10 Hz (ten calculations per second).

The condition for the end of fill criteria to be met for non-communication fueling is for the station pressure to be greater than or equal to the non-communication pressure target. The station shall end the fill immediately when this criterion is satisfied. In Equation J85, as per 6.2.2, the station pressure measurement shall account for the sensor error.

Evaluate End of Fill Criteria for Non-Communication Fueling (Eq. J85)

$$IF\ \ Indicator\ Comm\ Fill\ = \ FALSE\ \ \ AND\ \ P_{station} \geq P_{target\_non\_comm},\ \ THEN\ \ \ END\ FILL$$

The condition for the end of fill criteria to be met for communication fueling is for either the station pressure $P_{station}$ or the vehicle pressure MP to be greater than or equal to the communication pressure target, or the communication pressure limit. The dispenser may utilize either criteria (i.e., station pressure $P_{station}$ or vehicle pressure MP). The station shall end the fill immediately when this criterion is satisfied.

Evaluate End of Fill Criteria for Communication Fueling (Eq. J86)

$$IF\ \ Indicator\ Comm\ Fill\ = \ TRUE\ \ \ AND\ \ P_{station} \geq MINIMUM\ \left[P_{target\_comm}, P_{limit\_comm}\ \right],\ \ THEN\ \ END\ FILL$$

OR

$$IF\ \ Indicator\ Comm\ Fill\ = \ TRUE\ \ \ AND\ \ MP \geq MINIMUM\ \left[P_{target\_comm}, P_{limit\_comm}\ \right],\ \ THEN\ \ END\ FILL$$

J.2.9 Process Check Subroutine

This subroutine is used to check if temperature, pressure, and mass flow rate are within the process limits. If any of the process condition checks are not satisfied, the process check subroutine fails, and the fill shall terminate as soon as possible, but within 5 seconds. Note than in Equation J89, the station pressure must stay above the lower limit pressure of the pressure corridor only when mass is flowing, which excludes intended non-fueling events such as a leak check or bank switch.

The unit of measure for $P_{station}$, P_{limit_high}, and P_{limit_low} is MPa. The unit of measure of T_{amb} is °C. The unit of measure for MT, T_{fuel}, and MAT_{30} is Kelvin (K). The unit of measure for t is seconds, and the unit of measure for $\dot{m}$ is g/s.

The calculations in this subroutine shall be conducted based on a time step j, which is advanced every 1 second. Thus, each calculation in this subroutine is conducted once every second.

$$IF\ P_{station} \leq 87.5,\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL \qquad \text{(Eq. J87)}$$

$$IF\ t > 15\ AND\ IF\ P_{station} \leq P_{limit\_high},\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL^{\dagger} \qquad \text{(Eq. J88)}$$

$$IF\ t > 15\ AND\ IF\ P_{station} \geq P_{limit\_low},\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL^{\dagger\dagger} \qquad \text{(Eq. J89)}$$

$$IF\ \ \text{-}40 \leq T_{amb} \leq 50,\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL \qquad \text{(Eq. J90)}$$

$$IF\ Indicator\ Comm\ Fill\ = \ TRUE\ AND\ MT < 358.15,\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL \qquad \text{(Eq. J91)}$$

$$IF\ T_{fuel} \geq 233.15,\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL \qquad \text{(Eq. J92)}$$

$$IF\ n > 30\ AND\ IF\ MAT_{30} \leq 255.65,\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL^{‡} \qquad \text{(Eq. J93)}$$

$$IF\ t > 0\ \ AND\ IF\ \dot{m} \leq 60,\ \ THEN\ \ PASS,\ \ \ ELSE\ \ FAIL \qquad \text{(Eq. J94)}$$

† Note to Eq. J88: As per 9.3.2.1, if the station pressure exceeds the upper pressure limit by 5 MPa or less, it shall come back within the limit within 5 seconds of the initial excursion, or shall stop fueling within 5 seconds of the initial excursion. If the magnitude of the excursion is greater than 5 MPa, the station shall stop fueling within 5 seconds of the initial excursion.

†† Note to Eq. J89: the station pressure must stay above the lower limit pressure of the pressure corridor only when mass is flowing, which excludes intended non-fueling events such as a leak check or bank switch. Also, as per 9.3.2.1, if the station pressure falls below the lower pressure limit, it shall come back within the limit within 15 seconds of the initial excursion, not counting intended non-fueling time, and if it does not, the station shall stop fueling within 15 seconds of the initial excursion.

‡ Note to Eq. J93: If an intended non-fueling event occurs between 20 ≤ n ≤ 30, then enforce this requirement from n > 40. Additionally, the requirement for MAT_{30} ≤ 255.65 only applies when the mass flow rate has been greater than 0.6 g/s for more than 10 seconds (see 9.1.2.1).

J.3 REFERENCE EQUATIONS

Application of the MC Formula-based protocol utilizing the MC Method for the ending pressure control option requires calculation of hydrogen thermo physical properties. The thermo physical properties used in the application of the MC Formula-based protocol should be referenced to NIST data. The programmer should ensure that the equations chosen for calculating the thermo physical properties of hydrogen are as accurate as possible compared to the NIST Standard Reference Database.

Equations J95 through J99 are given as a reference for calculating thermo physical properties of hydrogen which are required in the MC Method. These equations are generally accurate to within 0.5 to 1%. The programmer may utilize these reference equations or another set of reference equations provided they have documented and comparable accuracy.

J.3.1 Enthalpy (kJ/kg)

(Eq. J95)

$$h = (4.92522\text{E} - 15 \times P^5 - 0.0000000000016076 \times P^4 + 0.000000000214858 \times P^3 - 0.0000000146189 \times P^2 + 0.000000454324 \times P - 0.00000987705) \times T^3 + (0.00000000055184 \times P^4 - 0.000000141472 \times P^3 + 0.0000132881 \times P^2 - 0.000497343 \times P + 0.0108438) \times T^2 + (0.00000000202796 \times P^5 - 0.000000664561 \times P^4 + 0.0000901478 \times P^3 - 0.00639724 \times P^2 + 0.225139 \times P + 10.4372) \times T + (-0.000000255167 \times P^5 + 0.0000852825 \times P^4 - 0.0119306 \times P^3 + 0.894471 \times P^2 - 27.6592 \times P + 112.034)$$

where:

P = absolute pressure in units of MPa

T = absolute temperature in units of Kelvin

Example input/output:

Inputs		Output	
P (MPa)	***T*** (K)	***h*** (kJ/kg) - NIST	***h*** (kJ/kg) - Eq. above
70.1	288.15	4232.1	4232.0

J.3.2

J.3.3 Specific Internal Energy (kJ/kg)

(Eq. J96)

$$u = 496.1 \times [(-0.000000251102 \times P^2 + 0.00003270544 \times P + 0.020635744157) \times T + (0.000110237178 \times P^2 - 0.014948338423 \times P - 0.706955972653)]$$

where:

P = absolute pressure in units of MPa

T = absolute temperature in units of Kelvin

Example input/output:

Inputs		Output	
P (MPa)	***T*** (K)	***u*** (kJ/kg) - NIST	***u*** (kJ/kg) - Eq. above
70.1	288.15	2488.8	2499.4

J.3.4 Temperature (K)

(Eq. J97)

$$T = (0.000001148 \times P^2 - 0.000148149 \times P + 0.0976624642) \times u + (-0.0047605417 \times P^2 + 0.6412591317 \times P + 34.3729762461)$$

where:

P = absolute pressure in units of MPa

u = specific internal energy in units of kJ/kg

Example input/output:

Inputs		Output	
P (MPa)	***u*** (kJ/kg)	***T*** (K) - NIST	***T*** (K) - Eq. above
70.1	2488.8	288.15	287.19

J.3.5 Density (kg/m³)

(Eq. J98)

$$\rho = (-1.1671\text{E}-16 \times P^4 + 0.000000000000035429 \times P^3 - 0.00000000000380467 \times P^2 + 0.000000000151947 \times P - 0.00000000000376254) \times T^4 + (0.000000000000159364 \times P^4 - 0.0000000000491286 \times P^3 + 0.00000000538378 \times P^2 - 0.000000222007 \times P + 0.00000000512189) \times T^3 + (-0.0000000000826768 \times P^4 + 0.000000026014 \times P^3 - 0.00000293356 \times P^2 + 0.00012714 \times P - 0.00000263185) \times T^2 + (0.0000000195877 \times P^4 - 0.00000634261 \times P^3 + 0.0007478 \times P^2 - 0.0354828 \times P + 0.000608078) \times T + (-0.0000018437 \times P^4 + 0.000623884 \times P^3 - 0.0798237 \times P^2 + 4.77618 \times P - 0.0536549)$$

where:

P = absolute pressure in units of MPa

T = absolute temperature in units of Kelvin

Example input/output:

Inputs		Output	
P (MPa)	***T*** (K)	***ρ*** (kg/m³) - NIST	***ρ*** (kg/m³) - Eq. above
70.1	288.15	40.21	40.21

J.3.6 Specific Heat Capacity at Constant Volume (kJ/kgK)

(Eq. J99)

$$c_v = 0.49608 \times [(-2.6305218\text{E}-13 \times T^3 + 2.9504059885\text{E}-10 \times T^2 + -0.000000114316 \times T + 0.000015724461) \times \times P^3 + (2.239406732\text{E}-11 \times T^3 + -0.000000026242 \times T^2 + 0.000010846506 \times T + -0.001653192666) \times P^2 + (-0.000000000909584 \times T^3 + 0.000001163147 \times T^2 + -0.000549326926 \times T + 0.106819055) \times \mathrm{P} + (0.000000183407 \times T^3 + -0.000222580465 \times T^2 + 0.091271823485 \times T + 8.231398432926)]$$

where:

P = absolute pressure in units of MPa

T = absolute temperature in units of Kelvin

Example input/output:

Inputs		Output	
P (MPa)	***T*** (K)	c_v (kJ/kgK) - NIST	c_v (kJ/kgK) - Eq. above
70.1	288.15	10.703	10.678

J.4 REFERENCE CALCULATIONS

When first programming the MC Formula-based protocol, it is important to check the calculations for t_{final} against known values. Tables J18 through J33 provide the correct t_{final} value for inputs of ambient temperature and MAT_C. Tables J18 through J25 correspond to the t_{final} coefficient Tables J1 through J8. Tables J26 through J33 correspond to the t_{final} coefficient Tables J9 through J16.

The values in Tables J18 through J33 are to be compared to the equations for t_{final} found in Equations J58 through J61. The values of α and β are set to 1.0.

Table J18 - Reference values for t_{final} based on Table J1 coefficients

	MATC (°C/K)					
T_{amb} (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	1376.1	1950.5	4196.6	7534.6	11384.5	13320.3
45/318.15	586.2	742.9	1042.9	1555.8	2351.0	2876.3
40/313.15	350.5	496.7	666.2	874.4	1136.4	1292.4
35/308.15	313.4	444.5	599.5	785.7	1010.4	1139.4
30/303.15	250.9	351.0	470.7	612.1	777.0	868.9
25/298.15	206.6	284.7	380.2	493.0	622.9	694.3
20/293.15	173.2	237.3	315.1	406.6	511.9	569.8
15/288.15	149.3	205.3	271.7	349.4	439.2	488.9
10/283.15	129.9	179.3	236.9	303.9	381.2	424.1
5/278.15	105.2	149.2	197.9	252.6	315.0	349.4
0/273.15	89.1	126.0	167.3	213.8	265.8	294.2
-10/263.15	73.9	108.4	146.5	189.0	236.2	261.8
-20/253.15	71.3	97.0	129.2	167.3	210.8	234.4
-30/243.15	54.6	81.8	113.0	148.4	188.1	209.6
-40/233.15	54.5	75.5	101.2	131.8	167.4	187.1

Table J19 - Reference values for t_{final} based on Table J2 coefficients

	MATC (°C/K)					
Tamb (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	544.0	738.6	1582.0	3933.8	8653.8	12170.5
45/318.15	267.4	487.0	820.2	1362.5	2209.2	2776.6
40/313.15	216.5	358.5	574.3	874.1	1268.1	1503.7
35/308.15	205.8	332.8	533.6	811.5	1170.0	1380.5
30/303.15	180.0	277.8	434.3	649.7	923.8	1082.9
25/298.15	160.0	238.4	363.5	535.4	754.3	881.4
20/293.15	142.7	208.9	311.1	450.8	629.7	734.2
15/288.15	129.9	189.2	276.6	395.4	548.9	639.6
10/283.15	124.7	172.7	247.5	350.8	484.3	563.0
5/278.15	124.7	155.5	213.3	296.9	405.2	468.3
0/273.15	92.6	133.5	187.0	256.0	343.8	395.6
-10/263.15	91.0	125.4	172.8	235.7	316.8	364.9
-20/253.15	118.2	127.4	161.5	217.9	293.9	338.4
-30/243.15	69.0	106.1	149.4	203.1	271.2	312.1
-40/233.15	71.1	100.9	139.1	188.5	251.6	289.1

Table J20 - Reference values for t_{final} based on Table J3 coefficients

	MATC (°C/K)					
Tamb (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	274.0	524.8	1008.5	2420.4	5455.5	7798.9
45/318.15	195.4	354.2	675.1	1217.7	2041.2	2576.9
40/313.15	176.4	280.3	500.4	855.3	1363.8	1681.5
35/308.15	170.8	269.3	475.9	809.4	1288.6	1588.8
30/303.15	155.4	238.1	400.7	661.3	1038.1	1275.6
25/298.15	141.9	214.4	345.5	554.1	859.1	1053.5
20/293.15	130.4	194.8	303.4	474.3	725.7	887.3
15/288.15	132.6	181.6	277.6	427.7	638.8	769.4
10/283.15	133.2	170.3	251.8	382.7	568.4	683.3
5/278.15	126.3	156.1	221.8	327.5	477.4	570.2
0/273.15	100.6	139.5	198.8	285.8	407.8	484.3
-10/263.15	96.3	133.7	189.1	270.2	384.9	457.3
-20/253.15	105.1	132.3	180.6	256.2	365.0	433.7
-30/243.15	109.1	130.1	173.3	243.6	345.9	410.6
-40/233.15	122.4	130.8	166.7	232.0	328.6	389.2

Table J21 - Reference values for t_{final} based on Table J4 coefficients

	MATC (°C/K)					
Tamb (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	290.5	370.1	825.4	1856.0	3661.7	4917.6
45/318.15	192.2	291.6	570.3	1072.0	1840.7	2338.8
40/313.15	210.2	246.2	434.3	778.9	1284.7	1599.5
35/308.15	212.3	242.3	421.0	749.8	1230.1	1527.7
30/303.15	219.6	222.8	359.6	623.9	1009.7	1246.3
25/298.15	198.2	204.6	316.6	531.6	847.1	1041.7
20/293.15	197.5	195.6	284.1	460.8	723.5	886.6
15/288.15	219.8	198.9	265.2	415.0	644.6	788.1
10/283.15	219.4	195.1	248.7	377.5	579.0	706.2
5/278.15	173.5	169.6	220.0	326.1	489.1	592.3
0/273.15	136.9	150.4	198.9	287.4	420.8	505.8
-10/263.15	204.0	175.8	200.4	276.7	403.5	485.4
-20/253.15	173.5	162.1	192.3	266.6	387.3	465.9
-30/243.15	171.9	159.2	186.8	257.0	372.1	447.3
-40/233.15	173.7	158.3	182.5	248.1	357.4	429.1

Table J22 - Reference values for t_{final} based on Table J5 coefficients

	MATC (°C/K)					
Tamb (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	784.3	1179.7	1951.4	3505.5	6247.8	8191.4
45/318.15	451.7	645.0	865.4	1151.4	1541.7	1788.0
40/313.15	302.3	424.2	565.1	730.1	924.7	1034.7
35/308.15	267.5	378.1	506.9	656.7	830.5	927.4
30/303.15	207.0	290.4	390.0	505.8	637.9	710.0
25/298.15	165.1	229.9	308.4	400.2	504.9	562.0
20/293.15	132.1	185.9	249.4	323.0	407.6	454.1
15/288.15	110.1	156.9	211.1	273.5	345.0	384.5
10/283.15	89.4	132.4	180.0	233.7	294.7	328.5
5/278.15	62.8	102.3	143.6	188.2	237.3	264.1
0/273.15	51.8	82.0	115.8	153.4	194.8	216.9
-10/263.15	41.4	68.4	98.8	132.7	170.2	190.3
-20/253.15	31.5	55.9	83.5	114.5	149.0	167.6
-30/243.15	26.0	47.4	71.9	99.5	130.5	147.2
-40/233.15	46.8	65.0	84.0	103.6	123.9	134.3

Table J23 - Reference values for t_{final} based on Table J6 coefficients

	MAT$_C$ (°C/K)					
T$_{amb}$ (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	319.1	643.6	1187.0	2288.2	4286.7	5728.4
45/318.15	220.8	412.1	678.8	1052.2	1563.4	1880.5
40/313.15	176.2	288.1	464.2	705.1	1011.4	1189.3
35/308.15	165.8	266.3	428.6	651.7	934.9	1098.6
30/303.15	139.9	217.2	341.0	511.7	729.5	856.3
25/298.15	120.0	182.0	278.8	412.5	584.9	686.2
20/293.15	110.9	156.8	232.9	340.3	480.0	562.2
15/288.15	94.8	138.1	203.7	294.2	412.1	482.3
10/283.15	83.4	123.0	179.6	256.6	357.2	417.4
5/278.15	131.8	124.9	153.2	210.7	291.7	339.1
0/273.15	51.8	85.6	126.4	177.2	241.1	278.9
-10/263.15	80.0	91.1	118.6	162.0	220.4	255.2
-20/253.15	63.4	79.6	107.8	148.6	202.4	234.2
-30/243.15	60.9	75.0	100.3	137.2	186.2	215.3
-40/233.15	60.9	72.0	93.7	126.5	171.0	197.7

Table J24 - Reference values for t_{final} based on Table J7 coefficients

	MAT$_C$ (°C/K)					
T$_{amb}$ (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	94.5	483.5	868.3	1584.1	2966.3	4012.1
45/318.15	169.3	276.4	533.8	959.6	1571.9	1953.7
40/313.15	139.6	216.8	382.8	656.0	1054.4	1306.3
35/308.15	135.3	207.4	362.9	619.9	996.7	1235.8
30/303.15	120.2	179.3	299.6	496.8	786.9	971.6
25/298.15	104.4	159.0	253.4	407.2	640.0	792.1
20/293.15	123.1	145.8	218.0	344.0	528.5	644.0
15/288.15	100.4	131.6	196.2	302.4	458.2	557.3
10/283.15	76.2	119.3	178.1	267.6	402.4	491.5
5/278.15	130.0	124.5	155.4	223.5	329.1	396.2
0/273.15	60.0	91.9	133.0	191.1	273.8	326.8
-10/263.15	55.9	87.8	126.7	180.6	257.4	306.9
-20/253.15	58.9	86.0	121.0	171.0	242.9	289.2
-30/243.15	134.6	114.4	124.0	162.6	229.2	272.9
-40/233.15	144.3	119.4	123.5	156.0	216.2	256.5

Table J25 - Reference values for t_{final} based on Table J8 coefficients

	MAT$_C$ (°C/K)					
T$_{amb}$ (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	163.4	298.1	629.8	1289.4	2407.9	3180.1
45/318.15	207.2	230.5	433.2	825.1	1415.8	1788.6
40/313.15	195.0	195.5	324.9	584.6	976.2	1221.9
35/308.15	197.2	190.8	312.7	561.8	936.9	1171.4
30/303.15	173.3	171.5	265.3	457.9	752.7	939.5
25/298.15	197.6	169.9	231.1	380.8	618.3	769.9
20/293.15	210.0	168.0	206.4	323.3	517.0	642.1
15/288.15	186.5	155.1	188.9	288.3	453.8	561.5
10/283.15	134.9	133.8	173.3	260.1	401.2	494.2
5/278.15	178.3	147.7	161.3	221.2	329.6	402.6
0/273.15	158.2	134.0	144.5	191.7	277.6	335.6
-10/263.15	152.9	129.8	139.6	184.2	265.5	320.5
-20/253.15	146.7	125.1	134.6	177.1	254.4	306.8
-30/243.15	186.7	148.9	144.5	175.6	244.1	293.0
-40/233.15	210.1	169.5	156.2	175.8	233.8	279.1

Table J26 - Reference values for t_{final} based on Table J9 coefficients

	MAT$_C$ (°C/K)					
T$_{amb}$ (°C/K)	-40/233.15	-35/238.15	-30/243.15	-25/248.15	-20/253.15	-17.5/255.65
50/323.15	381.8	569.6	961.4	1932.3	3857.7	86601.5
45/318.15	251.3	395.0	571.7	813.4	1151.9	9997.9
40/313.15	207.4	299.5	420.8	575.5	767.6	3823.4
35/308.15	199.8	287.4	402.3	547.1	724.5	3362.8
30/303.15	175.7	247.2	339.6	454.1	591.8	2480.4
25/298.15	155.8	216.8	293.7	387.5	499.2	1998.9
20/293.15	139.1	193.0	258.8	337.7	430.8	1688.1
15/288.15	126.9	176.9	235.9	305.3	386.8	1541.7
10/283.15	115.5	162.5	216.3	278.6	351.0	1378.1
5/278.15	99.9	142.4	189.4	242.4	302.8	1136.1
0/273.15	89.1	126.0	167.3	213.8	265.8	894.7
-10/263.15	73.9	108.4	146.5	189.0	236.2	803.8
-20/253.15	64.6	94.3	128.4	167.2	210.7	705.2
-30/243.15	54.6	81.8	113.0	148.4	188.1	640.3
-40/233.15	54.5	75.5	101.2	131.8	167.4	612.7