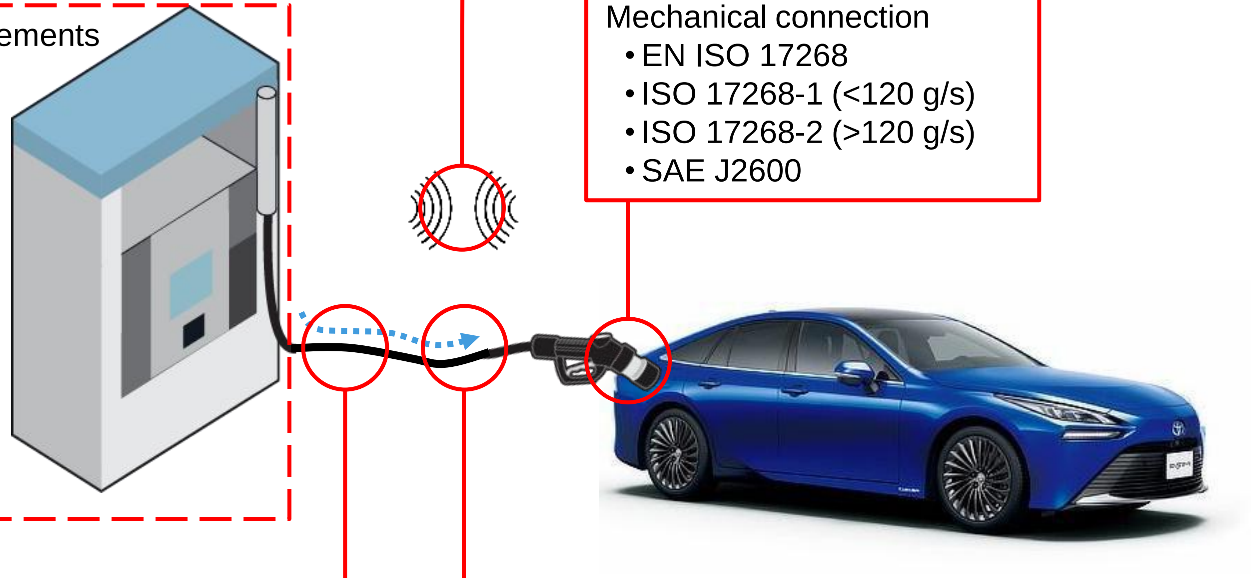
SAE J2601-5
HYDROGEN
Heavy-Duty fuelling

natürlich wasserstoff.

Agenda

Standards on inter-operability between vehicle and dispenser for cGH2



Communication
- **SAE J2799**
- ISO 19885-2

General Requirements
- ISO 19880-1

Dispenser
- ISO 19880-2

Mechanical connection
- EN ISO 17268
- ISO 17268-1 (<120 g/s)
- ISO 17268-2 (>120 g/s)
- SAE J2600

Hydrogen quality
- EN 17124
- ISO 14687 (H2 quality specs)
- ISO 19880-8 (H2 quality control)
- ISO 19880-9 (H2 sampling)
- SAE J2719

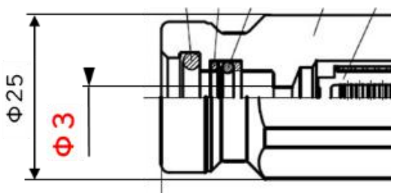
Fuelling protocol
- EN 17127
- SAE J2601 (LDV)
- SAE J2601-4 (Ambient Temp Fuelling)
- **SAE J2601-5 (HDV)** ← Focus of this presentation
- ISO 19885-1 (general)
- ISO 19885-3 (HDV)

This slide does not even cover:

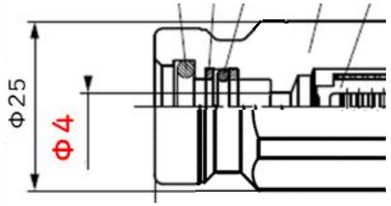
- Liquid fuelling
- Cryo-compressed gas fuelling
- Standards of the tank system (ISO 19881, UNR 134, ISO 19882)
- Standards of the vehicle fuelling system (e.g. ISO 19887)

Mechanical Connection for H70

ISO 17268:2020
H70_F60

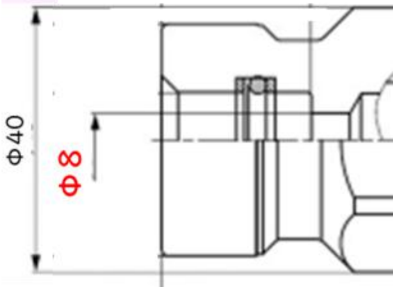


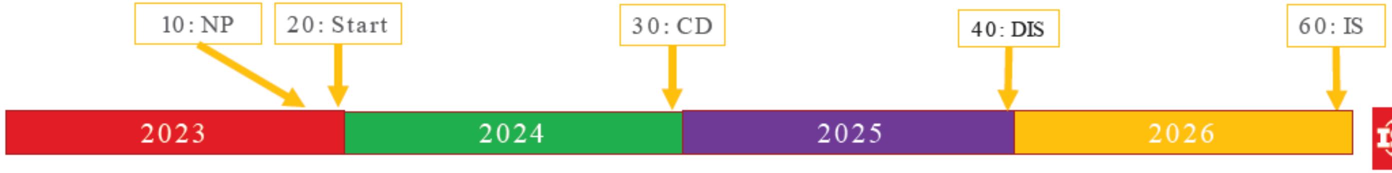
ISO 17268-1:2024
H70_F90



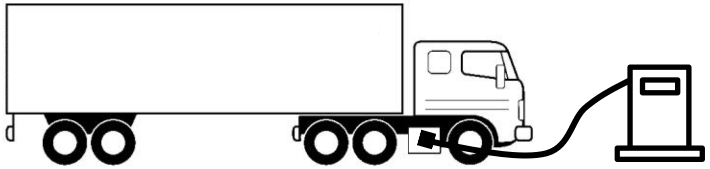
ISO 17268-2:2026
H70_F300

Receptacle dimension are not decided yet. Right picture is only an example.



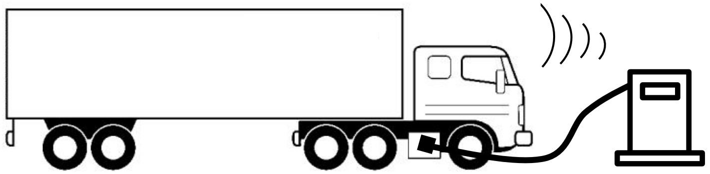


Standards on Communication



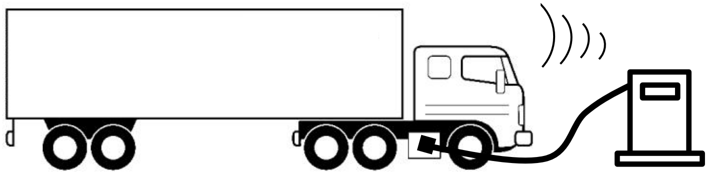
No communication

Low Speed
Low SOC



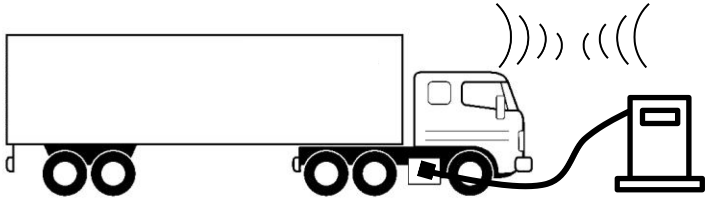
SAE J2799 v1.00, 1.10
IrDA MT, MP, TV, RT

Normal performance
Good SOC



SAE J2799 v2.0
IrDA MT, MP, **TV**, **RT**, **OD**
TV: expanded up to 9999.9 L
OD: includes protocol, FMXXX and TVL

Better performance
Good SOC
Used for SAE J2601-5



ISO 19885-2
Advanced communication

Best performance
Excellent SOC

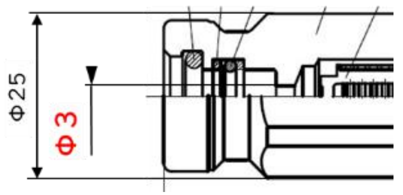
SAE J2601 Protocol For H70

Pressure Class Designation	H70			
CHSS Capacity Range (Litres)	49.7 - 99.4	99.4 – 174.0	174.0 – 248.6	>248.6
CHSS Capacity Range (kg)	2 to 4	4 to 7	7 to 10	>10
CHSS Capacity Category	A	B	C	D
Maximum Flow Rate (g/s)	≤60	≤60	≤60	≤60
Fuel Delivery Temperature Category	T20, T30, T40	T20, T30, T40	T20, T30, T40	T20D, T30D, T40D

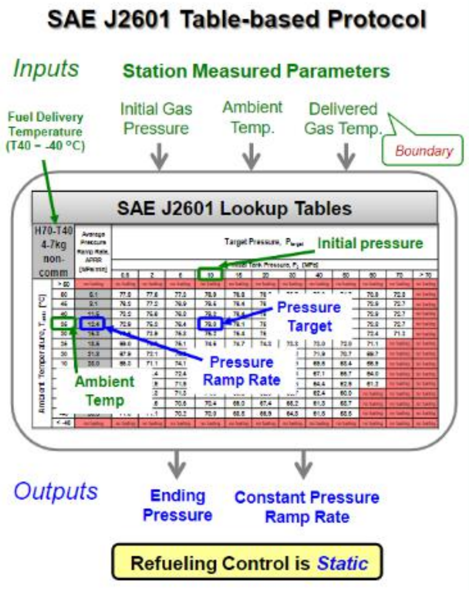
Category D will probably be removed in SAE J2601:2024. Category D will become a part of SAE J2601-5.

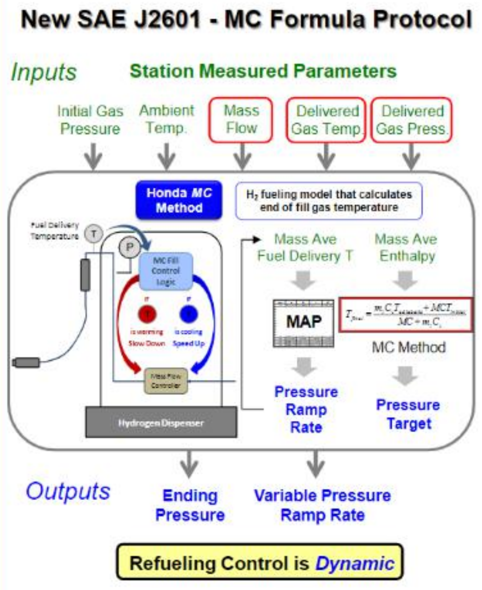
ISO 17268:2020

H70_F60



Review of SAE J2601 in 2024





Due to limitations on the maximum flow rate (60 g/s), D-category fuelling is not practical above 20~30 kg total tank capacity.

Agenda

SAE J2601-5 SCOPE

Pressure Class Designation	H35	H70		
Protocol Name	MCF-HF-G	Category D HF	MCF-HF-G	
Protocol type	MC Formula	Table Based	MC Formula	
CHSS Capacity Range (Litres)	248.6 to 7500	248.6 to 5000		
CHSS Capacity Range (kg)	5.97 to 180	10 to 201		
Single Tank Size (Litres)	50 to 1000	50 to 800		
Maximum Flow Rate Class (g/s) COMM	FM120	FM90	FM90	FM300
Maximum Flow Rate Class (g/s) NON-COMM	FM120	FM60	FM60	FM300
Coupling Type	H35HF	H70 (4mm)	H70 (4mm)	H70HF
Fuel Delivery Temperature Category	Ta, T0, T10, T20, T30, T40	T20D, T30D, T40D	T0, T10, T20, T30, T40	

Note: The Fuel Delivery Temperature Category of the MCF-HF-G protocol is only a “rating” that shows the station’s expected MAT_{30} at the end of the fuelling event.

Ta: 0°C to 20°C
T0: -10°C to 0°C
T10: -17.5°C to -10°C
T20: -26°C to -17.5°C
T30: -33°C to -26°C
T40: -40°C to -33°C

T20D: -40°C to -17.5°C
T30D: -40°C to -26°C
T40D: -40°C to -33°C

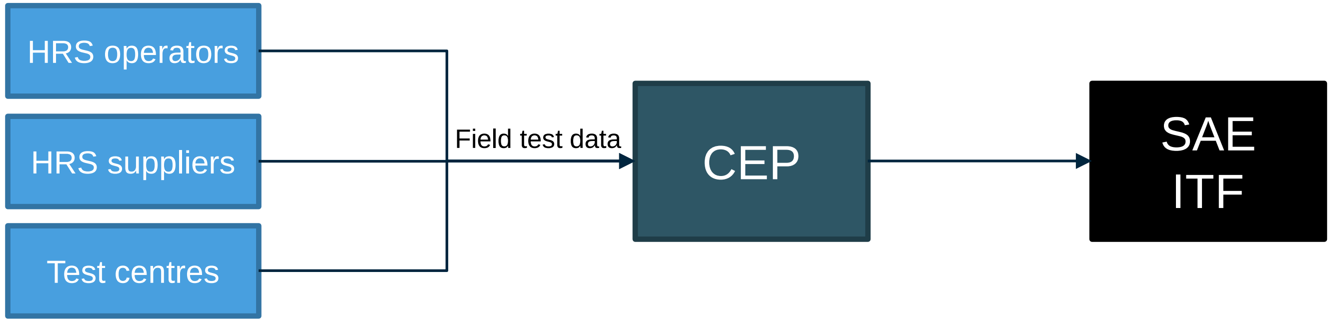
T0: -10°C to 0°C
T10: -17.5°C to -10°C
T20: -26°C to -17.5°C
T30: -33°C to -26°C
T40: -40°C to -33°C

Request

Request for HRS Operators, HRS Manufacturers, Notified Bodies, Testing agencies, etc…

SAE J2601-5 is currently a TIR (Technical Information Report), not yet a standard.

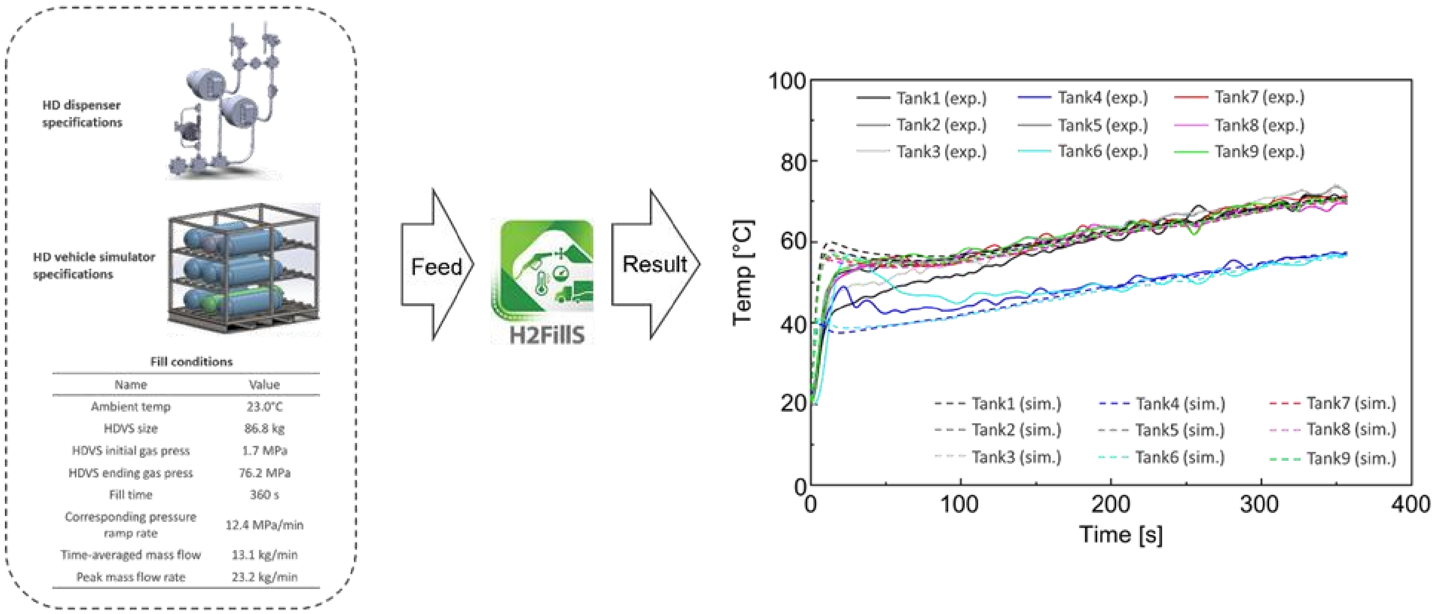
Please provide feedback such as fuelling test results, corrections and advise to the CEP.
We can forward it to the SAE ITF.



Agenda

Thermodynamic fuelling simulation

Protocols are initially often simulated. For SAE J2601-5, H2Fills is being used as a simulating model.

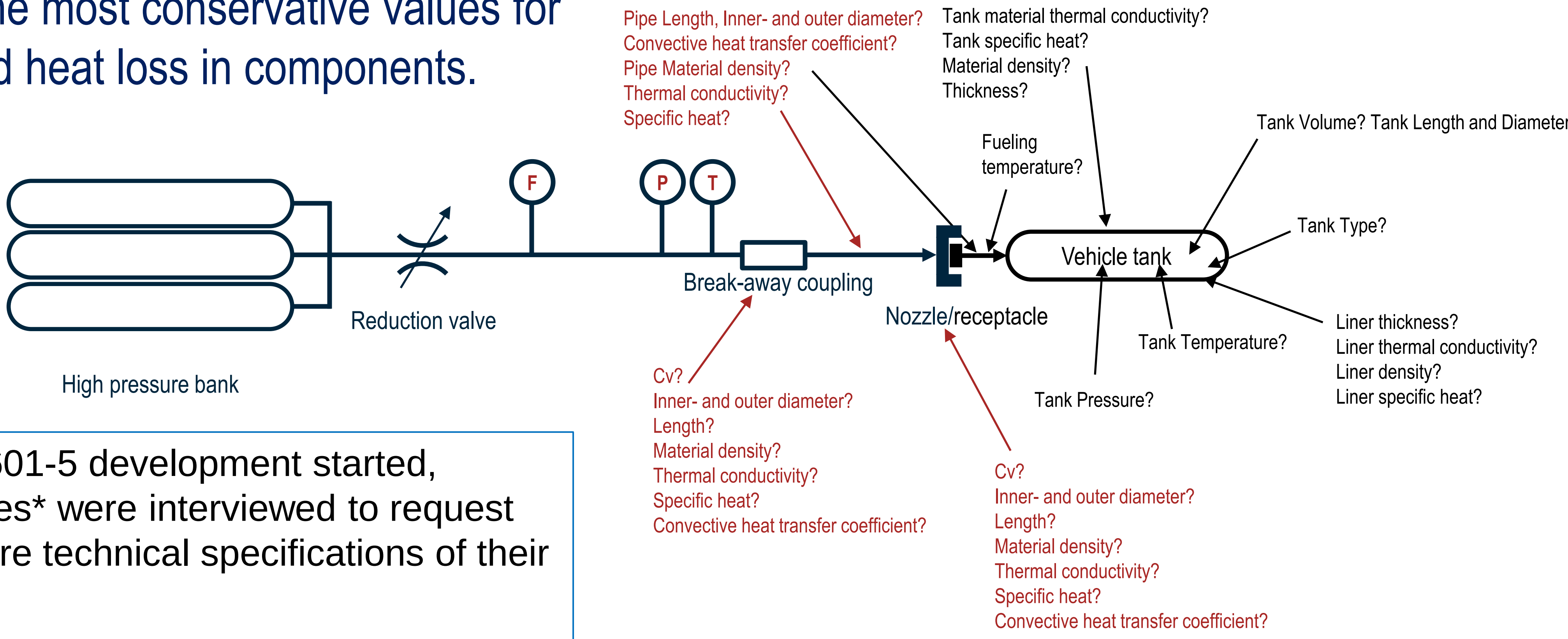


Name	Value
Ambient temp	23.0°C
HDVS size	86.8 kg
HDVS initial gas press	1.7 MPa
HDVS ending gas press	76.2 MPa
Fill time	360 s
Corresponding pressure ramp rate	12.4 MPa/min
Time-averaged mass flow	13.1 kg/min
Peak mass flow rate	23.2 kg/min

Using a vehicle simulator equipped with thermocouple trees, H2Fills simulation has been validated under different conditions. The simulation corresponded with the measured results of the simulator.

Fuelling assumptions

There are many unknown variables from both station and vehicle side.
A protocol uses the most conservative values for pressure drop and heat loss in components.



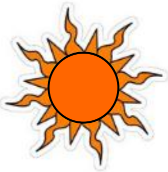
Before the SAE J2601-5 development started, numerous companies* were interviewed to request the current and future technical specifications of their products.

*vehicle OEMs, tank suppliers, tank integrators, nozzle, receptacle and hose manufacturers, …

Fuelling assumptions

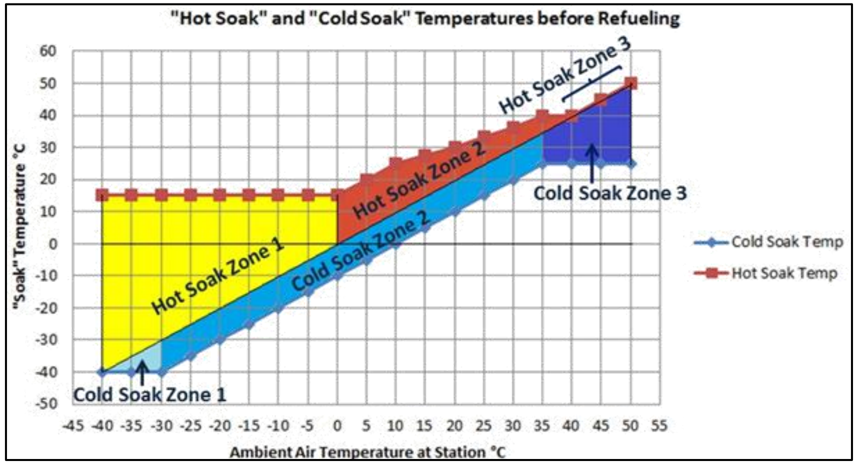
Because gas temperature in the tank is unknown, worst case assumptions must be used

Hot Case



Hot Soak
Park in the hot sun in summer or in heated garage during winter

Hot Tank "Type 4" Plastic Liner + **Tank is at minimum pressure**



Cold Case

Cold Soak
Park in the A/C garage

+ Defueling
Drive high speed on autobahn (rapid defueling)

Cold Tank Small "Type 3" Aluminum Liner

All Vehicle Fuelings Fall Within This Range of Boundary Conditions

Hotter ending gas temperature ← **Absorbs Heat Less** | **Absorbs Heat More** → **Colder ending gas temperature**

To Prevent Overheating:

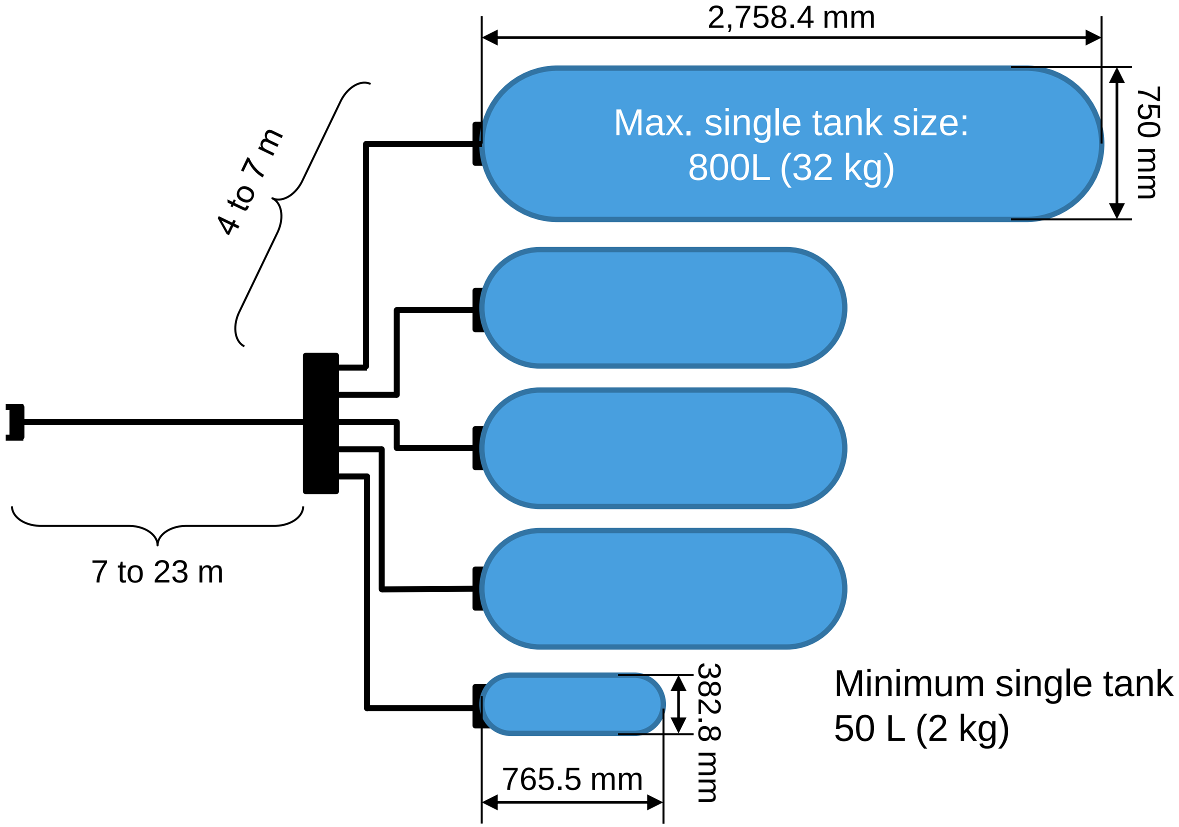
Pressure Ramp Rate determined by Hot Case Boundary Conditions

To Prevent Overfilling:

End-of-fill pressure target determined by Cold Case

Assumptions for 70 MPa

Tank and tubing geometries based on a survey



Minimum single tank size:
50 L (2 kg)

Minimum Vehicle Fuel System volume: **248.6 L (10 kg)**

Maximum Vehicle Fuel System volume: **5000 L (201 kg)**

Assumptions for 70 MPa

	SAE J2601 D-category	SAE J2601-5 D-category
Assumptions based on…	**LDV specifications**	**HDV specifications**
Min/Max single tank size	50 L / 250 L	50 L / 800 L
Min/Max tank length	800 mm / 1298 mm	765.5 mm / 2758.4 mm
Min/Max tank diameter	347 mm / 600 mm	382.8 mm / 750 mm
Plastic liner thermal conductivity	0.5 W/m.K	0.25 W/m.K
Plastic liner specific heat capacity	2100 J/kg.K	2500 J/kg.K
Plastic liner density	1070 kg/m³	945 kg/m³
Min/Max CFRP wall thickness	22.2 mm / 38.3 mm	24.5 mm / 47.9 mm
Etc…	**See appendix A of both SAE J2601 and J2601-5 for all assumptions**	

The assumptions of the vehicle are very different between D-category from SAE J2601 and SAE J2601-5. Mainly because of the extensive use of PA as a tank liner and the possibility of having single tanks larger than 250 L in HDVs, SAE J2601 D-category protocol should not be used anymore.

Request

Request for HRS Operators, HRS Manufacturers, Notified Bodies, Testing agencies, etc…

Please provide the CEP with a list of stations that use the D-category fuelling protocol of SAE J2601.

Agenda

SAE J2799:2024 vs J2799:2019

Item	Tag	SAE J2799:2019	SAE J2799:2024
Software version	VN	Version 01.10	Version 01.10 and 02.00
Tank Volume	TV	Up to 5000 L	Up to 9999.9 L for v02.00
Optional Data	OD	Up to 74 characters not including "|"	Up to 240 characters not including "|", "\" and ","

SAE J2799 has defined a voluntary OD Data Block which consists of Start of OD (|OD=)

OD Header (Defined by SAE J2799)

OD Data (Defined by the protocol)

End of Data Block (\)

End of OD (|)

|OD=ODHeaderA,ODDataA1,ODDataA2,ODData3\ ODHeaderB, ODDataB1\|

OD Header OD Data OD Data OD Data

OD Header	Fuelling Protocol	Publication/Source
CATDHF24	Category D High Flow	SAE J2601-5:2024
MCFHFG24	MC Formula High Flow General	SAE J2601-5:2024
CATDTWIN25	Category D High Flow Twin Nozzle	ISO 19885-3
MCFHFGTWIN25	MC Formula High Flow General Twin Nozzle	ISO 19885-3

OD data tags used in SAE J2601-5

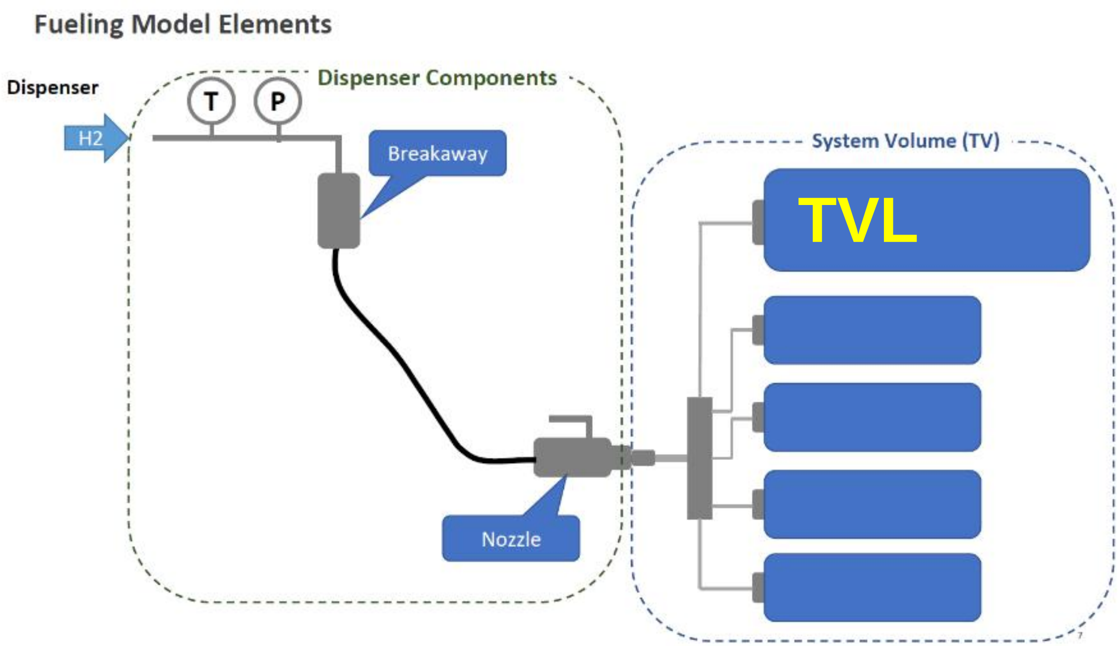
<table>
<tr><th>Fueling Protocol header</th><th>Tag name</th><th>Tag Command</th><th>Format</th><th>Example</th></tr>
<tr><td rowspan="2">CATDHF24</td><td>Maximum flow rate [g/s]</td><td>FM=</td><td>060 or 090</td><td>|OD=CATDHF24,FM=090\|</td></tr>
<tr><td>Largest tank volume [L]</td><td>TVL=</td><td>####</td><td>|OD=CATDHF24,FM=090,TVL=0360\|</td></tr>
<tr><td rowspan="2">MCFHFG24</td><td>Maximum flow rate [g/s]</td><td>FM=</td><td>120 (for H35MF)
060 or 090 (for H70)
300 (for H70HF)</td><td>|OD=MCFHFG24,FM=120\|
|OD=MCFHFG24,FM=090\|
|OD=MCFHFG24,FM=300\|</td></tr>
<tr><td>Largest tank volume [L]</td><td>TVL=</td><td>####</td><td>|OD=MCFHFG24,FM=090,TVL=0360\|</td></tr>
</table>

A total IrDA data field could look like this:

|ID=SAE_J2799|VN=02.00|TV=1491.9|RT=H70|FC=Dyna|MP=043.7|MT=353.0|OD=CATDHF24,FM=090,TVL=0360\MCFHFG24,FM=090,TVL=0360|

This vehicle is accepting both the Category D HF and the MCF-HF-G protocol and is equipped with a H70 receptacle of 4 mm inner diameter and therefore accepting 90 g/s maximum flow.

Largest tank volume



TV = **T**ank **V**olume
= Total Volume of the **V**ehicle **F**uel **S**ystem
(In SAE J2601-5 we still talk about CHSS even though VFS is meant)

TVL= Largest tank volume (**T**ank **V**olume **L**arge)

It is known that the largest tank has a high impact on the temperature build-up. This is due to the high volume/surface ratio.
(It seems that there are some specific conditions where the smallest tank volume has the biggest impact.)

Example: **|OD=MCFHFG24,TVL=0361\|**
(This vehicle uses SAE J2601-5 MCF-HF-G protocol.
The largest tank size of this vehicle is 361L)

Communication compatibility

Assumption: Vehicle transmits TV>0248.6 and/or start-up phase measures >248.6 L

H2 Truck transmits	HRS programming	Result
v01.10 or v02.00 or non-comm	Not programmed for Cat. D	No fuelling
v01.10	v01.10	J2601 Category D
v01.10	v02.00	No fuelling
v01.10	v01.10 and v02.00	J2601 Category D
v02.00	v01.10	No fuelling
v02.00	v02.00	J2601-5 Category D
v02.00	v01.10 and v02.00	J2601-5 Category D

Is your station programmed for J2601 Category D using v01.10 of SAE J2799?
Better upgrade it to J2601-5 and use v02.00 of SAE J2799.

Agenda

01 Standards concerning interoperability between vehicle and dispenser

02 General overview of SAE J2601-5

03 Fuelling protocol development process (assumptions and boundary conditions)

04 Communication

05 Category D protocol

06 MCF-HF-G protocol

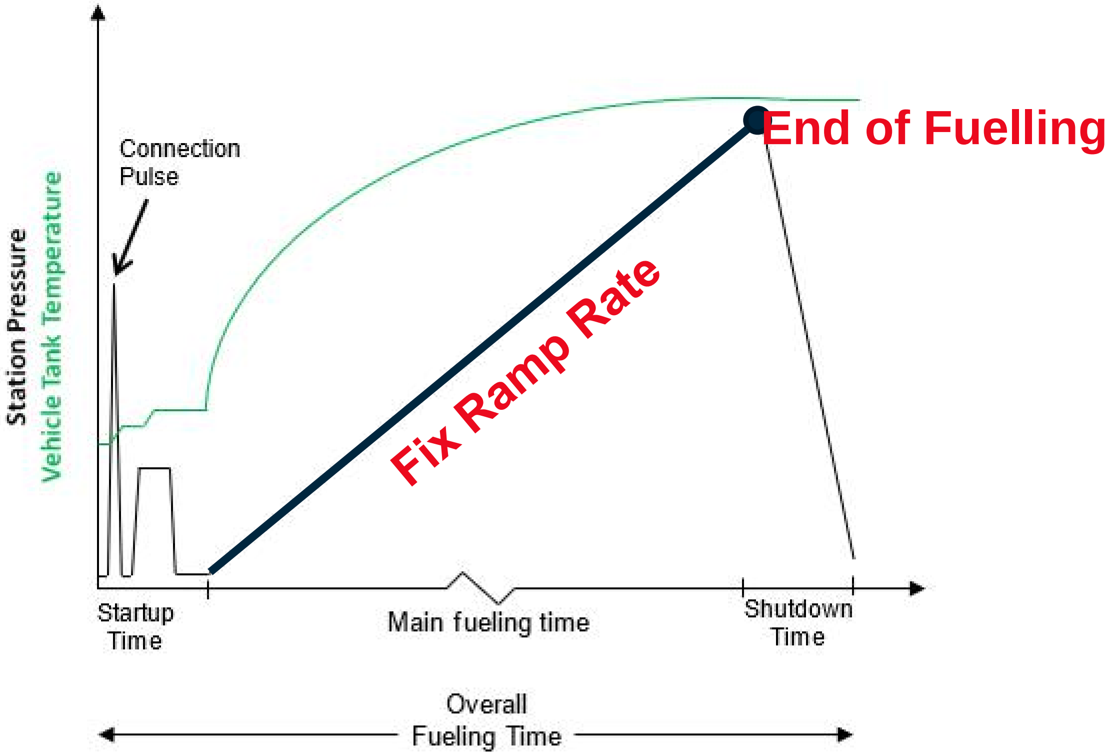
07 Precautions

08 Outlook

09 Next steps

SAE J2601-5 Category D Protocol

Basic Principle



RAMP RATE

- Target APRR is not variable. Fix rate in MPa/min.
- Depends on T_{amb}, Pre-cooling temperature, flow limitation and individual maximum tank size.
- Does not depend on initial CHSS pressure and temperature

END OF FUELLING

- Depends on T_{amb}, Pre-cooling temperature, individual maximum tank size and initial pressure.
- Can also depend on end CHSS temperature in case of Communication. (SOC calculation)
- Does not depend on initial CHSS temperature

SAE J2601-5 Category D Protocol

Basic Principle for Ramp Rate selection

① Select the right table

Comm/Non-Comm	Fuel delivery temperature category	SAE J2601-5 Category D HF Lookup Table	
		50 L < TVL < 250 L	250 L < TVL < 800 L
Non-Communications	T40D	Table G1	Table G2
	T30D	Table G3	Table G4
	T20D	Table G5	Table G6
Communications	T40D	Table G7	Table G8
	T30D	Table G9	Table G10
	T20D	Table G11	Table G12

Temperature based $APRR_{actual}$

H70-T40D Capacity Category D non-comm TVL ≤ 250	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	6,3	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	9,9	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	13,8	70,8	71,8	72,2	71,4	71,2	71,2	70,9	70,8	70,8	71,1	71,9	no fueling
35	14,6	70,0	71,3	71,3	71,1	70,9	70,8	70,6	70,6	70,7	71,0	71,9	no fueling
30	17,5	67,4	71,0	71,0	70,2	70,0	69,9	69,6	69,5	69,6	69,9	70,8	no fueling
25	20,4	64,6	69,7	69,6	69,3	69,0	68,9	68,6	68,4	68,5	68,8	no fueling	no fueling
20	22,2	65,2	68,9	68,8	68,4	68,1	67,9	67,5	67,4	67,4	67,7	no fueling	no fueling
10	22,2	67,8	67,8	67,3	66,3	65,9	65,6	65,1	64,7	64,5	64,6	no fueling	no fueling
0	22,2	67,3	67,3	66,8	65,9	64,9	64,0	63,4	63,0	62,9	63,2	no fueling	no fueling
-10	22,2	66,8	66,8	66,3	65,4	64,5	63,5	61,5	60,8	60,6	60,9	no fueling	no fueling
-20	22,2	66,3	66,3	65,8	65,0	64,1	63,0	61,2	59,4	57,5	no fueling	no fueling	no fueling
-30	22,2	65,8	65,8	65,3	64,5	63,7	62,7	61,0	59,3	57,5	no fueling	no fueling	no fueling
-40	22,2	65,3	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

e.g. T_{amb} = 25°C, TVL<250L and T30D pre-cooling:

→ 9.7 MPa/min

② Take the lowest ramp rate

Flow based $APRR_{calculated}$

$$APRR_{calculated} = \frac{FM}{60} \times 28.5 \times \frac{V_{station\_D}}{V_{CHSS}}$$

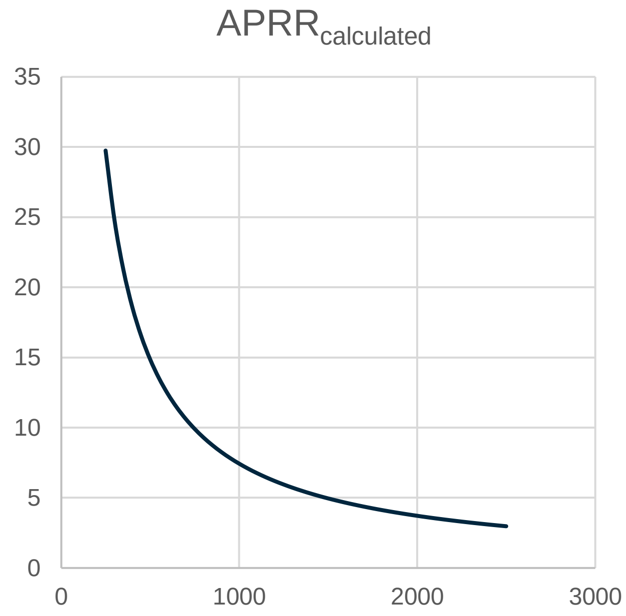
e.g. for 620 L (25 kg) tank at 90 g/s:

$V_{station\_D}$: 174L → 12 MPa/min

SAE J2601-5 Category D Protocol

Temperature Constrained $APRR_{actual}$ tables

Tamb	T40D			T30D			T20D		
	SAE J2601-5 D Category (TVL<250L)	SAE J2601-5 D Category (TVL>250L)	Current Cat D APRR	SAE J2601-5 D Category (TVL<250L)	SAE J2601-5 D Category (TVL>250L)	Current Cat D APRR	SAE J2601-5 D Category (TVL<250L)	SAE J2601-5 D Category (TVL>250L)	Current Cat D APRR
50	**6.3**	**6.3**	7.6	**1.8**	**1.8**	3.1	**no fueling**	**no fueling**	1.2
45	**9.9**	**9.9**	11.0	**3.6**	**3.6**	4.9	**1.4**	**1.3**	2.2
40	**13.8**	**13.8**	14.5	**5.6**	**5.6**	7.1	**2.3**	**2.1**	3.3
35	**14.6**	**14.6**	15.3	**6.0**	**5.9**	7.5	**2.5**	**2.2**	3.5
30	**17.5**	**17.5**	17.9	**7.8**	**7.5**	9.3	**3.3**	**2.9**	4.5
25	**20.4**	**20.4**	19.9	**9.7**	**9.2**	11.2	**4.2**	**3.6**	5.5
20	**22.2**	**22.2**	19.9	**11.8**	**10.9**	13.3	**5.2**	**4.3**	6.6
10	**22.2**	**22.2**	19.9	**15.5**	**14.0**	17.0	**7.2**	**5.6**	8.7
0	**22.2**	**22.2**	19.9	**22.0**	**22.0**	19.9	**11.2**	**9.1**	12.9
-10	**22.2**	**22.2**	19.9	**22.2**	**22.2**	19.9	**12.2**	**9.7**	13.6
-20	**22.2**	**22.2**	19.9	**22.2**	**22.2**	19.9	**13.0**	**10.4**	14.4
-30	**22.2**	**22.2**	19.9	**22.2**	**22.2**	19.9	**13.8**	**11.1**	15.0
-40	**22.2**	**22.2**	19.9	**22.2**	**22.2**	19.9	**14.6**	**11.8**	15.7



At T40D, no impact of single largest tank.

At T30D, minor impact between 10°C and 35°C.

At T20D, impact of TVL is everywhere

Flow constrained $APRR_{calculated}$ based on TV

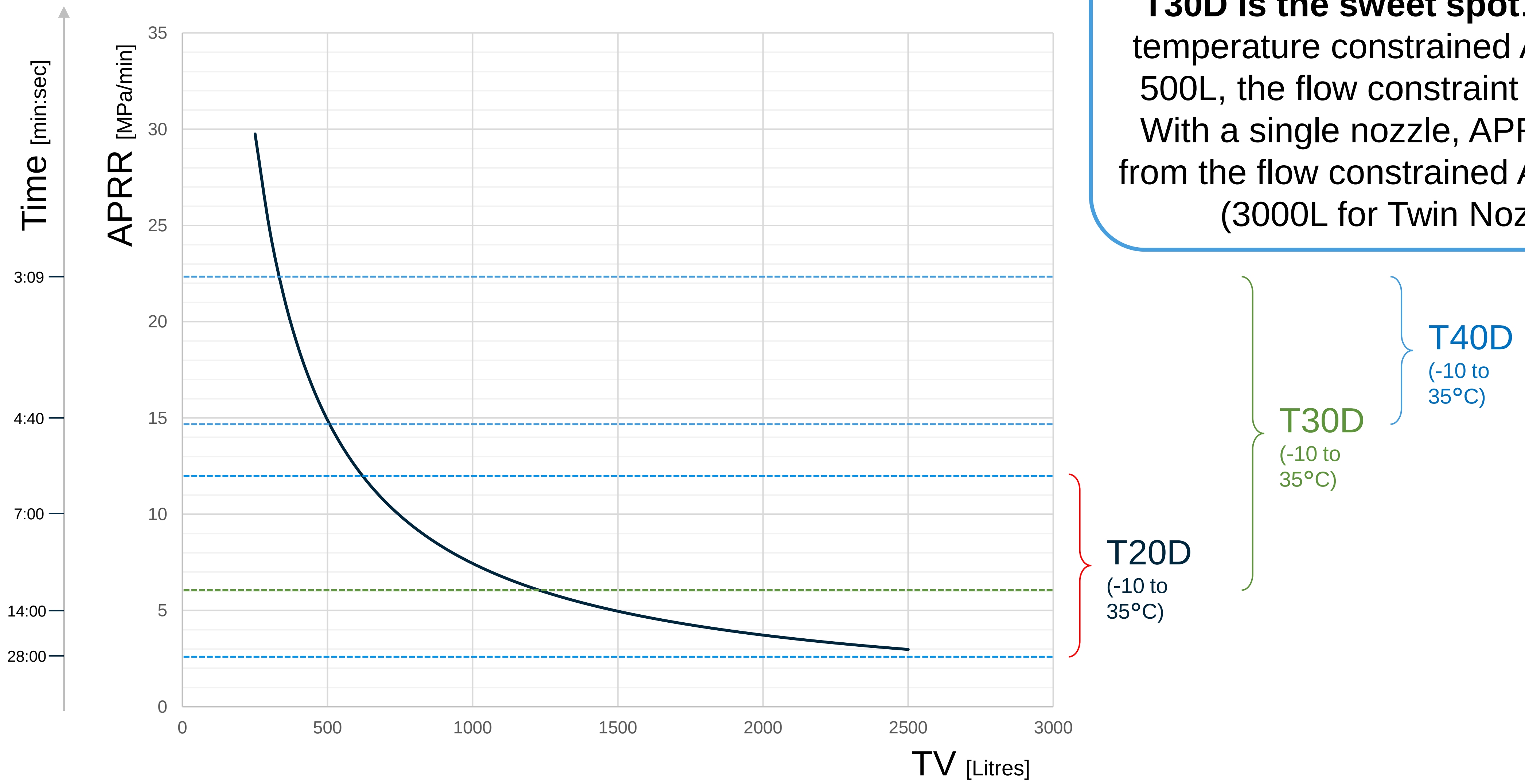
Below 27°C, SAE J2601-5 has faster fuelling than SAE J2601.

Below 5°C, SAE J2601-5 is faster than SAE J2601 D cat

APRR is considerably slower using SAE J2601-5

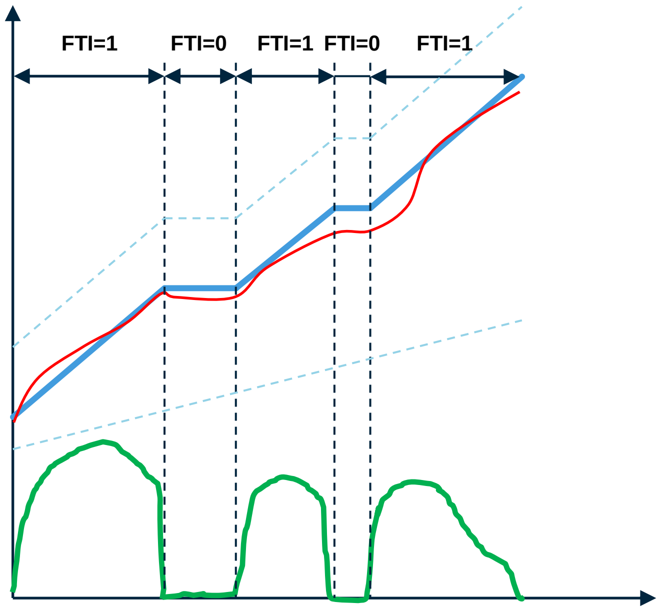
SAE J2601-5 Category D Protocol

Flow limitation to the ramp rate.

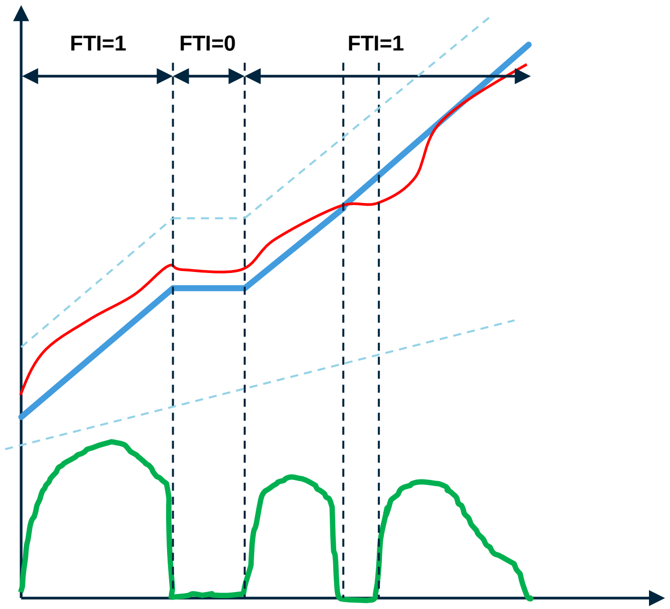


In European Climate conditions (-10°C to +35°C), **T30D is the sweet spot**. T40D has higher temperature constrained APRRs, but above 500L, the flow constraint value has priority. With a single nozzle, $APRR_{actual}$ takes over from the flow constrained APRR below 1250L (3000L for Twin Nozzle Fuelling)

Fuelling Time Indicator (FTI) and Minimum Mass Flow Rate

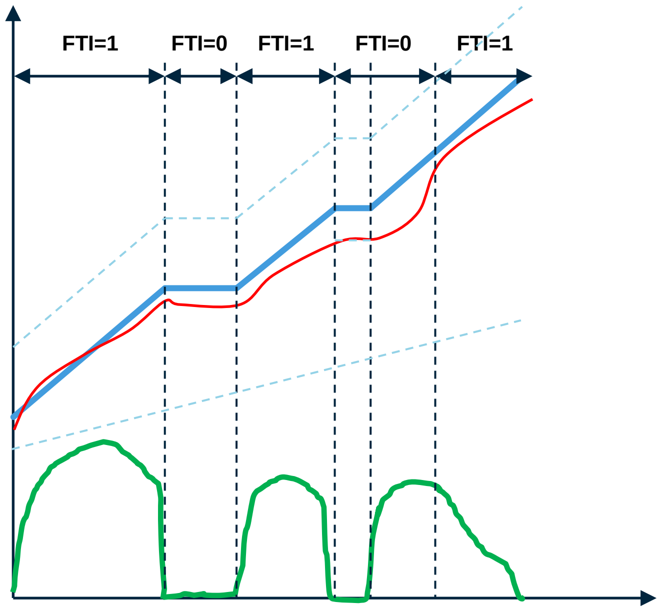


Allowed on condition that minimum mass flow while FTI=0 < 1% of FM value.
(<0.6 g/s for FM60 or <0.9 g/s for FM90)



Allowed on condition that mass flow does not drop below Minimum Flow Rate (below) for more than 10 seconds.

CHSS capacity (L)	Minimum Flow rate (g/s)
ND	1.25
250	1.25
500	2.5
750	3.75
1000	5.0
1500	7.5
≥ 2000	10.0



Not allowed.

Agenda

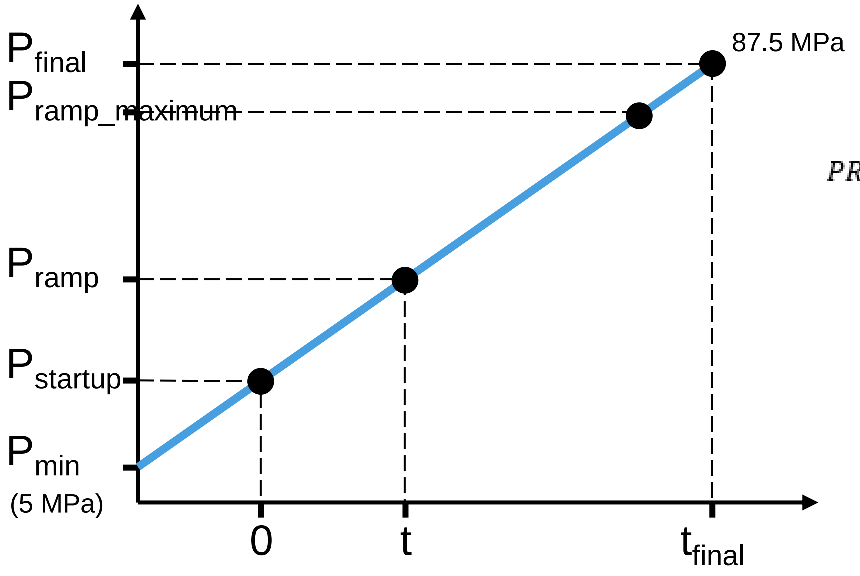
MCF-HF-G Classifications

Pressure Class	Flow Rate Maximum Class (Non-Comm)	Flow Rate Maximum Class (Comm)	Coupling Type	Range of CHSS Sizes (liters)	Range of Tank Sizes within the CHSS (liters)	Range of Fuel Delivery Temperatures (MAT_C)
H35	FM120	FM120	H35HF	248.6 to 7500	50 to 1000	-40 °C ≤ MATC ≤ 20 °C
H70	FM60	FM60 (no OD) FM90 (with FM=090 in OD)	H70	248.6 to 5000	50 to 800	-40 °C ≤ MATC ≤ 0 °C
	FM300	FM300	H70HF			

Basic Principle

The basic principle of the MCF-HF-G protocol is exactly the same as for the MC-Formula from SAE J2601.

The main difference is where t_{final} is coming from.



$$PRR_{MC(j)} = \frac{P_{final} - P_{ramp(j)}}{t_{final(j)} \times \left(\frac{P_{final} - P_{startup}}{P_{final} - P_{min}}\right) - t}$$ [MPa/s]

SAE J2601:2020 → $t_{final} = a \times MAT^3 + b \times MAT^2 + c \times MAT + d$

MCF-HF-G → *Mainly coming from table interpolation*

For both protocols, t_{final} value is adjusted with several correction values such as α, β (and ε for MCF) and it also has a minimum value based on the tank capacity to respect: t_{final_min}.

t_{final} Limitations on max tank temp.

The dispenser can be programmed with Option A or Option B.

OPTION A: "Advanced" provides fastest fuelling

H70

TVL (liters)	V_{chss} (liters)								
	248.6	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**5000**	**ND**
50 ≤ TVL ≤ 200	Table D37	Table D38	Table D39	Table D40	Table D41	Table D42	Table D43	Table D44	Table D72
200 < TVL ≤ 350	Table D45	Table D46	Table D47	Table D48	Table D49	Table D50	Table D51	Table D52	
350 < TVL ≤ 800	N/A	Table D53	Table D54	Table D55	Table D56	Table D57	Table D58	Table D59	

e.g. 1700 L (10 tanks of 6.84 kg) → Table D40 = Table_{below} and Table D41 = Table_{above}

OPTION B: "Basic" still fast fuelling but not as fast as OPTION A

H70

TVL (liters)	V_{chss} (liters)				
	$248.6 \leq V_{chss} \leq 1000$	**$1000 < V_{chss} \leq 2000$**	**$2000 < V_{chss} \leq 3000$**	**$3000 \leq V_{chss} \leq 5000$**	**ND**
50 ≤ TVL ≤ 200	Table D60	Table D61	Table D62	Table D63	Table D72
200 < TVL ≤ 350	Table D64	Table D65	Table D66	Table D67	
350 < TVL ≤ 800	Table D68	Table D69	Table D70	Table D71	

e.g. 1700 L (10 tanks of 6.84 kg) → Table D61 is selected

Option A interpolation

	MATc (°C)																		MATc (°C)		
T_{amb} (°C)	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
50	366	433	521	634	777	958	1188	1487	1889	2430	3101	3808	4673	5859	7114	8330	9457	10481	11429	12286	13076
45	286	328	377	436	508	593	694	848	1068	1329	1634	1986	2390	2849	3366	3943	4581	5270	5992	6723	7446
40	234	265	300	340	384	436	514	626	765	930	1121	1339	1585	1857	2155	2479	2832	3216	3631	4071	4535
35	223	253	286	323	365	414	499	606	738	895	1075	1280	1507	1756	2024	2311	2617	2944	3291	3653	4028
30	195	220	248	279	313	366	431	514	616	736	876	1034	1211	1405	1613	1835	2070	2320	2584	2858	3143
25	177	194	217	245	283	328	381	447	527	623	733	860	1002	1158	1326	1504	1695	1895	2107	2326	2554
20	177	177	197	225	258	297	342	396	461	538	628	731	847	975	1114	1262	1419	1586	1762	1944	2132
15	177	177	185	211	241	276	316	364	419	485	562	651	750	861	982	1111	1248	1394	1547	1705	1870
10	177	177	177	199	226	258	294	336	385	442	508	585	672	768	873	986	1108	1236	1372	1512	1657
5	177	177	177	179	203	230	261	296	336	381	433	493	562	639	723	814	913	1018	1129	1245	1366
0	177	177	177	177	183	206	233	263	297	335	377	425	480	542	611	685	766	853	945	1043	1144
-5	177	177	177	177	180	203	230	259	293	330	371	418	472	532	599	672	751	836	926	1021	1120
-10	177	177	177	177	178	200	226	256	288	325	365	411	463	523	588	659	736	819	908	1000	1097
-5	177	177	177	177	177	198	223	252	284	320	360	404	455	513	577	647	722	803	890	980	1074
-20	177	177	177	177	177	195	220	248	280	315	354	398	448	504	567	635	709	788	872	961	1053
-25	177	177	177	177	177	192	217	245	276	310	348	391	440	496	557	623	696	773	856	942	1032
-30	177	177	177	177	177	190	214	241	272	306	343	385	433	487	547	612	683	759	840	924	1012
-35	177	177	177	177	177	187	211	238	268	301	338	379	426	479	537	601	670	745	824	907	993
-40	177	177	177	177	177	185	208	234	264	297	333	373	419	471	528	591	658	731	809	890	975

T_{amb} = 23°C

Red area = slower than 1.0 MPa/min.

Yellow area = slower than 1.0 MPa/min in case $P_{initial}$ < 5 MPa

Step 1: Table D40 (CHSS 1500L and 50L<TVL<200L) = $Table_{below}$

Take the row of T_{amb} above and below the real ambient temperature.

Option A interpolation

	MATc (°C)																		MATc (°C)		
T_{amb} (°C)	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
50	426	493	577	683	817	985	1198	1473	1837	2325	2943	3628	4376	5466	6659	7857	8991	10044	11012	11890	12708
45	337	382	433	491	559	641	736	890	1094	1340	1628	1961	2345	2782	3275	3826	4437	5103	5807	6527	7246
40	276	310	348	391	437	488	573	679	811	966	1147	1356	1591	1853	2140	2454	2797	3170	3575	4007	4462
35	264	296	333	373	417	478	559	661	786	934	1106	1301	1519	1759	2019	2298	2597	2917	3258	3614	3985
30	232	259	289	323	371	427	492	572	669	784	916	1068	1238	1425	1626	1842	2072	2317	2576	2847	3128
25	205	229	259	295	337	385	441	506	583	675	781	901	1037	1188	1351	1525	1710	1907	2115	2331	2556
20	189	212	240	272	309	351	399	454	518	592	679	778	889	1012	1146	1290	1444	1608	1780	1959	2145
15	180	201	226	255	289	327	371	420	477	541	615	700	796	903	1019	1144	1279	1421	1571	1727	1889
10	177	191	213	240	271	306	346	391	441	498	562	636	720	813	915	1025	1143	1268	1401	1539	1682
5	177	177	194	217	243	273	308	346	389	436	488	546	612	687	769	857	953	1055	1164	1278	1397
0	177	177	177	197	220	246	276	309	346	386	430	479	532	592	659	731	810	895	985	1080	1180
-5	177	177	177	195	217	243	272	305	341	381	424	472	524	583	648	719	796	878	967	1059	1156
-10	177	177	177	193	215	240	268	301	337	376	418	465	517	574	638	707	782	863	949	1040	1134
-5	177	177	177	190	212	237	265	297	332	371	413	459	509	565	627	695	769	848	932	1021	1113
-20	177	177	177	188	209	234	261	293	328	366	407	452	502	557	618	684	756	833	916	1002	1093
-25	177	177	177	186	207	231	258	289	323	361	402	446	495	549	608	673	744	819	900	985	1073
-30	177	177	177	184	204	228	255	285	319	356	396	440	488	541	599	662	732	806	885	968	1054
-35	177	177	177	182	202	225	252	281	315	351	391	434	481	533	590	652	720	793	870	951	1036
-40	177	177	177	180	200	222	248	278	311	347	386	428	475	525	581	642	708	780	856	935	1018

T_{amb} = 23°C

Step 2: Table D41 (CHSS 2000L and 50L<TVL<200L) = $Table_{above}$

Take the row of T_{amb} above and below the real ambient temperature.

Option A interpolation

$Table_{below}$

V = 1500 L

T_{amb} (°C)	MATc (°C)																		MATc (°C)		
	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
25	177	194	217	245	283	328	381	447	527	623	733	860	1002	1158	1326	1504	1695	1895	2107	2326	2554

$Table_{above}$

V = 2000 L

T_{amb} (°C)	MATc (°C)																		MATc (°C)		
	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
25	205	229	259	295	337	385	441	506	583	675	781	901	1037	1188	1351	1525	1710	1907	2115	2331	2556

$$t_{final(MAT_C)(T_{amb\_above})} = t_{final(MAT_C)(T_{amb\_above})(Table_{below})} + \frac{\left[t_{final(MAT_C)(T_{amb\_above})(Table_{above})} - t_{final(MAT_C)(T_{amb\_above})(Table_{below})}\right] \times \left[V_{CHSS} - V_{table\_below}\right]}{\left[V_{table\_above} - V_{table\_below}\right]}$$

T_{amb} (°C)	MATc (°C)																		MATc (°C)		
	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
25	188.2	208.0	233.8	265	304.6	350.8	405.0	470.6	549.4	643.8	752.2	876.4	1016.0	1170.0	1336.0	1512.4	1701.0	1899.8	2110.2	2328.0	2554.8

Do the same for T_{amb} just below the real ambient temperature

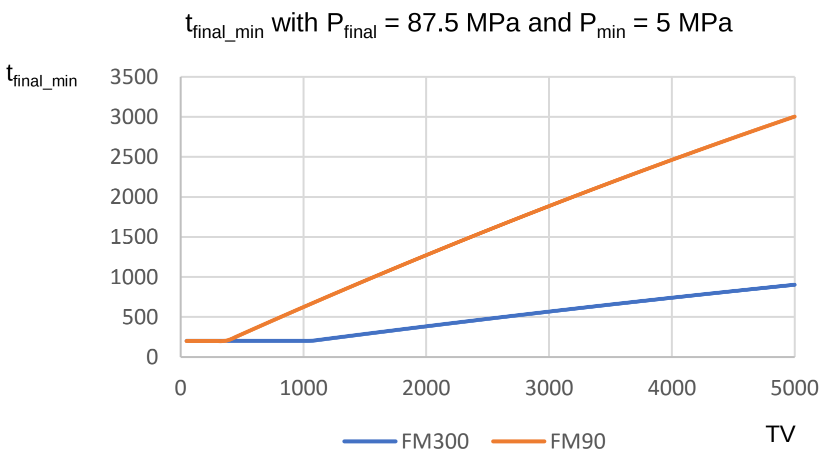
T_{amb} (°C)	MATc (°C)																		MATc (°C)		
	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
20	181.8	191.0	214.2	243.8	278.4	318.6	364.8	419.2	483.8	559.6	648.4	749.8	863.8	989.8	1126.8	1273.2	1429.0	1594.8	1769.2	1950.0	2137.2

t_{final} Limitations on peak mass flow

The peak mass flow of MCF-HF-G is 300 g/s for H70HF or 90 g/s for H70.
Depending on the V_{CHSS}, this will result in a minimum time to prevent exceeding this value.

$$t_{final\_min} = \left(\frac{87.5 - P_{min}}{82.5}\right) \times \left(\frac{300}{FM}\right) \times (0.2107041 \times V_{CHSS} - 0.00000538442 \times V_{CHSS}^2 - 18.2)$$

And t_{final_min} can never go below 200 s.



Option A interpolation

T_{amb} (°C)	MATc (°C)																		MATc (°C)		
	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
25	188.2	208.0	233.8	265	304.6	350.8	405.0	470.6	549.4	643.8	752.2	876.4	1016.0	1170.0	1336.0	1512.4	1701.0	1899.8	2110.2	2328.0	2554.8
20	181.8	191.0	214.2	243.8	278.4	318.6	364.8	419.2	483.8	559.6	648.4	749.8	863.8	989.8	1126.8	1273.2	1429.0	1594.8	1769.2	1950.0	2137.2

Finally interpolate according to the ambient temperature. (example 23°C)

T_{amb} (°C)	MATc (°C)																		MATc (°C)		
	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
23	185.6	201.2	226.0	256.5	294.1	337.9	388.9	450.0	523.2	610.1	710.7	825.8	955.1	1097.9	1252.3	1416.7	1592.2	1777.8	1973.8	2176.8	2387.8

These values will become 324 s for FM300.
Otherwise flow might be too high.

These values will become 1081 s for FM090.
Otherwise flow might be too high.

When we calculate t_{final_min}:

In case of V_{CHSS} = 1700 L:
t_{final_min} = 324 seconds for FM300
t_{final_min} = 1081 seconds for FM090

Conclusion: If we use a single H70 nozzle (FM090) it makes not a lot of sense to use T40 cooling.

Comparison between option A and B

Option A

	MAT_C (°C)																		MAT_C (°C)		
T_{amb} (°C)	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
23	185.6	201.2	226.0	256.5	294.1	337.9	388.9	450.0	523.2	610.1	710.7	825.8	955.1	1097.9	1252.3	1416.7	1592.2	1777.8	1973.8	2176.8	2387.8

Option B

	MAT_C (°C)																		MAT_C (°C)		
T_{amb} (°C)	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
23	198.6	222.2	251.4	285.8	325.8	371.4	424.2	485.2	557.0	641.8	740.2	851.8	977.8	1117.6	1269.0	1431.0	1603.6	1786.6	1981.0	2182.2	2392.8

Example: 1700 L Vehicle Fuel System consisting of 10 tanks, each 6.84 kg.

In this example Option B is ~30 seconds slower in the T20/T30 range using H70HF.

Calculation of $t_{final(j)}$

$$t_{final(j)} = \alpha \times \beta \times \varepsilon \times t_{final\_calc(j)}$$

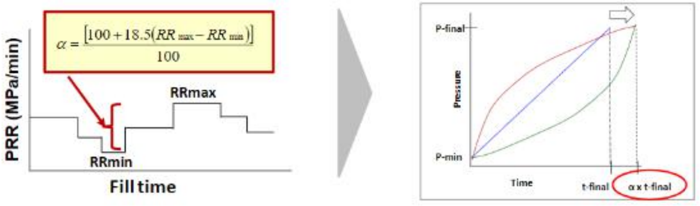
NEW

t_{final} is not calculated but coming from table interpolation depending on MAT_C
e.g. MAT_C = -23.5°C → t_{final_calc} = 545 s

MATc (ºC)			
-26	-24	-22	-20
450.0	523.2	610.1	710.7

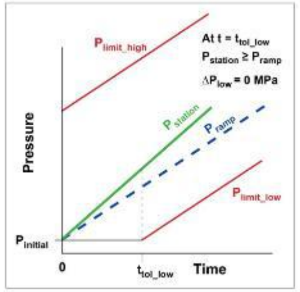
Same as J2601:2020

Accounting for deviations in Pressure Ramp Rate



Accounting for deviations in station pressure

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



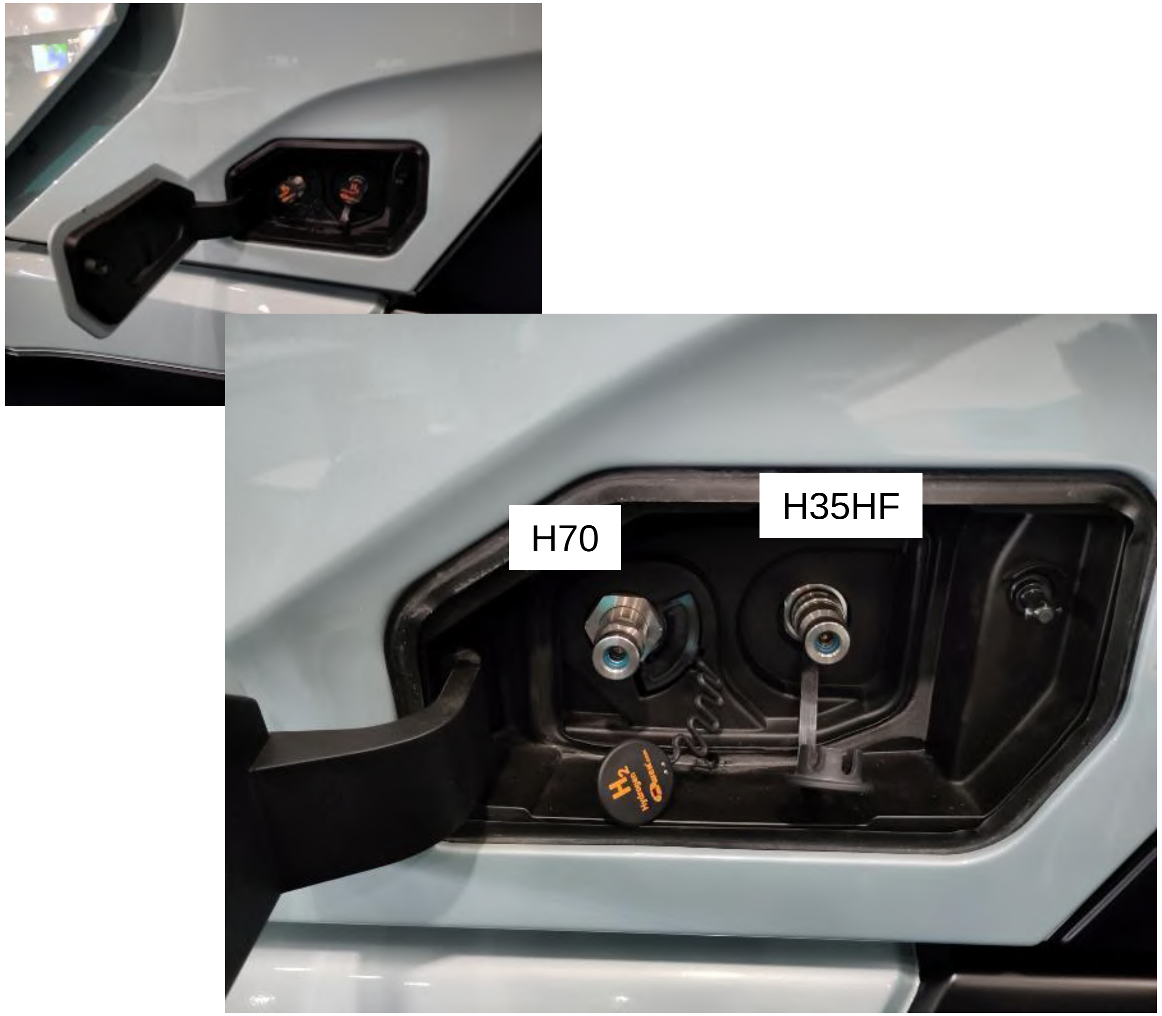
A parameter for in case the initial pressure is less than 5 MPa.

$$Set\ \varepsilon = \frac{(P_{final} - P_{initial})}{(P_{final} - 5) \times [1 - \omega \times (5 - P_{initial})]}$$

Where ω is a factor depending on T_{amb}

Agenda

Precautions



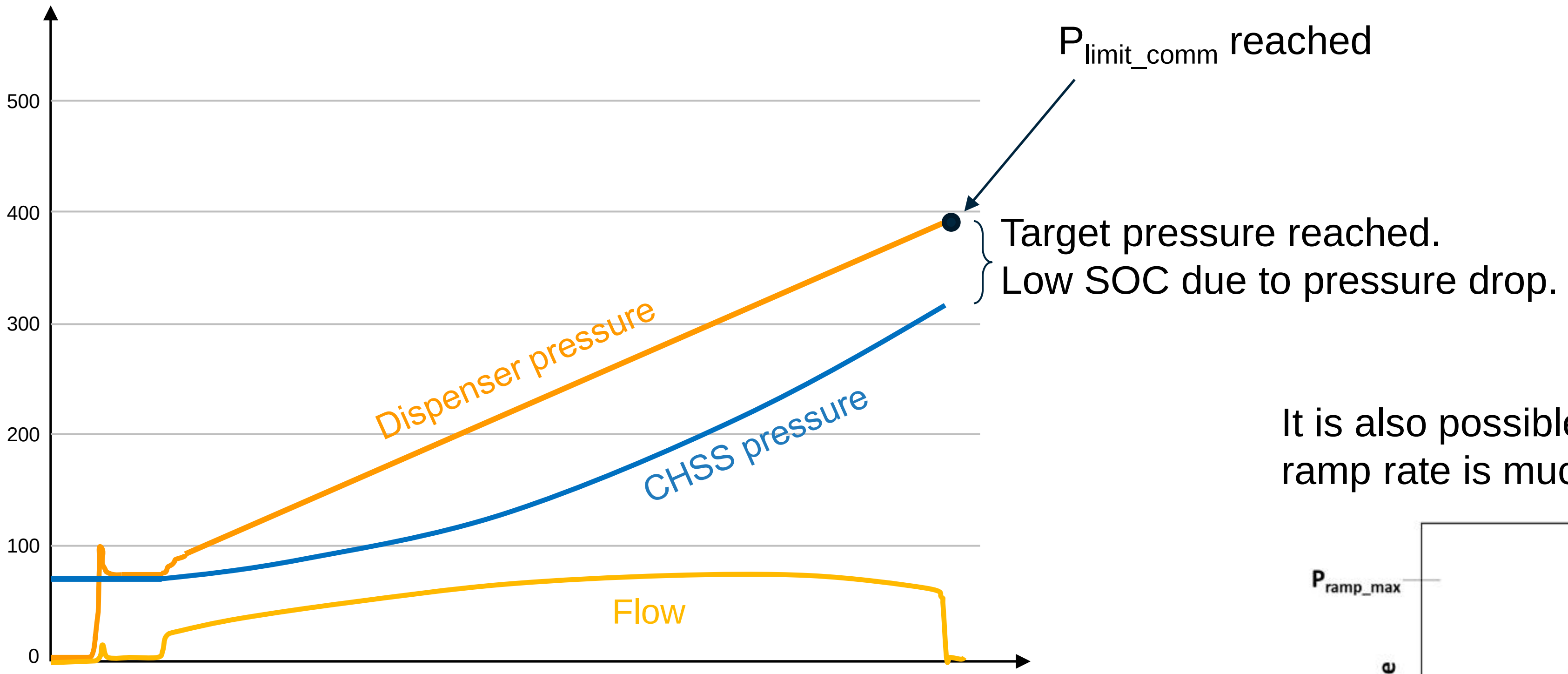
Consecutive fuelling of first H35HF followed by H70 or H70HF can result in overheating of the tanks and is thus not allowed.

HRS manufacturers should implement countermeasures to prevent this from happening.
E.g. limit the non-communication pressure target of H70 or H70HF to 55 MPa.

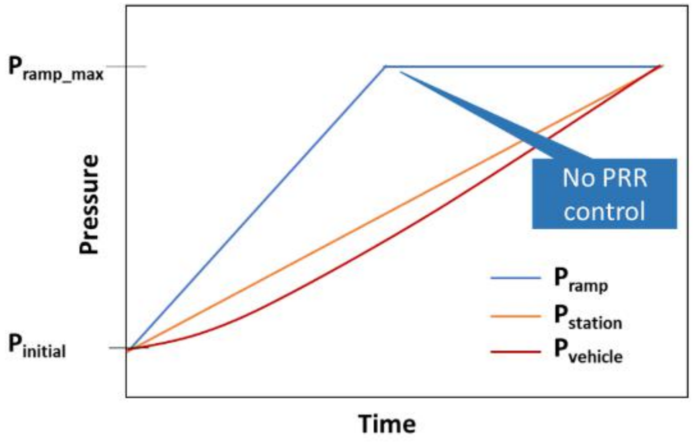
Agenda

Appendix E: PRR taper method

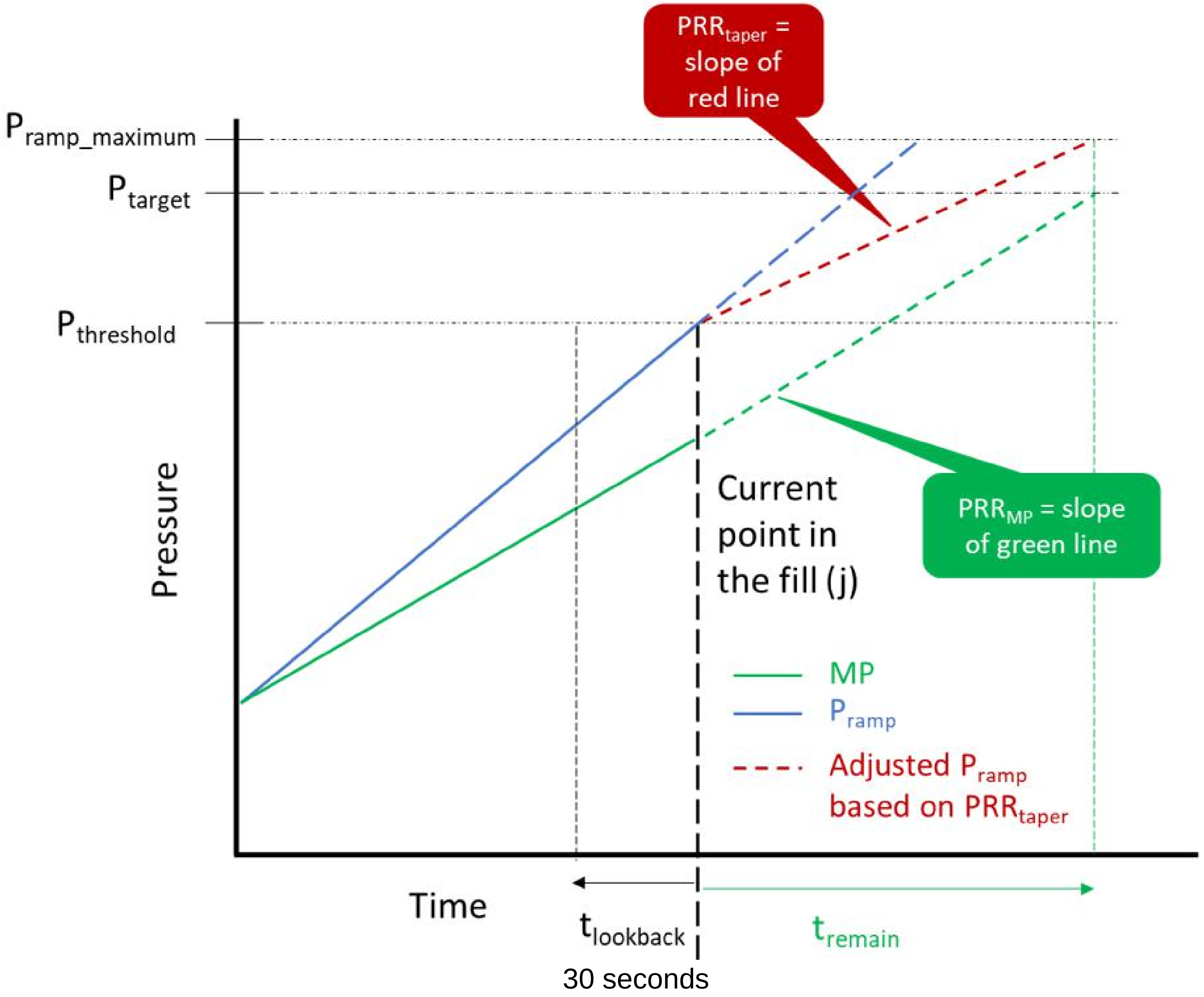
Background.



It is also possible that dispenser pressure ramp rate is much slower than APRR:



Appendix E: PRR taper method



In case of communication:

Monitor ΔP:

$$\Delta P_{(j)} = P_{ramp(j)} - MP_{(j)}$$

Start changing the ramp rate at $P_{threshold}$:

$$P_{threshold} = P_{ramp\_maximum} - \Delta P_{(j)}$$

Set the new PRR, called PRR_{taper}:

$$PRR_{taper(j)} = \frac{\left(P_{ramp\_maximum} - P_{ramp(j)}\right)}{t_{remain(j)}}$$

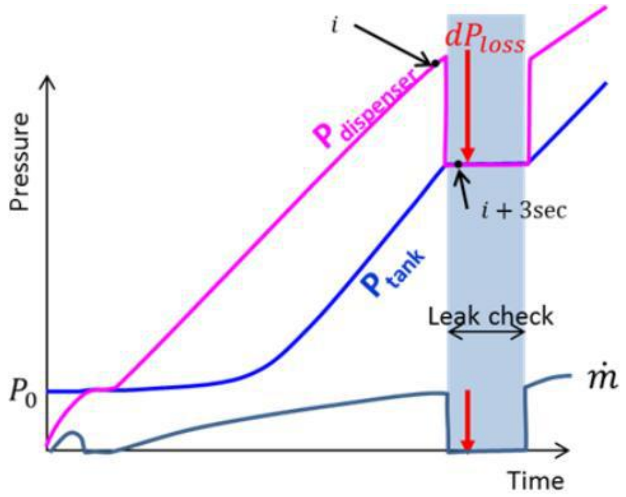
where $t_{remain(j)} = \frac{\left(P_{target\_comm} - MP_{(j)}\right)\ t_{lookback}}{\left(MP_{(j)} - MP_{(j-t_{lookback})}\right)}$

Appendix E: PRR taper method

Non-communication:

This is identical to communication except that the CHSS pressure is now calculated as MP_{calc}.

$$MP_{calc} = P_{station} - K_0 \frac{\dot{m}^2}{\rho}$$

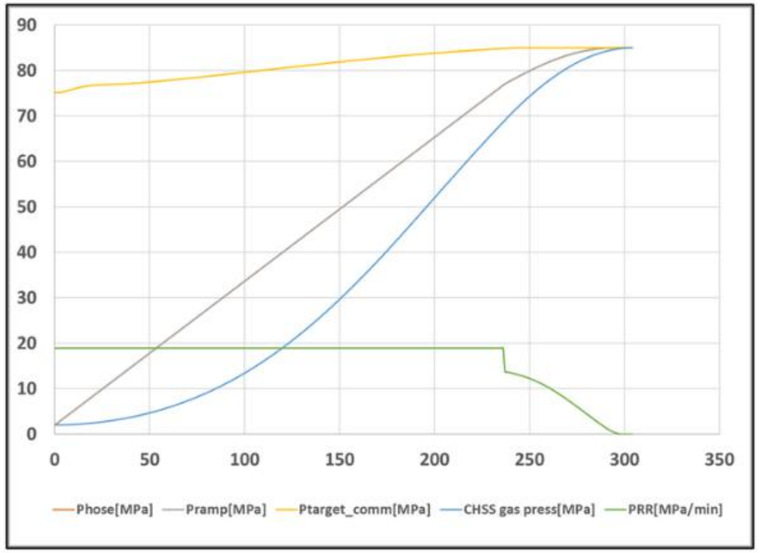


The calculation of K_0 is explained in
https://www.jstage.jst.go.jp/article/jsaeijae/9/4/9_20184125/_pdf/-char/en

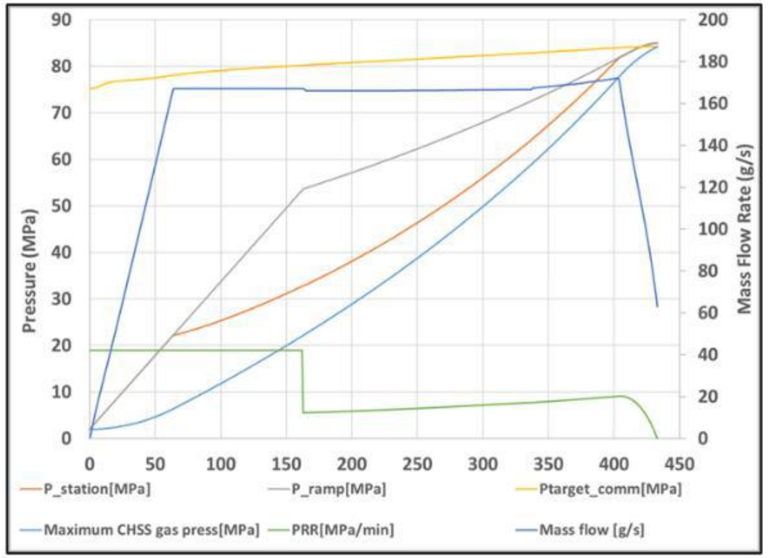
The pressure difference is measured by checking the dispenser pressure just before and during the leak check.

Appendix E: PRR taper method

Conclusion:
PRR Taper method has only be confirmed on LDV stations at this moment and not yet on HDV stations.
Simulations however have shown that the PRR Taper method seems to work well.



Implementation of PRR Taper for an H70 fueling with high pressure drop



Implementation of PRR Taper for an H70 fueling with restricted flow rate

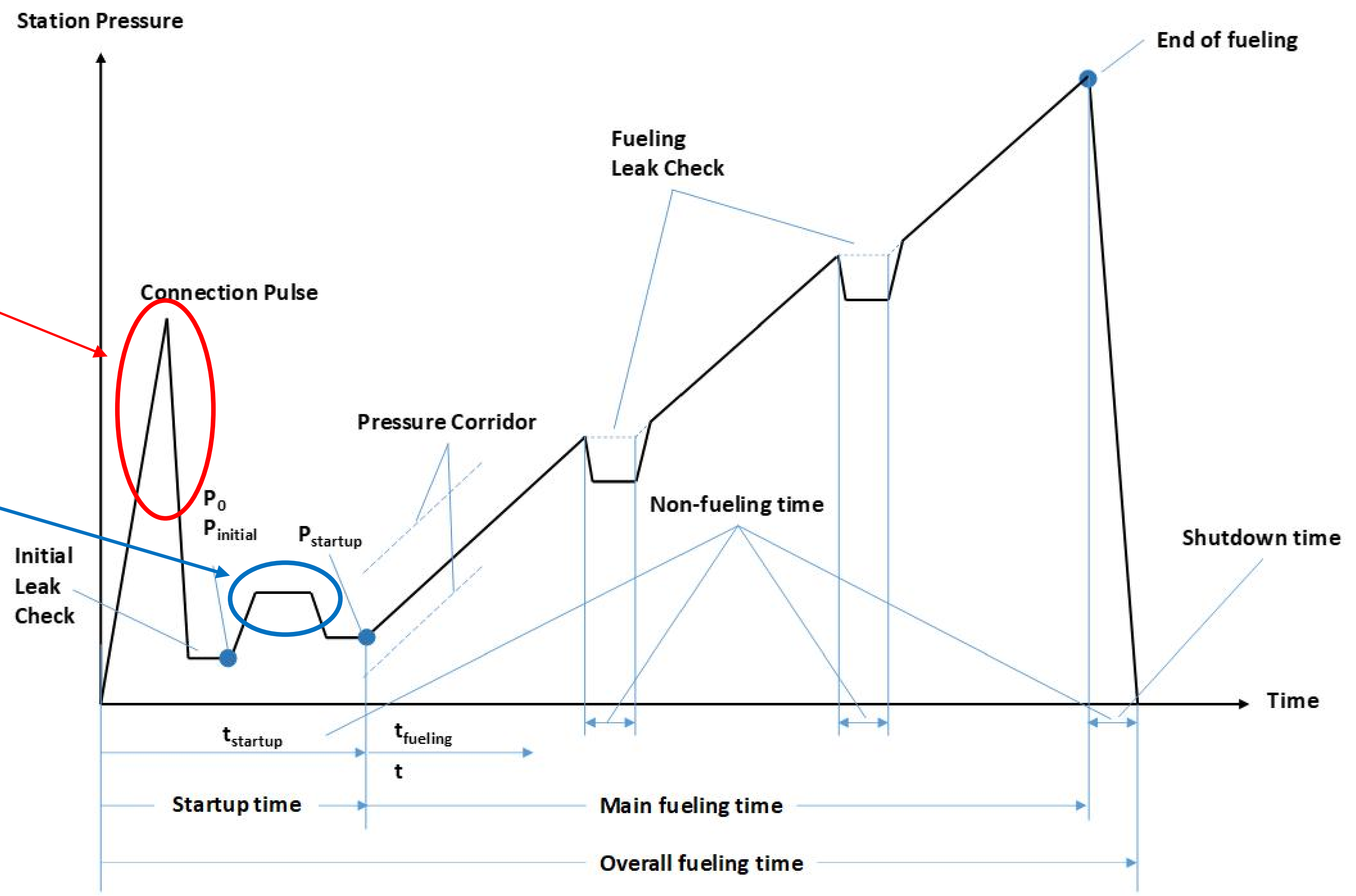
Please send feedback to the CEP if you have been testing the PRR Taper method.

Appendix F: CHSS volume estimation

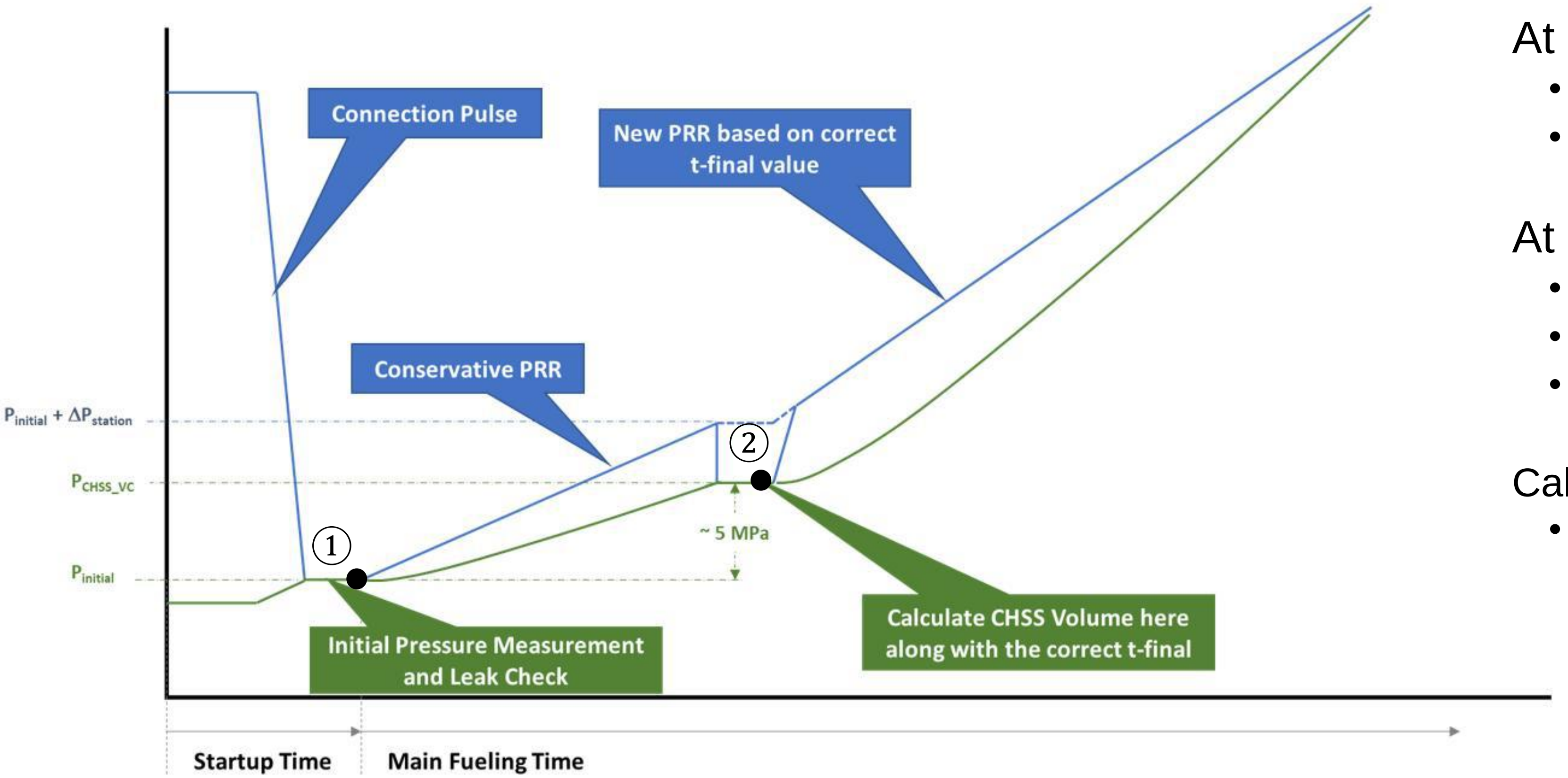
Connection pulse already increased to max. 500 g.

Volume estimation not possible without using very large mass of hydrogen.

A new method is needed to estimate the CHSS volume in case of no communication.



Appendix F: CHSS volume estimation



At point ①:

- T_{chss} is assumed to be T_{amb}
- $\rho_{startup}$ is calculated using T_{amb} and $P_{startup}$

At point ②:

- T_{chss} is estimated
- Mass between ① and ② is measured
- ρ_2 is calculated using $T_{estimated}$ and P2

Calculation:

- Using $\rho_2 - \rho_{startup}$ and measured mass, volume can be estimated.

Agenda

01 Standards concerning interoperability between vehicle and dispenser

02 General overview of SAE J2601-5

03 Fuelling protocol development process (assumptions and boundary conditions)

04 Communication

05 Category D protocol

06 MCF-HF-G protocol

07 Precautions

08 Outlook

09 Next steps

Next steps in HDV fuelling