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JRC Reference data from experiments of on-board hydrogen tanks fast filling

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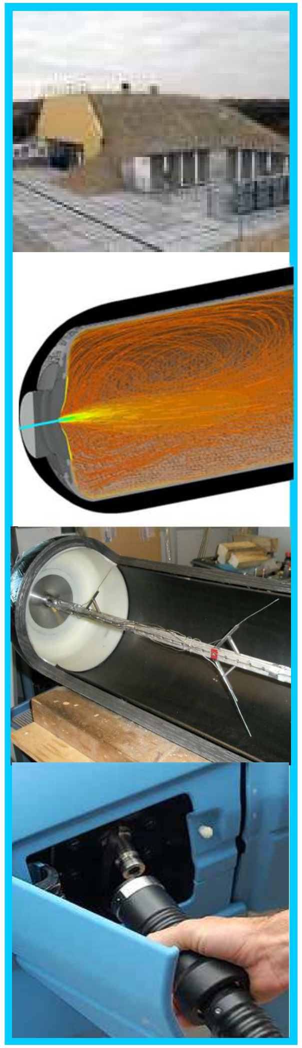
Outline

- Introduction
- JRC GasTeF facility
- Description of the Experimental Results Database
- Examples of Results
- Conclusion
- References



Introduction

European Commission

Regulations, codes and standards: compressed hydrogen storage system of a HFV

- **European Regulation on type-approval of hydrogen vehicles (EC/79/2009 and EU/406/2010)**

- **UN-ECE Global Technical Regulation on hydrogen and fuel cell vehicles (2013)**

Legally Binding

Alignment required

- **ISO** TS 15869 - Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks (2009)

- **SAE J2579** - Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles (2013)
- **SAE J2601** Hydrogen Fueling Protocol (2013)

Tests in RCS

European Commission

Performance requirements for hydrogen storage systems
Verification tests for expected on-road performance

Typical tests for high pressure H2 storage

- ✓ Burst test
- ✓ Bonfire test
- ✓ Chemical exposure test
- ✓ Ambient temperature and extreme temperature pressure cycle test (hydraulic)
- ✓ Accelerated stress rupture test
- ✓ Impact damage test
- ✓ Leakage test
- ✓ *Hydrogen gas cycle test*
- ✓ *Hydrogen permeation test*

- ➢ Need of harmonisation for the technical implementation of test requirements and procedures
- ➢ Need of scientific/technical data to justify globally harmonized test requirements and procedures

JRC facility

European Commission

- **GasTeF = an EU reference laboratory** for safety and performance assessment of high-pressure hydrogen (and natural gas) storage tanks
  - *Cycling tests: >1000 cycles of fast filling (≤ 5’) and slow empting (10’-60’) @ 80 MPa*
  - *Permeation measurements: tank is kept pressurised for 100-500 hours*

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Hydrogen tank life

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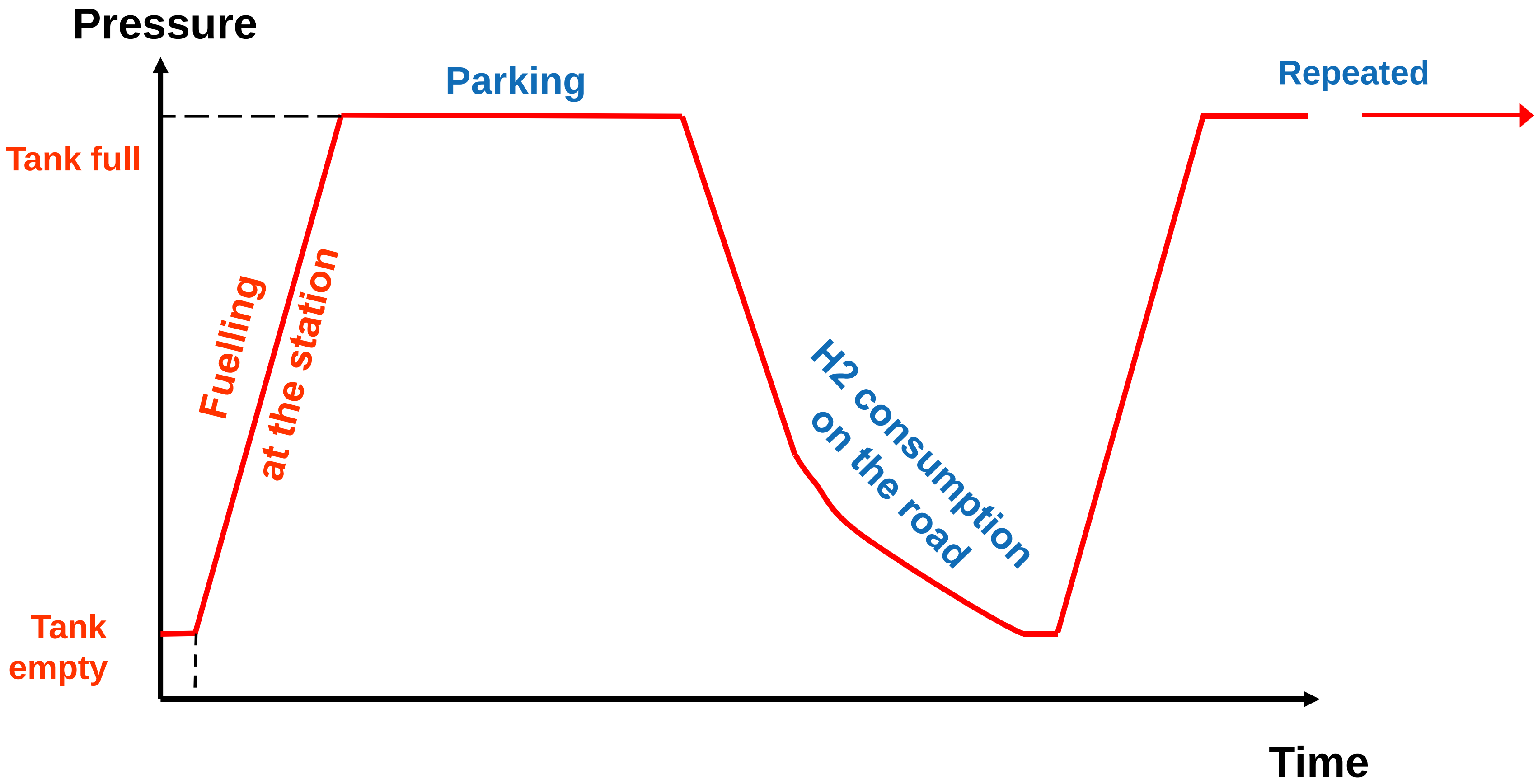
Simplified 'history' of a hydrogen tank



Requires consideration also in fuelling RCS and protocols

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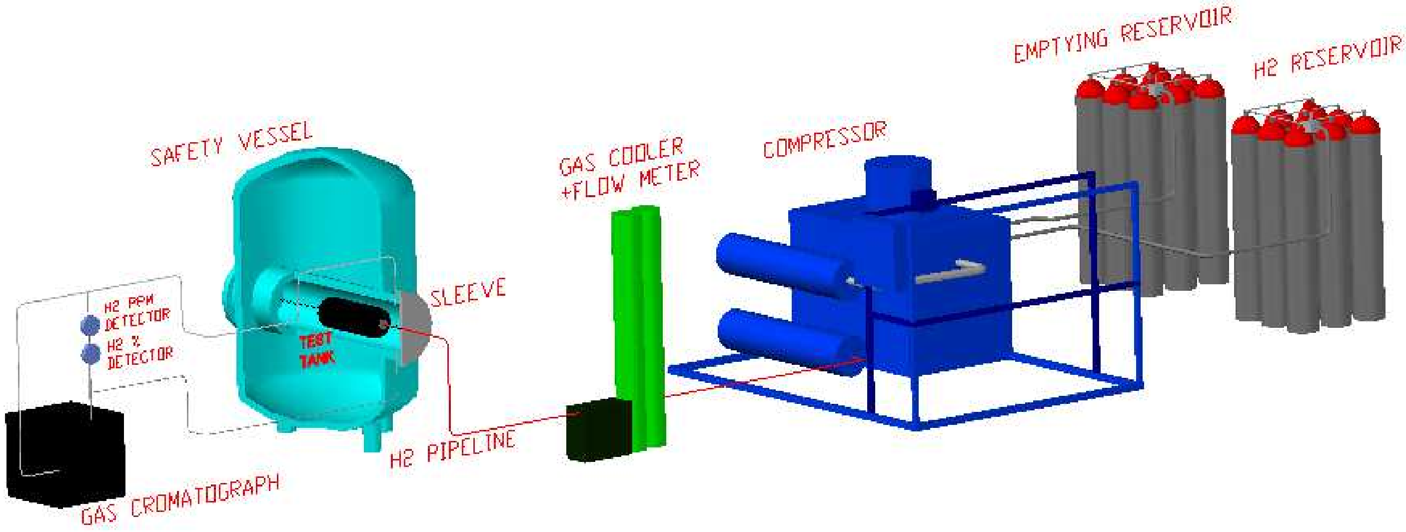
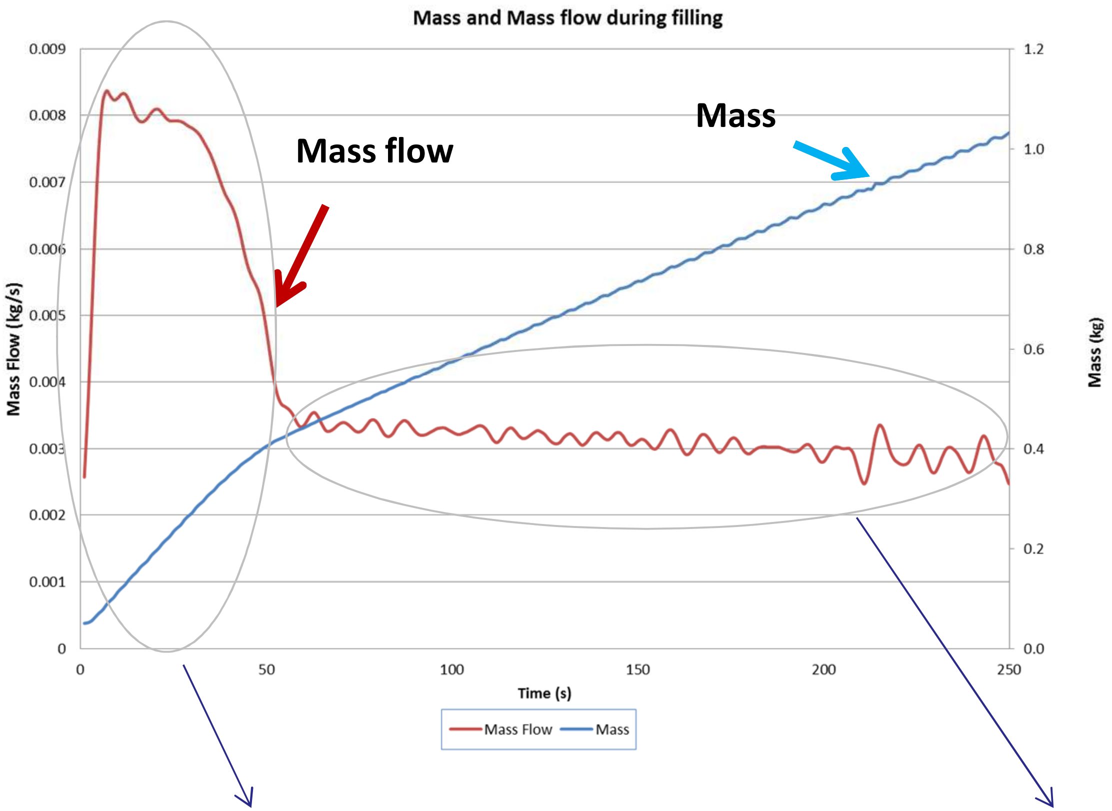
GasTeF Functioning



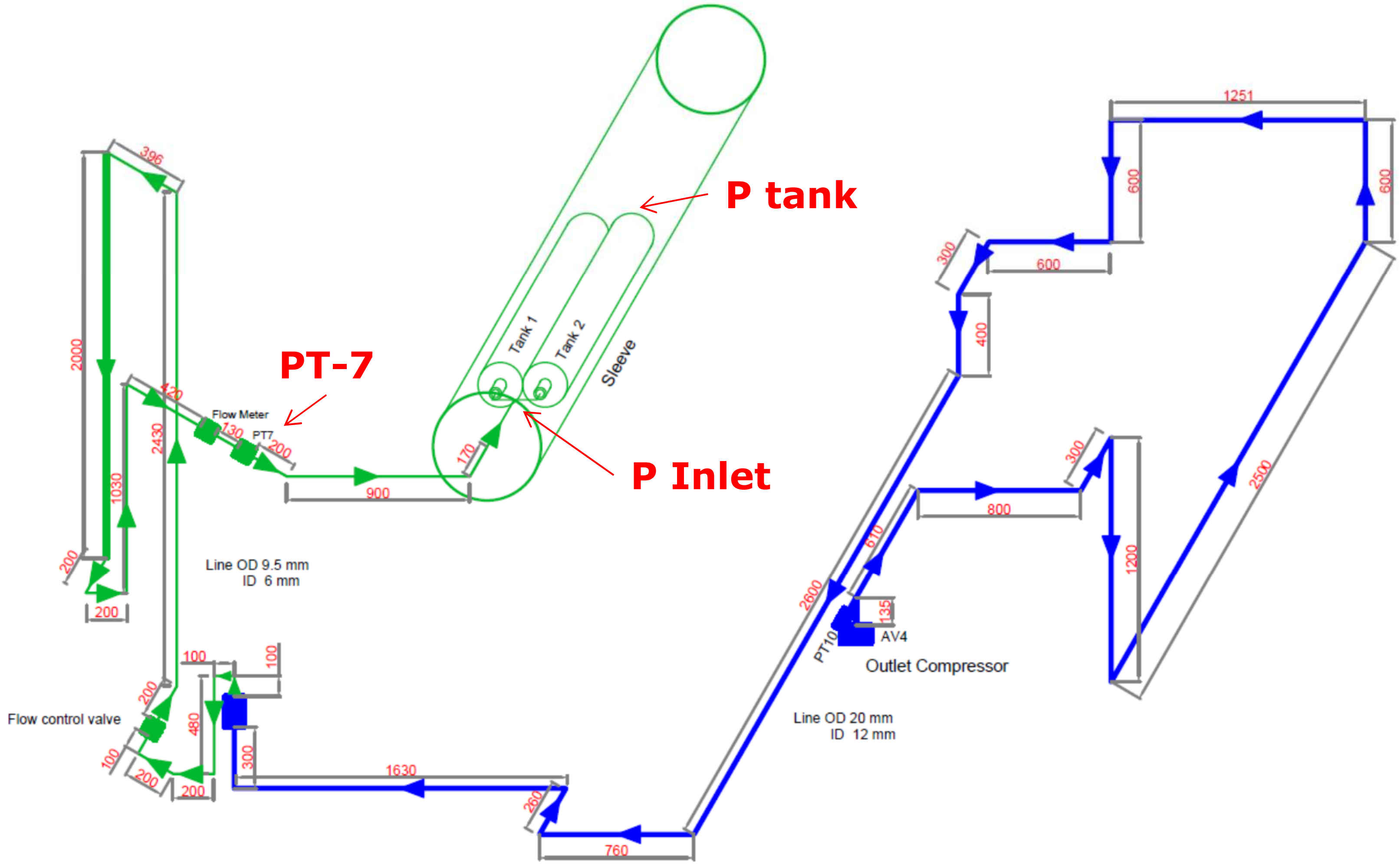
- **GasTeF operation mode** for tank fast filling is different than that of HRS:
  - *H_2 taken from a reservoir at 29 MPa*
  - *1st phase of filling is gas flowing from reservoir to tank till equilibrium*
  - *2nd phase is pumping the H_2 into the tank using the compressor*
  - *APRR regulated by the "compressor speed"*
  - *Semi-communication filling*

GasTeF refueling approach



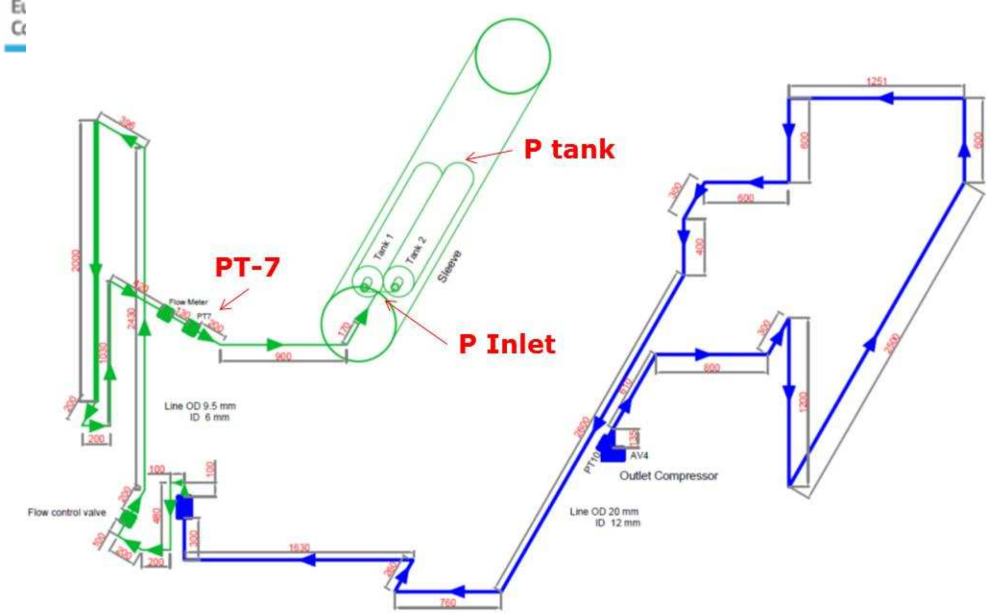
Two filling stages : (1) <u>Equilibration</u> with gas reservoir; (2) <u>compressor</u> pumping (visible effect of piston on tank pressure and mass flow signals).

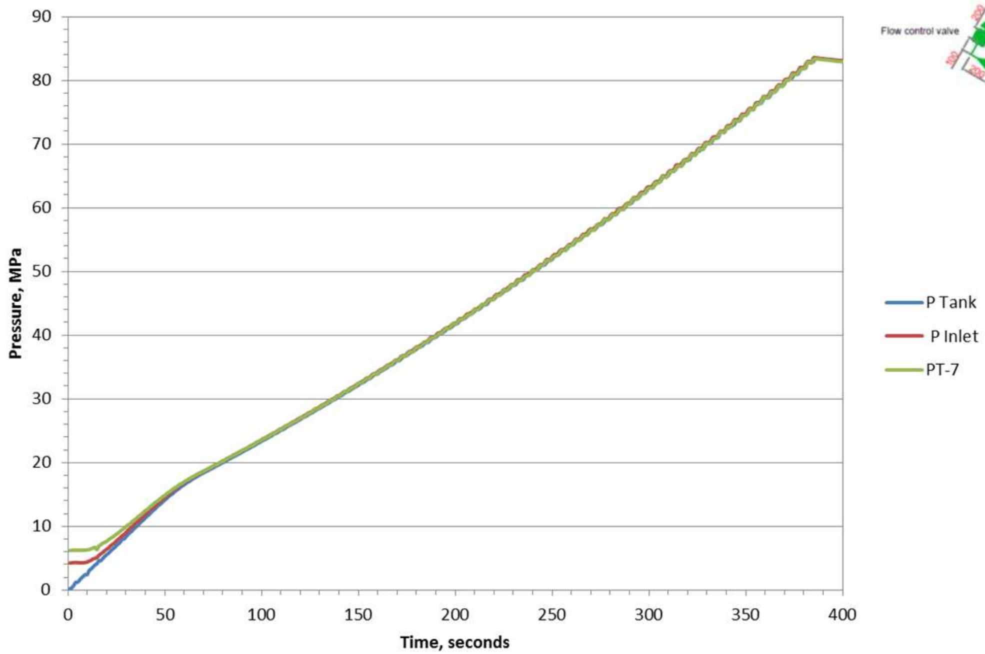
H_2 Path


P tank
PT-7
P Inlet
Tank 1
Tank 2
Sleeve
Flow Meter
PT7
Line OD 9.5 mm
ID 6 mm
Flow control valve
AV4
PT10
Outlet Compressor
Line OD 20 mm
ID 12 mm
396
2000
420
130
200
2430
1030
900
170
200
200
100
100
200
480
300
100
200
200
1630
260
760
2600
610
135
800
300
1200
2500
600
300
600
400
1251
600

H_2 Path

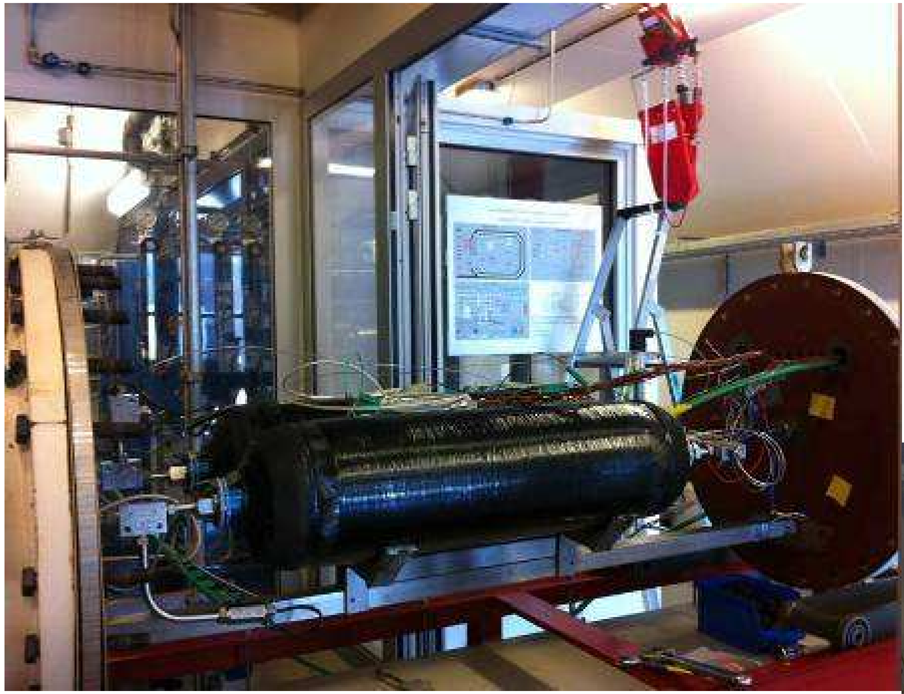
Hydrogen pre-cooler based on liquid nitrogen immersion



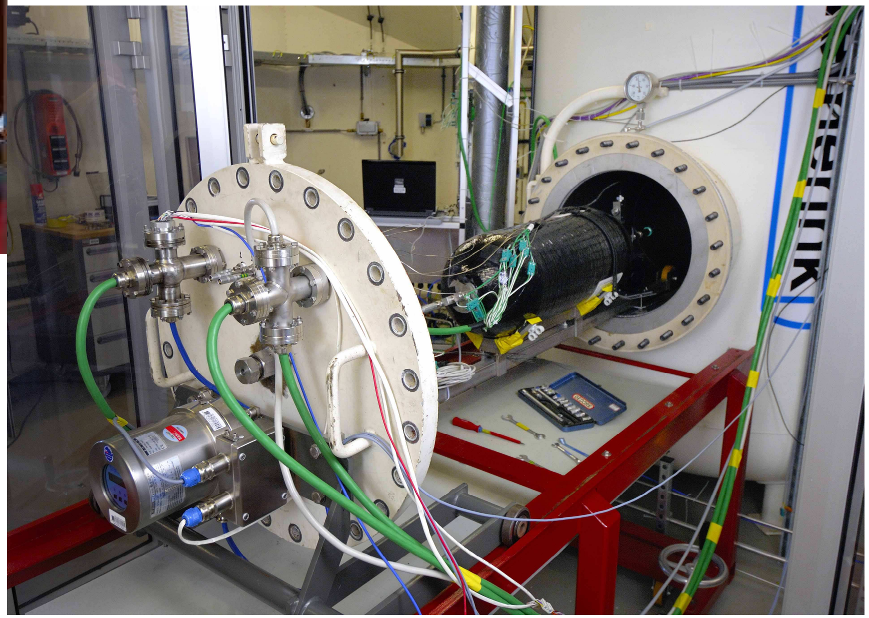


Experimental Instrumentation

European Commission

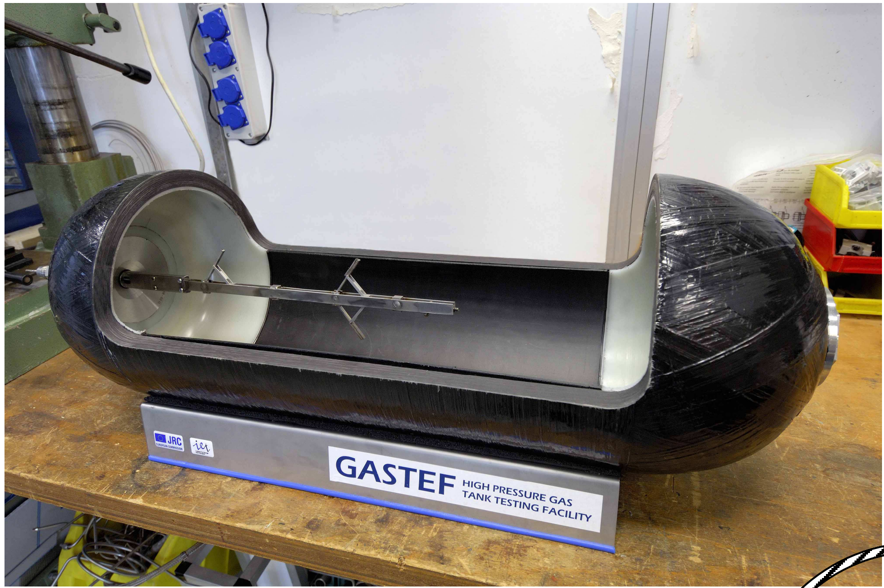


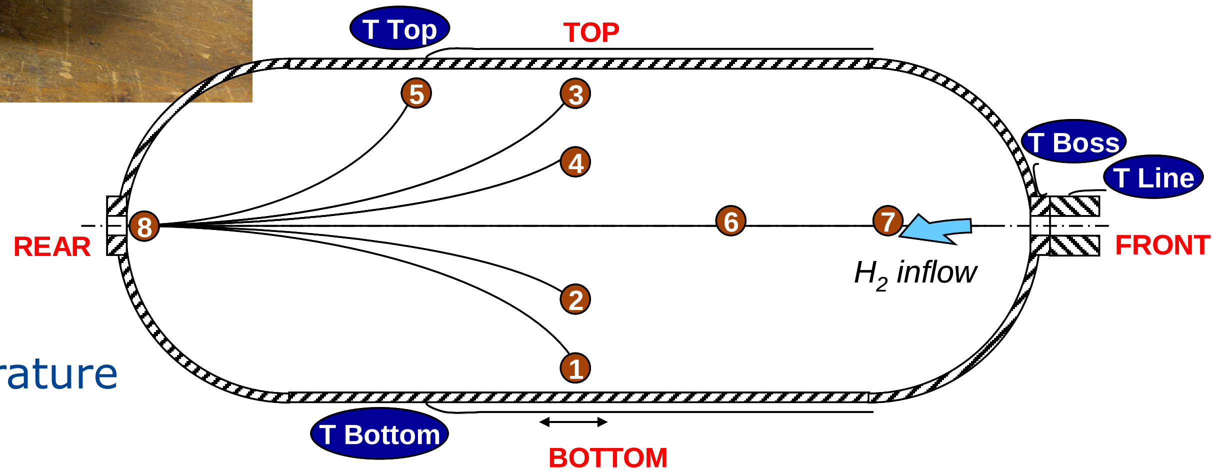
Tank internal and external instrumentation before start of the cycling



Temperature measurement

Example of a type 4 tank with internal thermocouples array system





Internal: 1 mm type K thermocouple

External: Resistance Temperature Detector

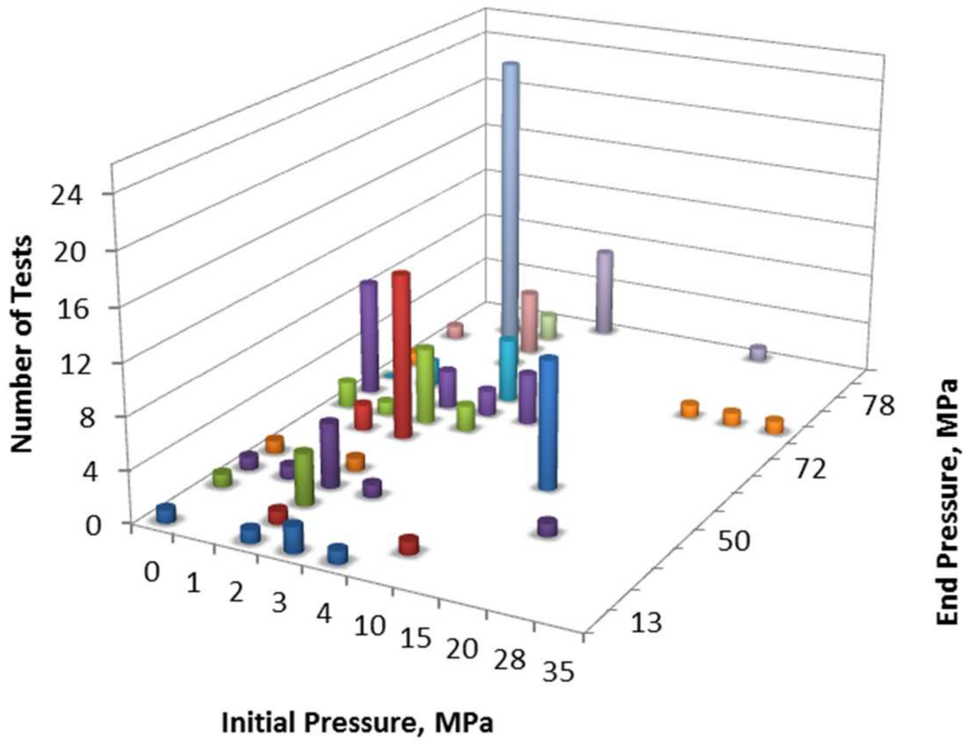
Tested Tanks

	Type 4 19 l	Type 4 29 l	Type 3 40 l
Materials Liner	HDPE	HDPE	AA
End Bosses	AA	SS	AA
Composite shell	CFRE	G&CFRE	CFRE
Vessel mass (Kg)	18.3	32.9	41.5
Storage volume (L) (at 700 bar)	19	28.9	40
H2 capacity (Kg) (with fill density of 40.22 Kg/m3)	0.76	1.16	1.60
Unpressurized dimensions (mm)			
External length	904	827	920
External diameter Internal diameter	228 180	279 230	329 290

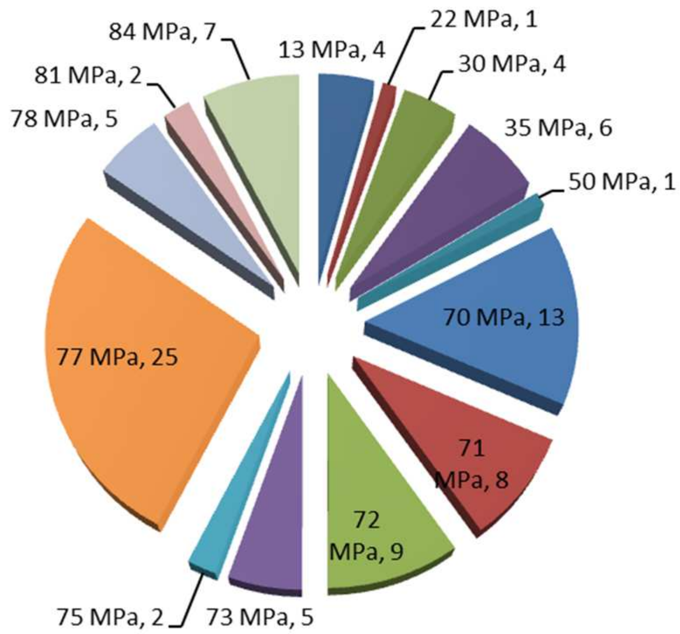
183 entries for filling tests in the database!

Tests on tanks type 4

European Commission



Matrix of Tests on Type 4 29 litres
133 fast filling tests



Filling Tests on Type 4 29l
with initial pressure 2-4 MPa

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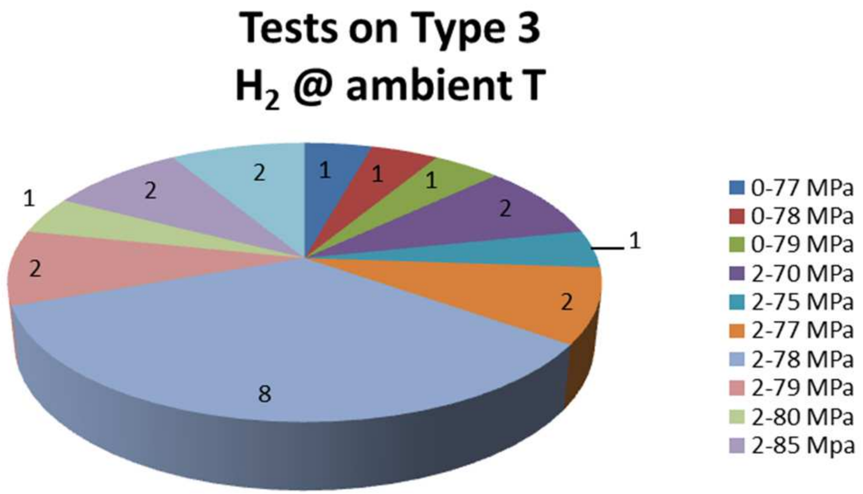
Tests on tanks type 3



23 Filling tests on Type 3, 40 l

FILLING CONDITION	APRR (MPa/min)	TANK INNER TEMPERATURE "ad initio" (°C)
0-77 MPa	9.2	22.9
0-78 MPa	16.5	19.9
0-79 MPa	33.8	17
2-70 MPa	7.8	1.6
2-75 MPa	4.3	1.8 & 4.5
2-77 MPa	8.9 & 10	22.9 & 47
2-78 MPa	5.5 – 18.6	-0.6 – 18.3
2-79 MPa	24.9 & 30.2	20
2-80 MPa	30.7	4.5
2-85 MPa	15.1 & 16.2	-1.2 & -0.2
3-70 MPa	6.5 & 8	3.6 & 1

Database assessment

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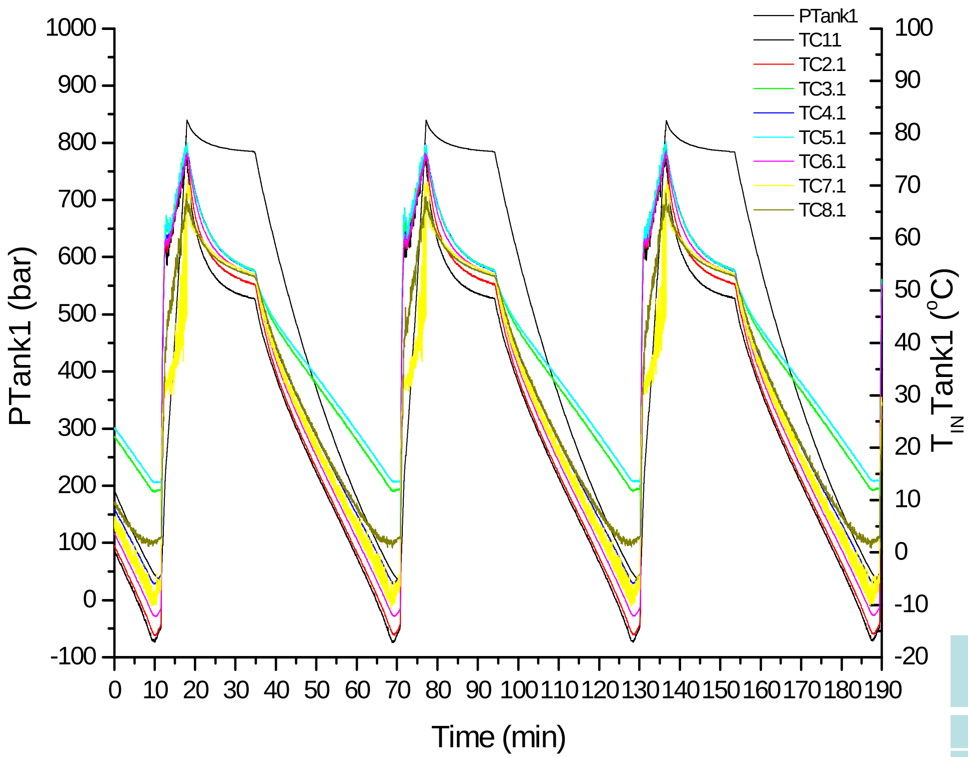


Filling-Holding-Emptying cycles Reproducibility

Results Repeatability

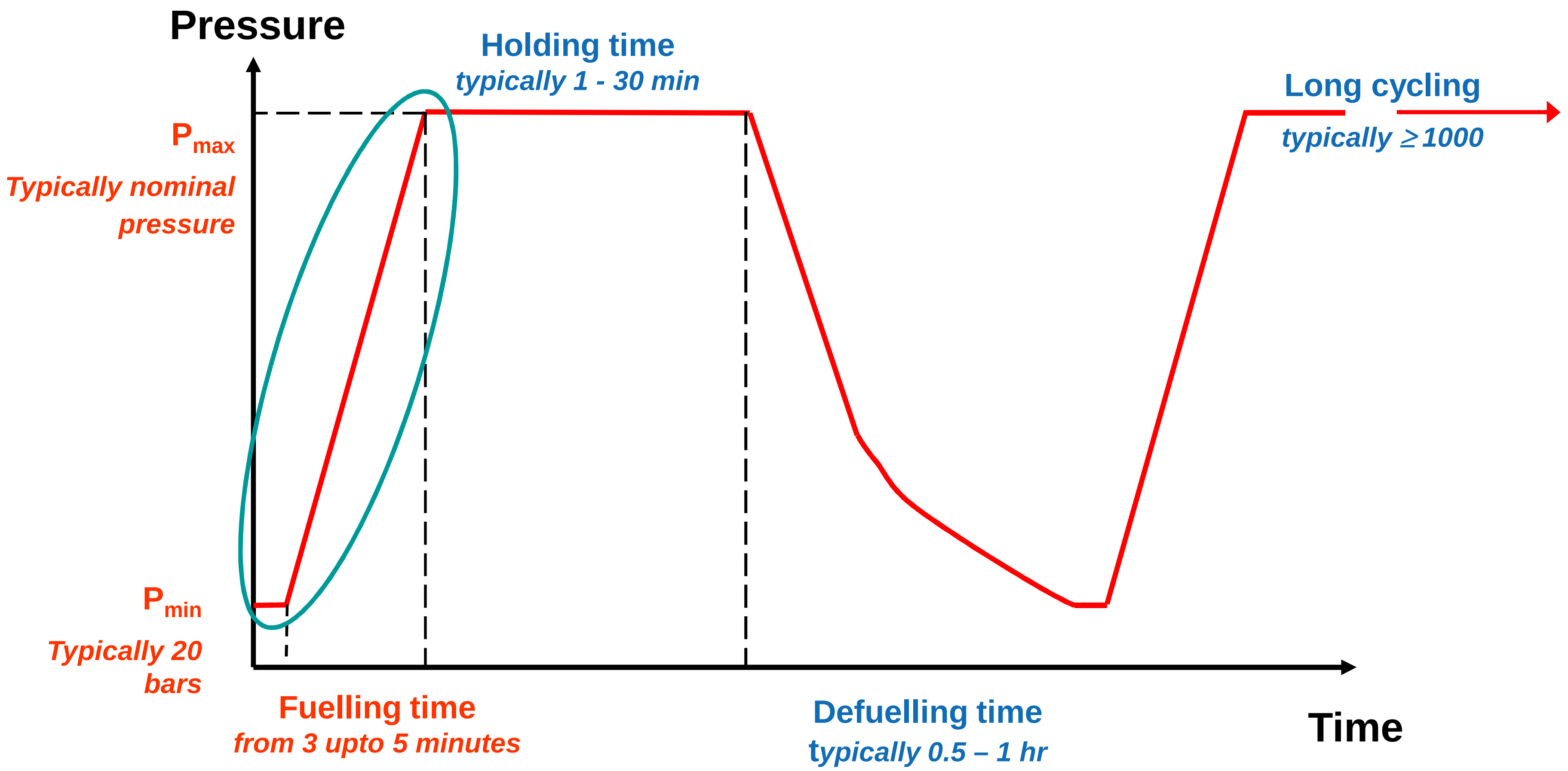
12 Filling Tests on Type 4 29l
2-76.9 MPa at 17.8 MPa/min

	MEAN	STANDARD DEVIATION
Filling Time, (s)	253	1.4
Initial P, (MPa)	1.99	0.36
Final P, MPa	76.89	0.91
Tank averaged Initial T, (°C)	11.2	3.7
Tank averaged Final T, (°C)	86.9	2.9
Increase in temperature, (°C)	75.6	0.9

Fast Filling Test

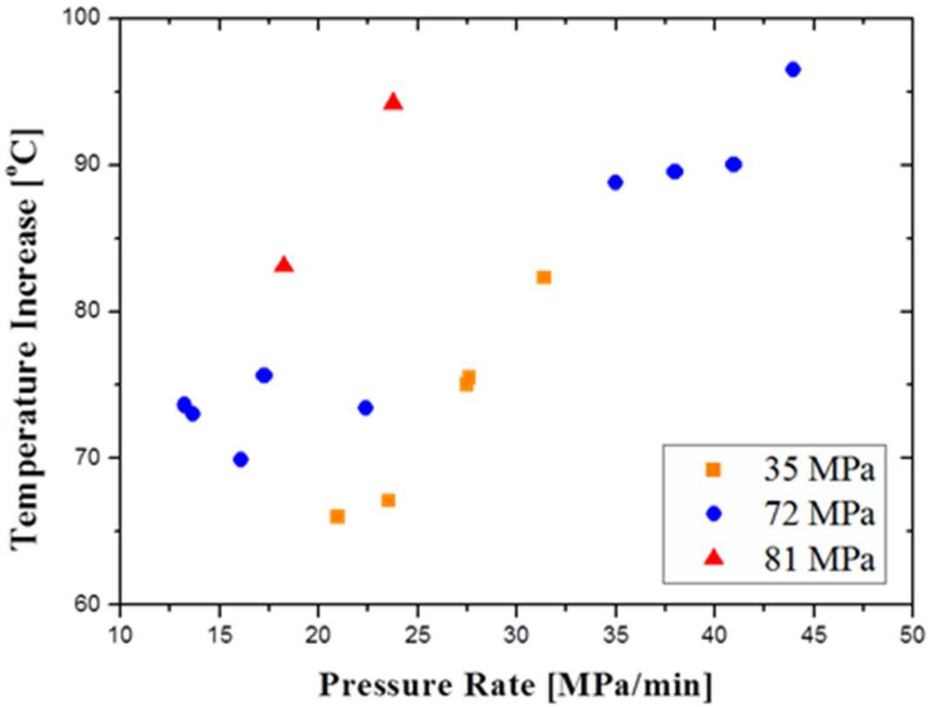
European Commission

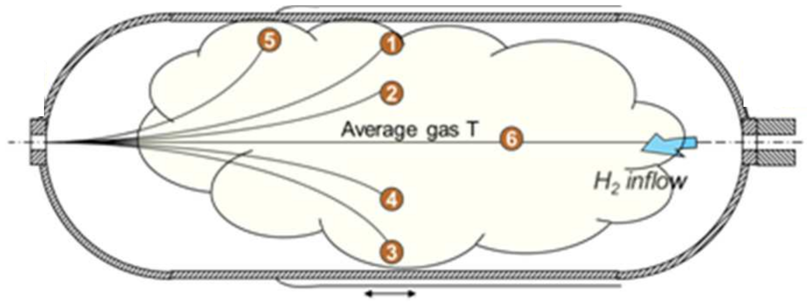
Typical RCS pneumatic (hydrogen) test parameters

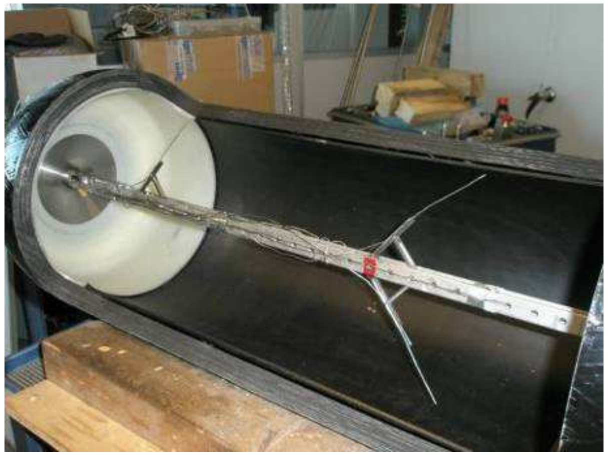


Example of results

APRR effect on internal gas temperature increase is compounded by different other boundary conditions







APRR = average pressure ramp rate

Hydrogen at ambient temperature

Type IV tank 28.9 l

Measuring tank temperature

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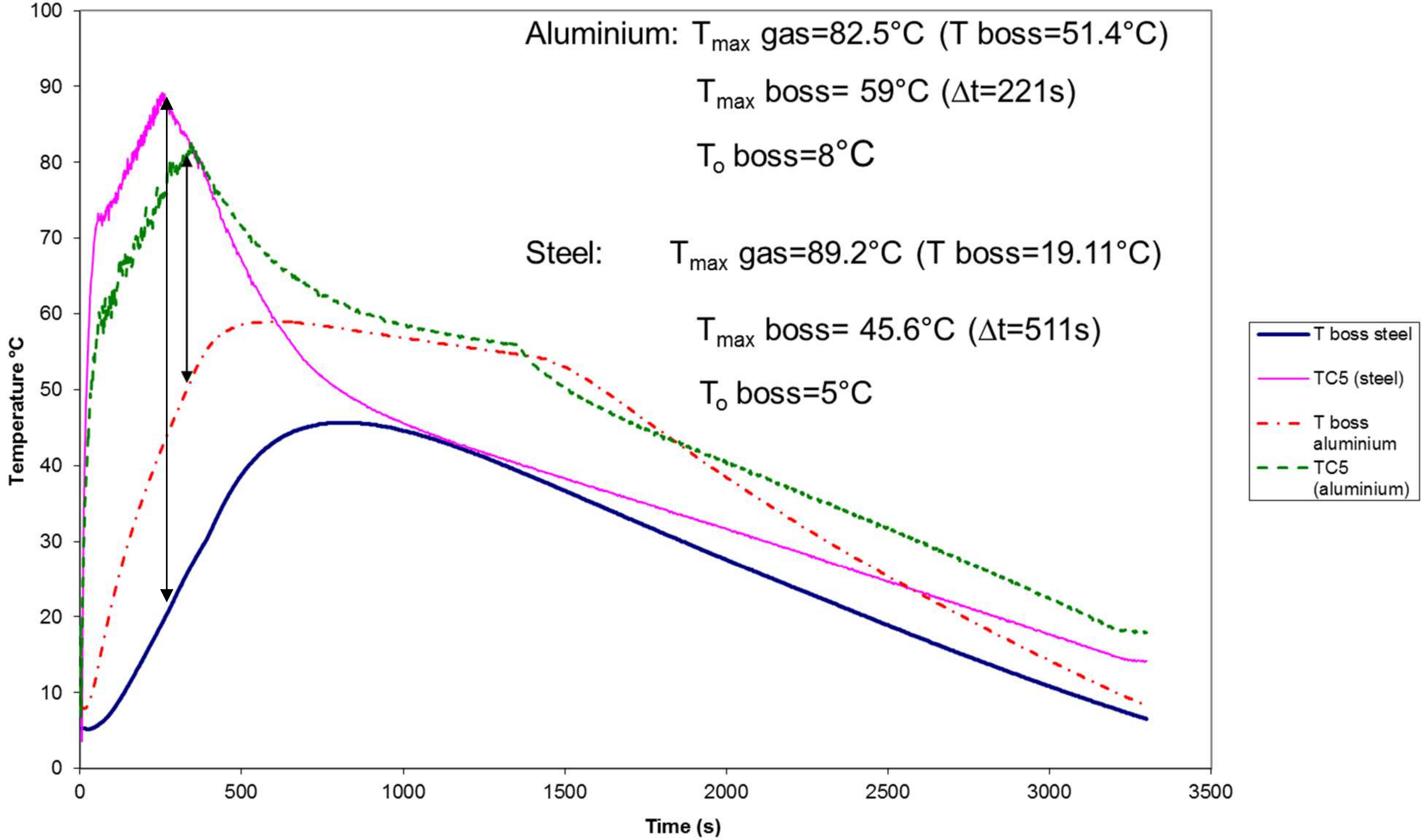
Measurement on tank metallic boss depends on boss material



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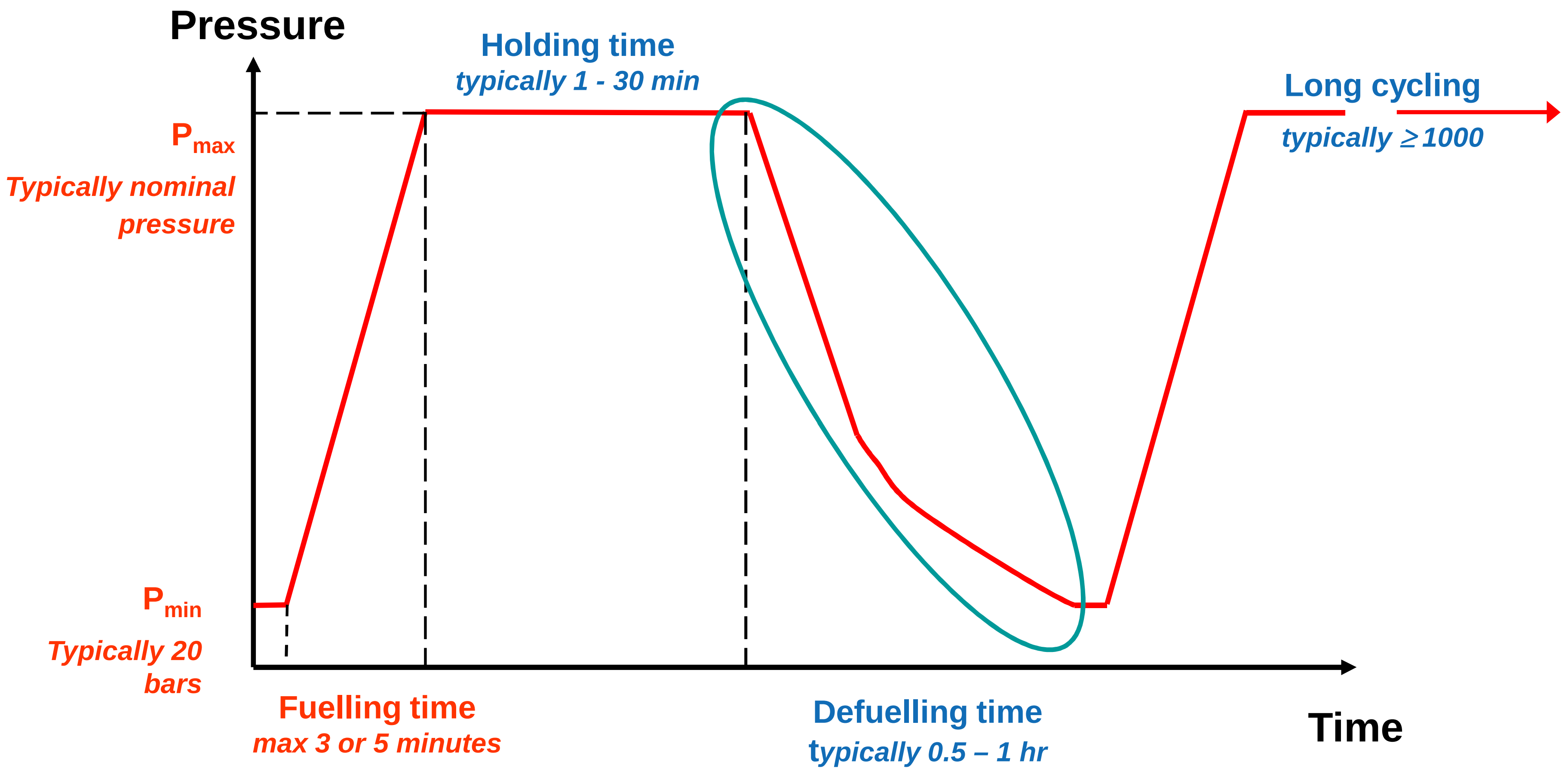
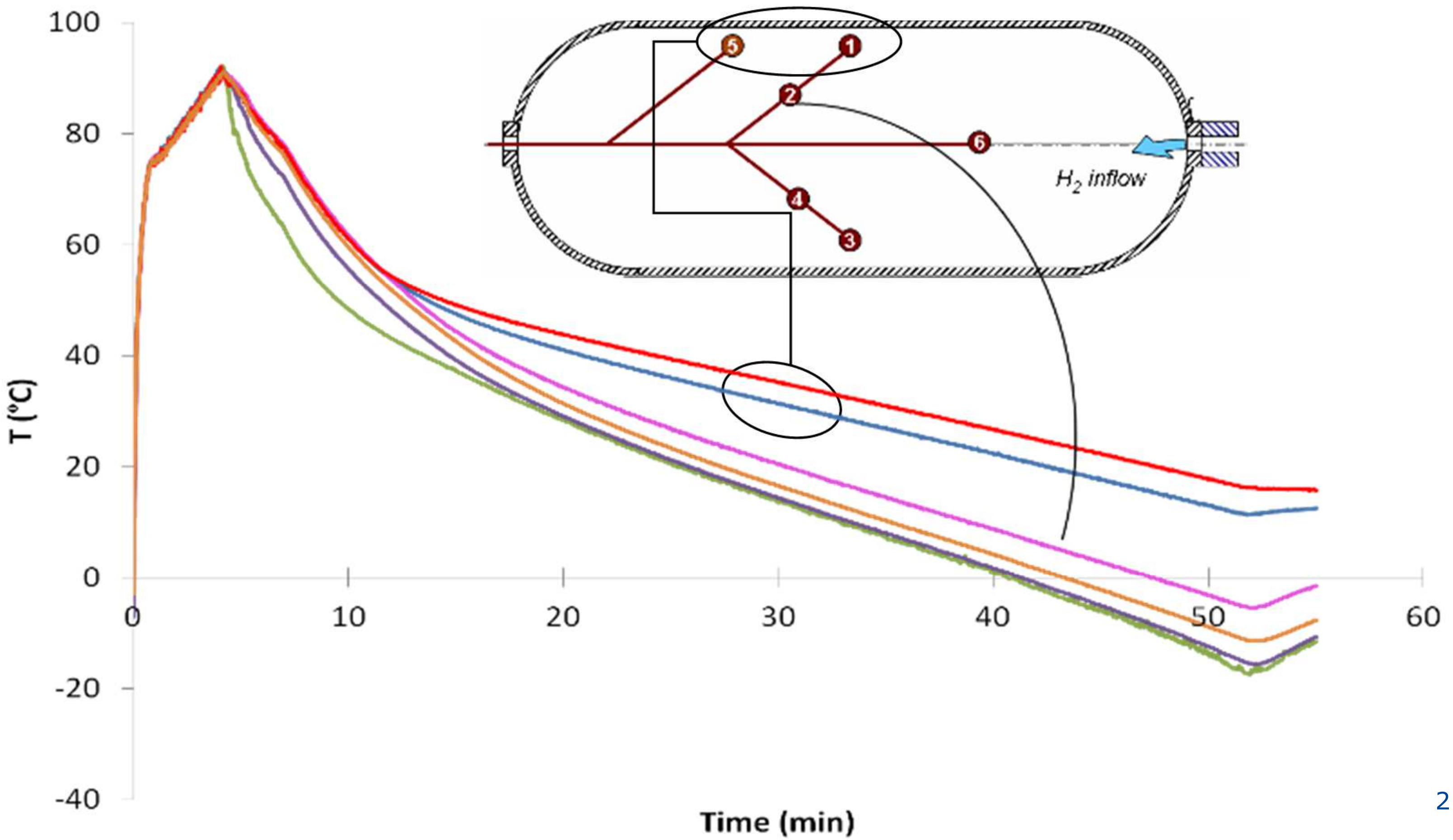
Defuelling

Typical RCS pneumatic (hydrogen) test parameters



Tank de-fuelling

"stratification" at the end of the emptying phase
Different tank conditions at the time of start of re-fuelling



Tests with pre-cooling

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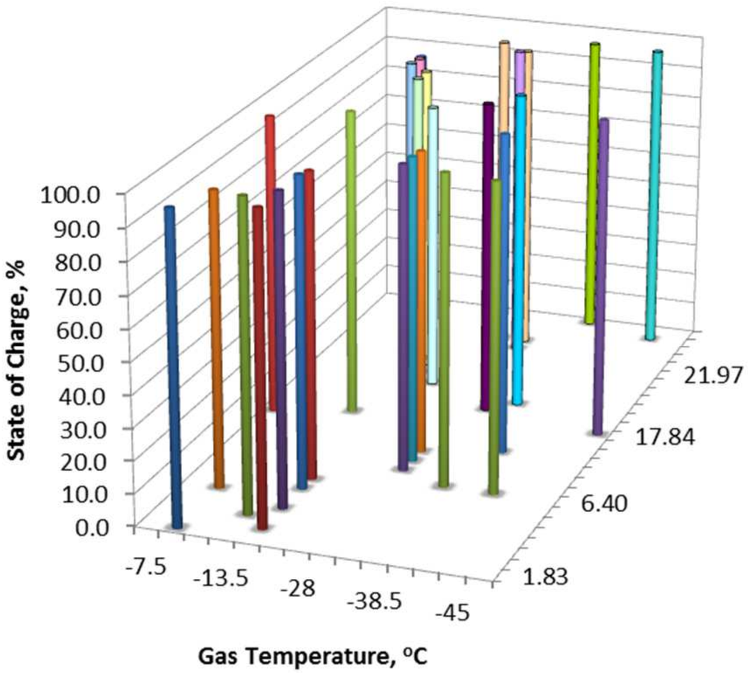
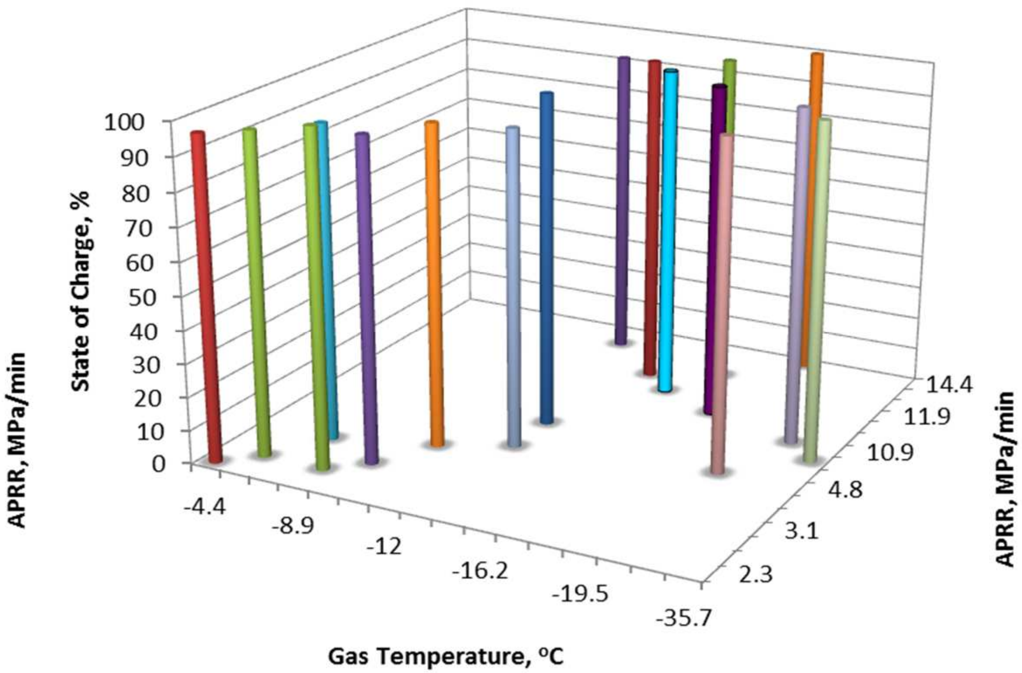
- From material and safety considerations point of view, the maximal temperature in the tank cannot exceed **85°C**, so that pre-cooling of hydrogen is required in many refuelling cases.



Type 4: 33 Fast Filling with H2 pre-cooled at temperatures -45, -30, -15 and -10 °C



Type 3: 26 Fast Filling with H2 pre-cooled at temperatures -35.7, -20, -16, -12, -9 and -4.5 °C

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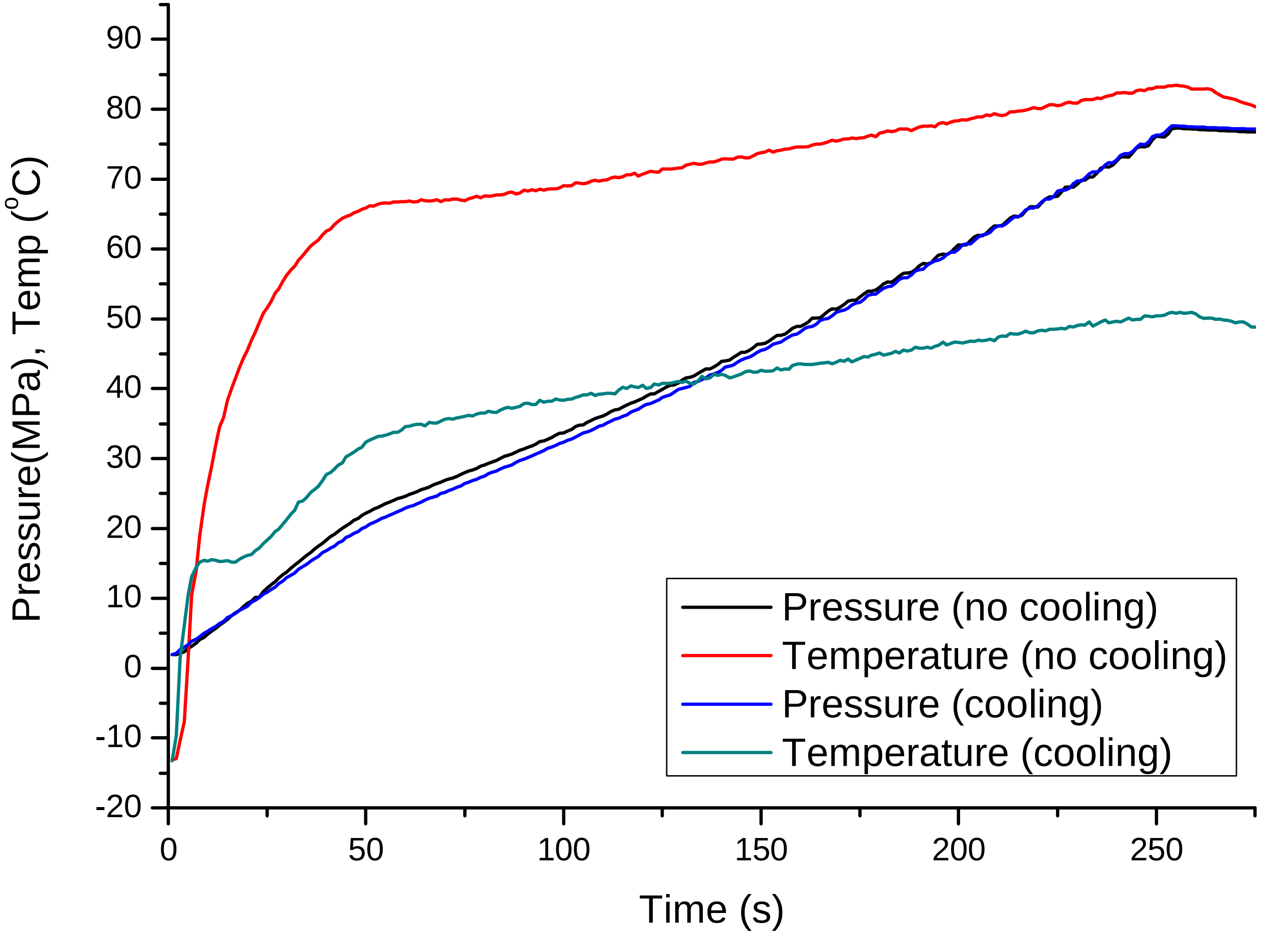
Filling with cold H_2

Filling Tests on Type 4 29l
2-78 MPa APPR 18 MPa/min

T inlet (no cooling) = 20 °C
T inlet (cooling) = -30 °C



Cycles with pre-cooling

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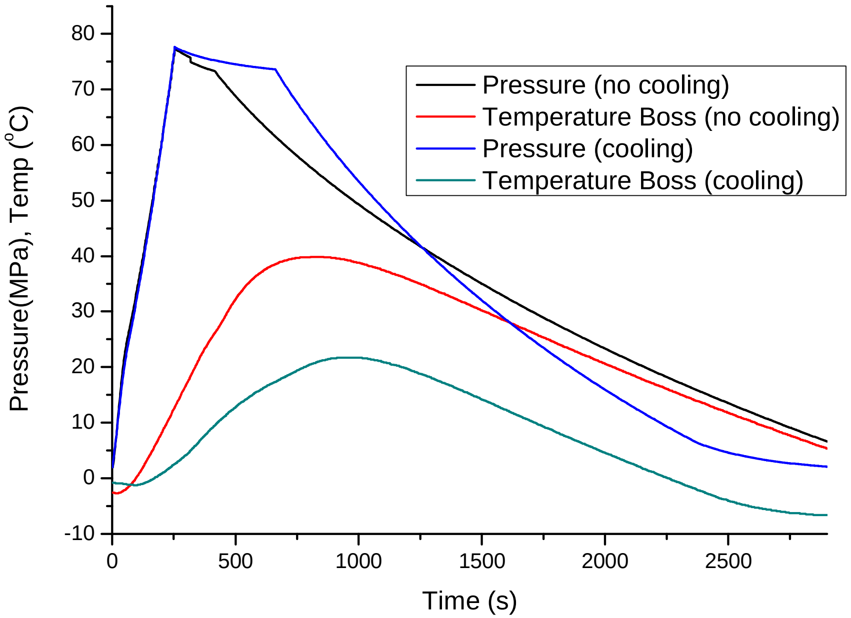

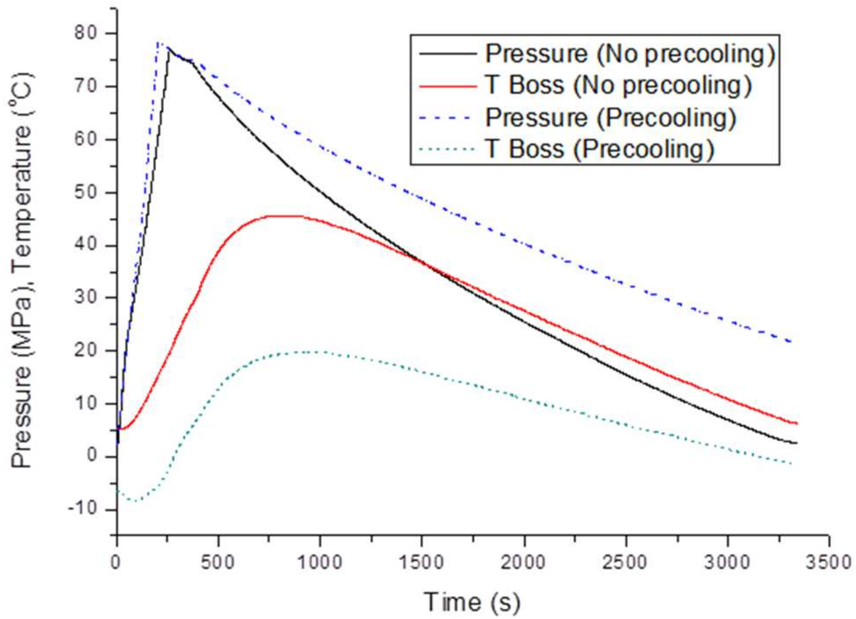

Temperature measured at the front boss

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Conclusions

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- GasTeF is designed to carry out H_2 cycle test and permeation according to EU regulation 406/2010 and to standards ISO and SAE.
- Results are used to validate and improve safety and performance requirements for H_2 tanks for transport applications. Results to be considered into RCS framework.
- 183 entries for tests conducted on type 3 and 4 commercial tanks. The database contains results of temperature measurement for filling and emptying conditions representative of operation of H_2 tanks.
- GasTeF data available as reference for safety studies and CFD validation.
- JRC is willing to contribute with it experimental data to inter-lab comparisons among other organisations involved in the same type of tests.

References

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4. Galassi M.C. et al., CFD analysis of fast filling scenarios for 70 MPa hydrogen type IV tanks, International Journal of Hydrogen Energy, 37 (2012), 6886–6892.
5. Galassi M.C., et al., Assessment of CFD models for hydrogen fast filling simulations, International Journal of Hydrogen Energy, (2013), in press available on-line.
6. De Miguel N., et al., Experimental study of the thermal behaviour of hydrogen tanks during hydrogen cycling, submitted to 5th International Conference on Hydrogen Safety, 9-11 September 2013, Brussels.
7. Acosta B. et al., JRC Reference data from experiments of on-board hydrogen tank fast filling, submitted to 5th International Conference on Hydrogen Safety, 9-11 September 2013, Brussels.
8. Melideo D. et al., Assessment of a CFD model for the simulation of fast filling of hydrogen tanks with pre-cooling, submitted to 5th International Conference on Hydrogen Safety, 9-11 September 2013, Brussels.

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THANK YOU FOR YOUR ATTENTION!

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