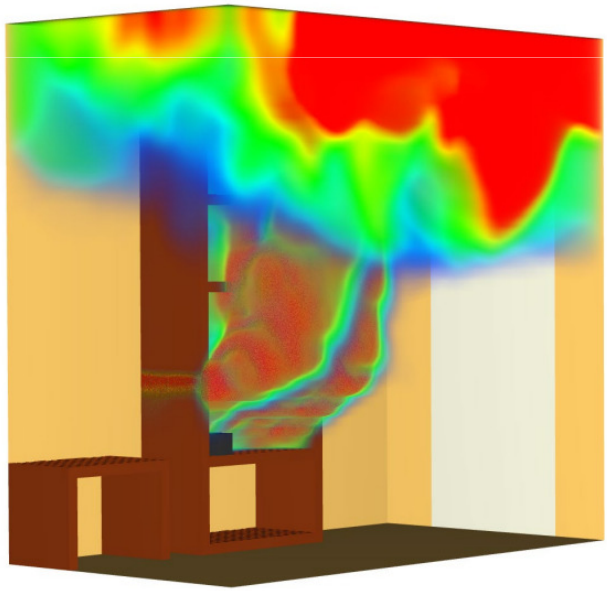
QUALIFICATION OF HYDROGEN TANKS FOR VEHICLES

Regulations and legislations



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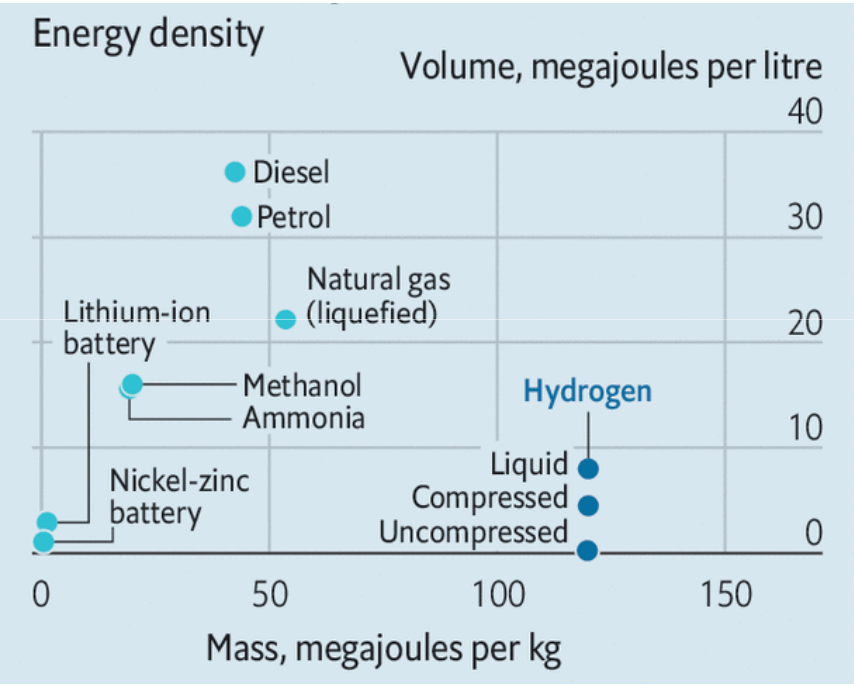
Summary

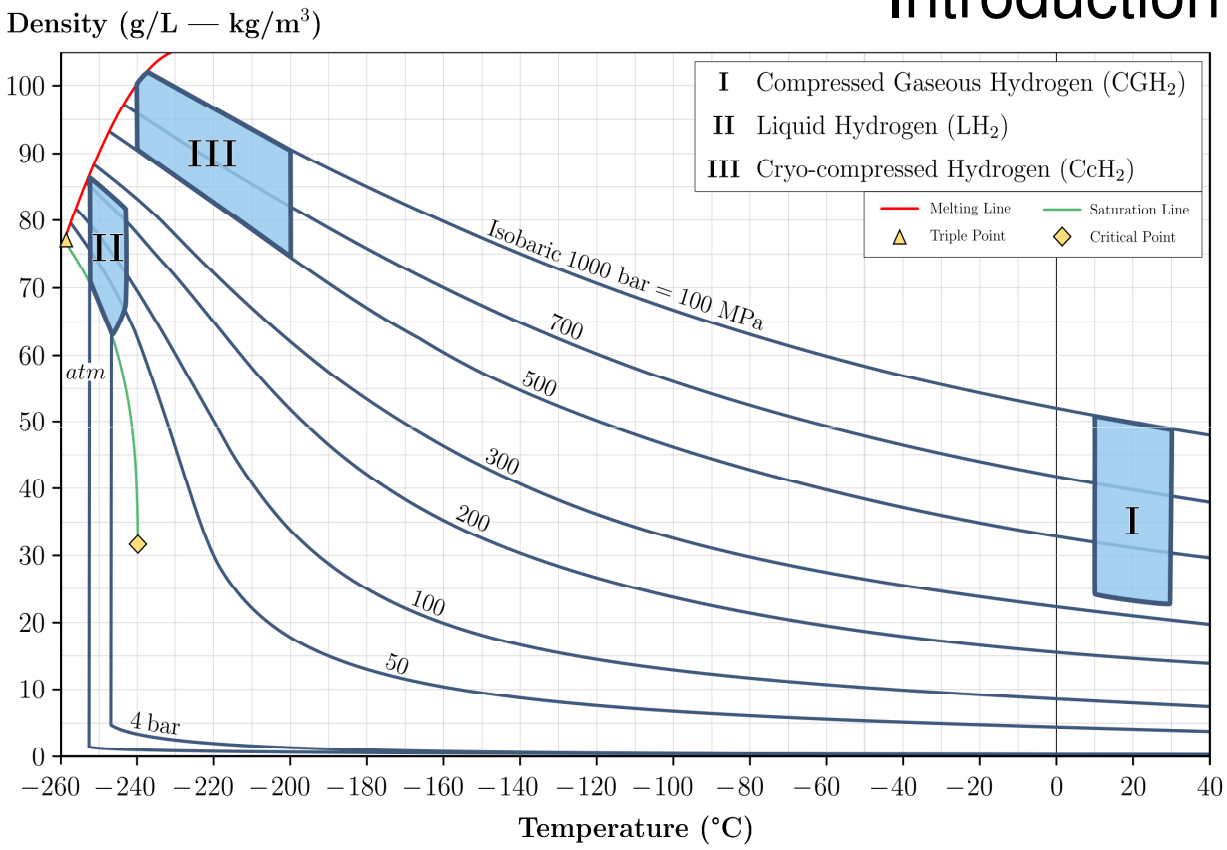
- Introduction
- Types of tanks
- Manufacturing
- Regulations and legislations
- Nomenclature
- R134 workflow
- Lessons learned
- Tank test facility in Borås?

Introduction



- Hydrogen storage are more than three times as efficient as fossil based alternatives considering the amount of energy per mass but…
- …considering the energy per volume the efficiency is less than 1/6
- Hydrogen have similar energy density as batteries considering energy per volume
- However the volumetric density is more than 10x higher for hydrogen than batteries
- Hydrogen therefore has an advantage for applications sensitive for weight but still allowing larger volumetric storage

Introduction



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- Gas
- Liquid
- Cryo compressed gas

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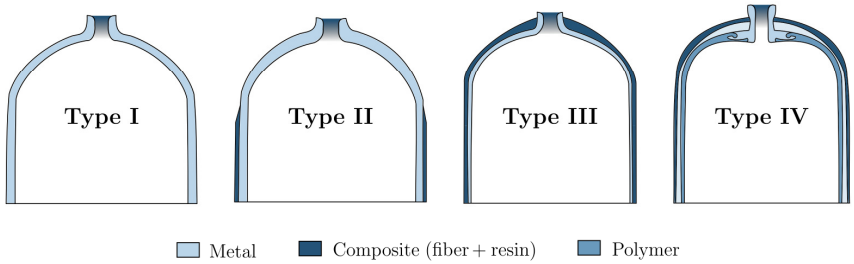
Types of tanks I-V



- Metal (alu/steel)
- Fiber reinforced metal cylinder
- Composite tanks with metal liner
- Composite tanks with polymer liner
- All composite linerless

https://encyclopedia.pub/entry/23402

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Manufacturing

- https://www.youtube.com/watch?v=KkLEEJYTSuA&ab_channel=RothCompositeMachineryGmbH

Regulations and legislations

- Safe on-road performance
- Safe service life
- Compability

Regulations and legislations

- R134, Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of Hydrogen Fuel Cell Vehicles (HFCV)
- GTR 13, Global technical regulation on hydrogen and fuel cell vehicles (review is expected)
- CMVSS, Canadian Motor Vehicle Safety Standard
- AIS 157, Automotive Industry Standard (India)

Note that GTR 13 is not yet adopted in US and Canada.

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Regulations and legislations

Hydrogen tank test cross reference list

R 134	R 134 Heavy Duty	EC 79, Annex IV & EU 406, Annex IV, Part 2	GTR 13	GTR 13.2 TBD	ISO19881 Category A & C	ISO19881 Category B	SAE J2579:2018	CSA/ANSI HGV 2:21 Category A	CSA/ANSI HGV 2:21 Category B	OEM spec	Dominating	Comments
5.1.1. Baseline initial burst pressure		4.2.1 Burst test	5.1.1.1. Baseline initial burst pressure		17.3.5 Hydrostatic burst test	17.5.3 Hydrostatic burst test (per 17.3.5)	5.2.2.1.2 New Vessel Burst Pressure	18.3.5 Burst test	18.5.3 Burst test (per Clause 18.3.5)		R134, NWP*225% + distribution of burst levels. Speed from CSA	
5.1.2. Baseline initial pressure cycle life	22k -> 30k cycles	4.2.2 Ambient temperature cycle test	5.1.1.2. Baseline initial pressure cycle life		17.3.2 Ambient cycling test	17.5.2 Ambient cycling test (per 17.3.2)	5.2.2.1.3 New Vessel Cycle Life	18.3.2 Ambient cycling test	18.5.2 Ambient cycling test (per Clause 18.3.2)		R134, 22k cycl@125%. **R406, 45k cycl@125%, ISO**	2pcs for type approval EU406
		4.2.3 Leak-Before-Break (LBB) performance test			17.3.14 Leak before break tests			18.3.14 Leak before break test			R406, 15k cycl@150%. ISO 2250*years, CSA 45k cycles 3pcs	Can be excluded if R406, 4,2,2 is ok.
5.2.1. Proof pressure test			5.1.2.1. Proof pressure test			17.5.4.2 Proof pressure test	5.2.3.1a Routine proof pressure tests		18.5.4.2 Proof pressure test		NWP*150% for 30 sec.	
5.2.2. Drop (impact) test			5.1.2.2. Drop (impact) test			17.5.4.3 Drop test	5.2.2.3.1 Drop (Impact) Test		18.5.4.3 Drop test			Recommended. Allthough In R406, Not applicable to type 1 tanks (metal)
5.2.3. Surface damage			5.1.2.3. Surface damage			17.5.4.4 Surface damage test	5.2.2.3.2 Surface Damage Test		18.5.4.4 Surface damage test			Recommended. Allthough In R406, Not applicable to type 1 tanks (metal)
5.2.4. Chemical exposure and ambient temperature pressure cycling tests			5.1.2.4. Chemical exposure and ambient temperature pressure cycling tests			17.5.4.5 Chemical exposure and ambient pressure cycling	5.2.2.3.3 Chemical Exposure Test/ 5.2.2.3.4 Extreme Usage Fueling - Ambient Temperature Pressure Cycling Test/ 5.2.2.3.5 Extreme Pressure Fueling - Ambient Temperature Over-Pressure Cycling Test		18.5.4.5 Chemical exposure and ambient pressure cycling			In R406, Not applicable to type 1 tanks (metal), should be handeled on material level. In CS
5.2.5. High temperature static pressure test			5.1.2.5. High temperature static pressure test			17.5.4.6 High temperature static pressure test	5.2.2.3.6 Extreme Parking Durability - High Temperature Static Pressure Test		18.5.4.6 High temperature static pressure test		R406, 191% of NWP after 1000h at 85 deg/ SAE 1.35*NWP for trucks	In R406, Not applicable to type 1 tanks (metal), should be handeled on material level
5.2.6. Extreme temperature pressure cycling			5.1.2.6. Extreme temperature pressure cycling			17.5.4.7 Extreme temperature pressure cycling test	5.2.2.3.7 Extreme Temperature Fueling - Extreme Temperature/Pressure Cycling Test		18.5.4.7 Extreme temperature pressure cycling test		see 135%	In R406, Not applicable to type 1 tanks (metal), should be handeled on material level
5.2.7. Residual proof pressure test			5.1.2.7. Residual proof pressure test			17.5.4.8 Hydraulic residual pressure test	5.2.2.3.8 Proof Pressure Test (Hydraulic)		18.5.4.8 Hydraulic residual pressure test			
5.2.8. Residual strength burst test			5.1.2.8. Residual strength Burst Test			17.5.4.9 Residual burst test	5.2.2.3.9 Residual Strength Burst Test (Hydraulic)		18.5.4.9 Residual burst test			
		4.2.15 Hydraulic test									NWP*150% for 30 sec.	
		4.2.10 Impact damage test (includes cycling)			17.3.7 Drop test			18.3.7 Drop test				
		4.2.7 Composite flaw tolerance test			17.3.6 Flaw tolerance test			18.3.6 Flaw tolerance test				Recommended. Allthough In R406, Not applicable to type 1 tanks (metal)
		4.2.6 Chemical exposure test			17.3.3.2.3 Environmental fluids for exposure			18.3.3 Environmental test				Recommended. Allthough In R406, Not applicable to type 1 tanks (metal)
		4.2.8 Accelerated stress rupture test			17.3.9 Accelerated stress rupture test			18.3.9 Accelerated stress rupture test			R406, 191% of NWP after 1000h at 85 deg/ SAE 1.35*NWP for trucks	In R406, Not applicable to type 1 tanks (metal), should be handeled on material level
		4.2.9 Extreme temperature pressure cycle test			17.3.4 Extreme temperature cycling test			18.3.4 Extreme temperature cycling test			see 135%	In R406, Not applicable to type 1 tanks (metal), should be handeled on material level
5.3.1. Proof pressure test		4.2.15 Hydraulic test	5.1.3.1. Proof pressure test				5.2.3.1 Routine production test				NWP*150% for 30 sec.	
5.3.2. Ambient and extreme temperature gas pressure cycling test (pneumatic)			5.1.3.2. Ambient and extreme temperature gas pressure cycling test (pneumatic)		17.3.13 Hydrogen gas cycling test		5.2.2.2.1 Fueling/Defueling Performance Verification Test - Extreme and Ambient Temperature Gas Cycling	18.3.13 Hydrogen gas cycling test			R134 more complex **check SAE**	Recommended. Allthough in R406, Not applicable to type 1 tanks (metal), applies to tanks
5.3.3. Extreme temperature static gas pressure leak/permeation test (pneumatic)			5.1.3.3. Extreme temperature static gas pressure leak/permeation test (pneumatic)				5.2.2.2.2 Parking Performance - Static Gas Pressure Permeation & Localized Leak Tests				SAE >30 hrs	
5.3.4. Residual proof pressure test			5.1.3.4. Residual proof pressure test				5.2.2.2.3 Proof Pressure Test (Hydraulic)					
5.3.5. Residual strength burst test (hydraulic)			5.1.3.5. Residual strength burst test (hydraulic)				5.2.2.2.4 Residual Burst Strength Test (Hydraulic)					
5.4. Verification test for service terminating performance in fire		4.2.4 Bonfire test	5.1.4. Verification test for service terminating performance in fire		17.3.8 Fire test	17.3.8 Fire test	5.2.2.4.1 Localized Fire Test	**18.3.8 Bonfire test**	18.3.8 Bonfire test		ANSI	
							5.2.2.4.2 Extended Engulfing Fire Test					
		4.2.5 Penetration test			17.3.10 High strain rate impact test		5.2.2.4.3 High Strain Rate Impact Test	18.3.10 High strain rate impact test	18.5.5 High strain rate impact test (per Clause 18.3.10)			Gunshot at 45 deg
		4.2.11 Leak test										Recommended. Allthough in R406, Not applicable to type 1 tanks (metal), applies to tanks
		4.2.12 Permeation test			17.3.11 Permeation test			18.3.11 Permeation test	18.5.6 Permeation test (per Clause 18.3.11)			Recommended. Allthough In R406, Applicable to type 4 tanks only
		4.2.13 Boss torque test			17.3.12 Boss torque test			18.3.12 Boss torque test				
						17.5.5 Container test for expected on-road performance			18.5.7 Container test for expected on-road			Applies to category B tanks
								18.6 Mechanical tests (CT category only)				
		4.2.14 Hydrogen gas cycling test										
										Vibration test		
To be made sequential, hydraulic												
To be made sequential, pneumatic												

Nomenclature

- NWP – Normal Working Pressure
- TPRD – Thermal Pressure Relief Device
- LEL – Lower Explosion Limit
- UEL – Upper Explosion Limit
- LBB – Leak Before Break

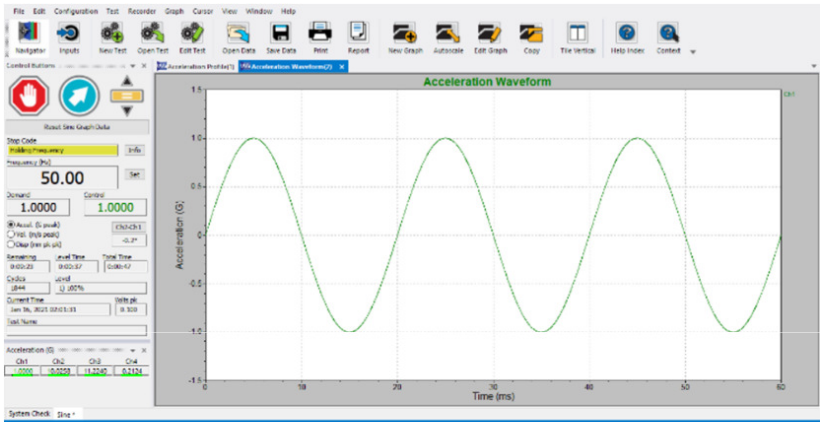
R134 workflow

- Baseline test 1 – Initial burst test

- Purpose
  - Secure integrity
  - Establish margin against defects
  - Evaluate reproducibility
  - Secure container stability before further tests are undertaken
- Qualification - Burst pressure >225% of NWP + no burst outside BP_0 ±10% (carbon fiber tanks)

R134 workflow

- Baseline test 2 – Pressure cycle life test

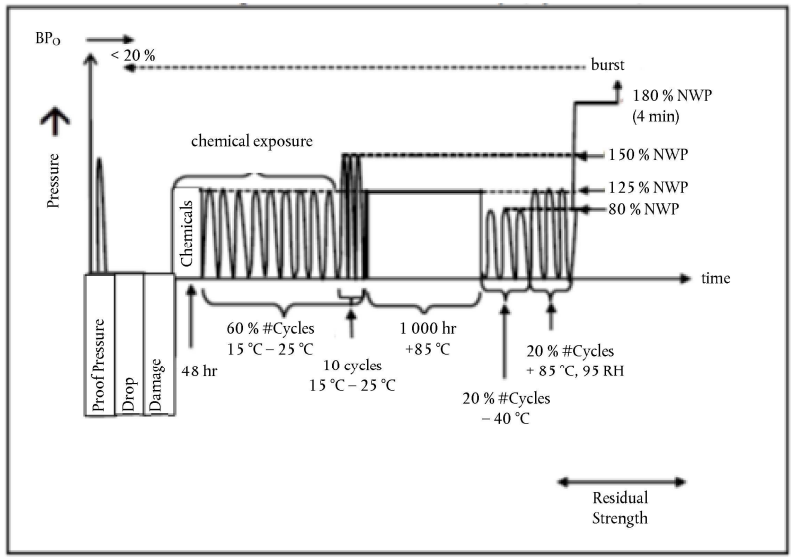


- Purpose – Test 7 million kilometers traveled with 350-500 km per full-fueling
- Qualification – 22 000 full fill cycles to 125% NWP without burst (and no leaks before 11 000 cycles)

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 1, Proof pressure

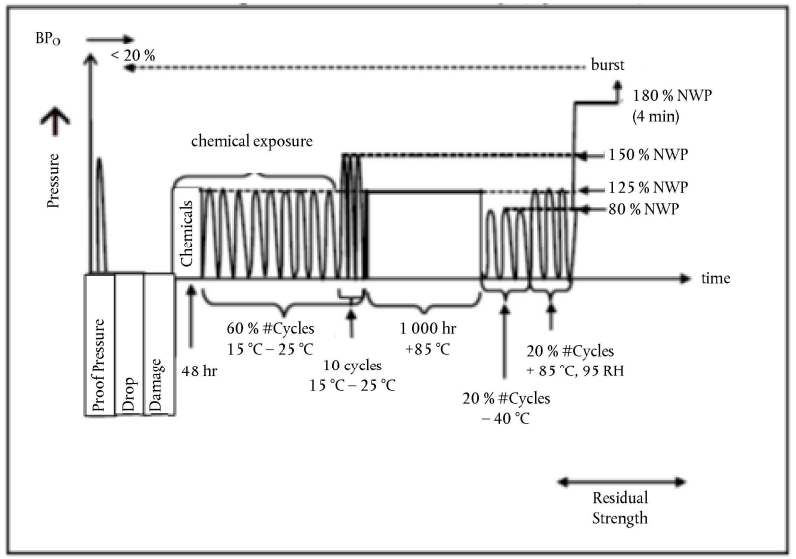


- Purpose – Secure container stability before further tests are undertaken
- Qualification – 150% NWP for >30 seconds, no leak or burst

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 2, Drop test



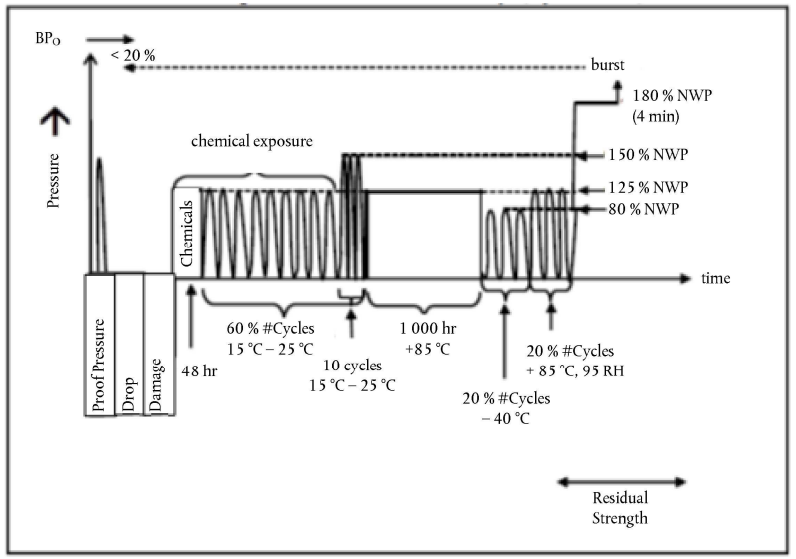
- Purpose – Subject the tank for violence that may occur during manufacturing / aftermarket repairs
- Qualification – Drop from 180 cm (no evaluation of subtest)

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 3, Chemical exposure test

  Battery acid
  Washer fluid
  Fertilizer nitrates
  Methanol
  Gasoline

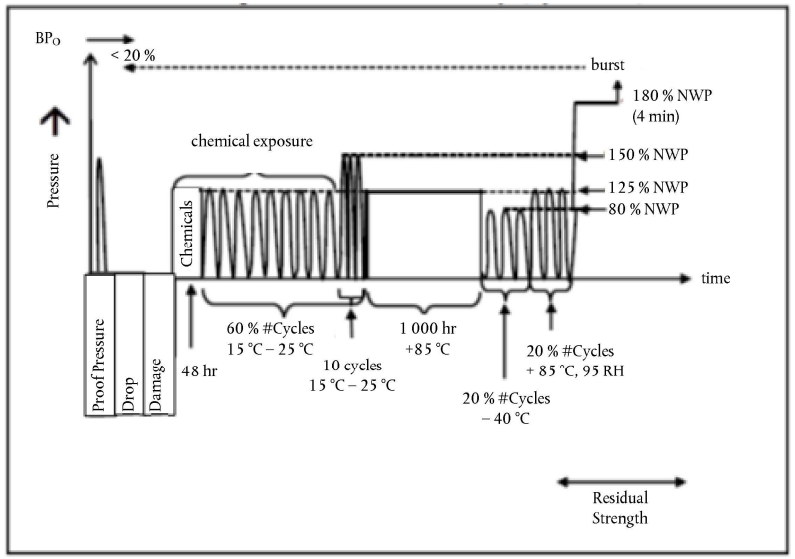


- Purpose – Subject the tank for chemical substances found in on-road environments
- Qualification – 60% of 22 000 full fill cycles to 125% NWP + 10 cycles to 150% NWP without burst

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 4, Hi temp static pressure test

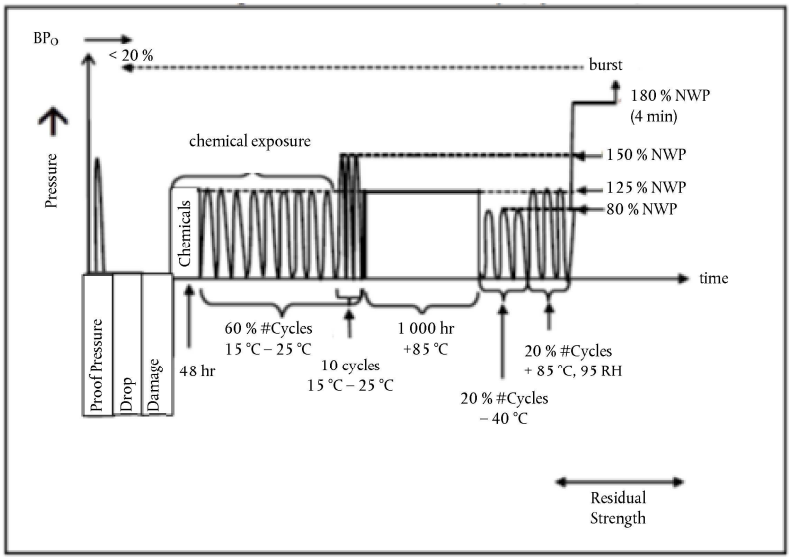


- Purpose – Subject the tank for a performance test corresponding to full-fill parking for 25 years
- Qualification – 125% NWP for >1000 hours without burst

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 5, Extreme temperature pressure cycling test

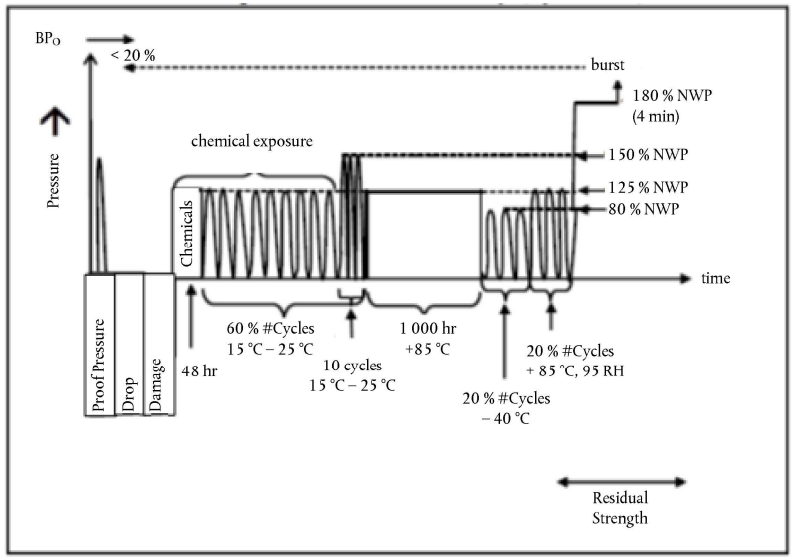


- Purpose – Subject the tank for cold and hot environments combined with moist
- Qualification – 4400 cycles at -40°C at 80% NWP + 4400 cycles at +85°C/95% RH at 125% w/o burst

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 6, Residual pressure test

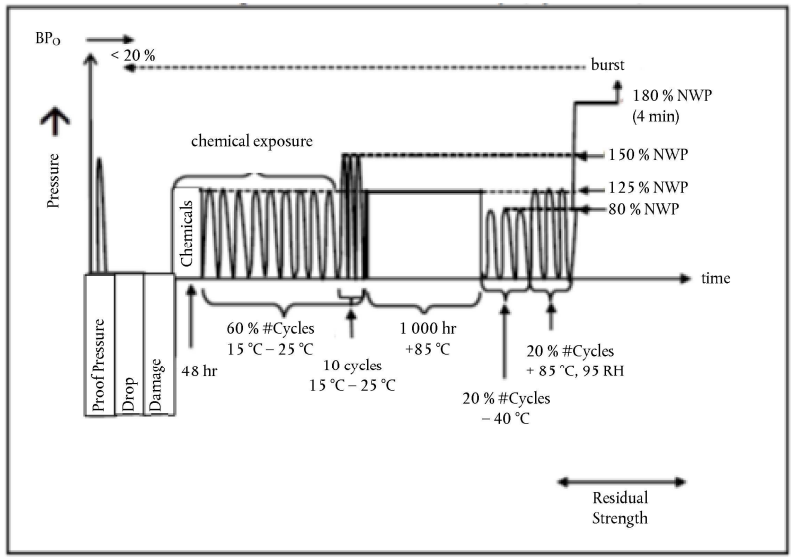


- Purpose – Subject the tank for a overpressure caused by a malfunctioning fueling station
- Qualification – 180% NWP for >4 minutes w/o burst

R134 workflow

- Test 3 – Verification tests (hydraulic)

  -Subtest 7, Residual strength test

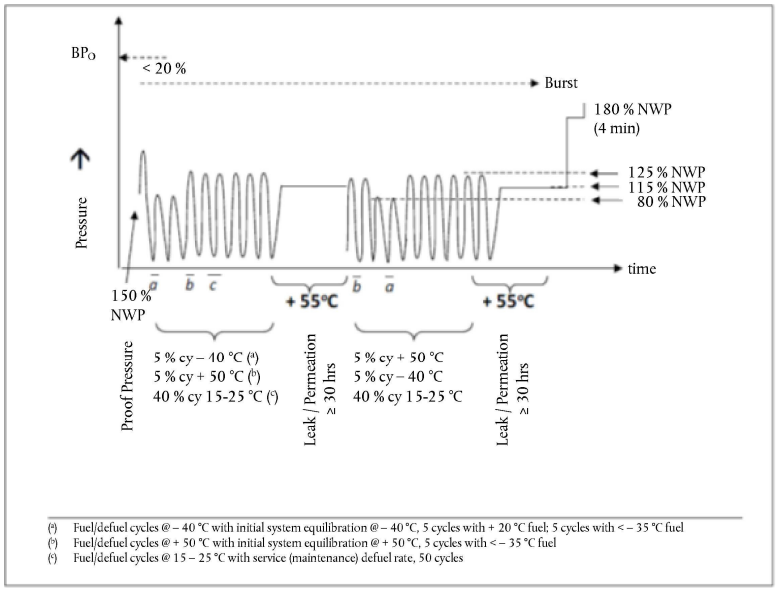


- Purpose – Secure a ±10% manufacturing variability to secure 25 years of ruprure resistance at NWP
- Qualification – Burst >80% BP_0

R134 workflow

- Test 4 – Verification tests (hydraulic/pneumatic)

  -Subtest 1, Proof pressure test



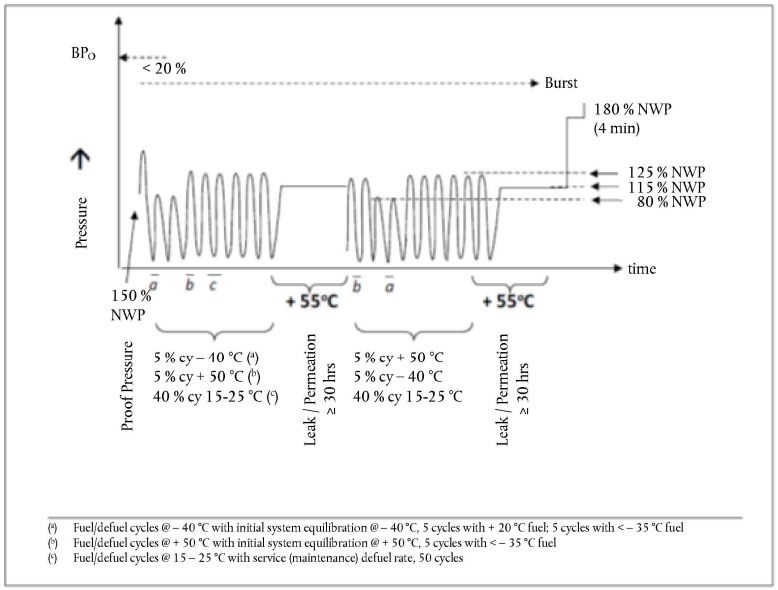
- Purpose – Secure container stability before further tests are undertaken
- Qualification – 150% NWP for >30 seconds, no leak or burst

R134 workflow

- Test 4 – Verification tests (hydraulic/pneumatic)

  -Subtest 2, Ambient and extreme temperature gas pressure cycling test

  250 cycles + 250 cycles from -40° to +50°C
  Measure permeation



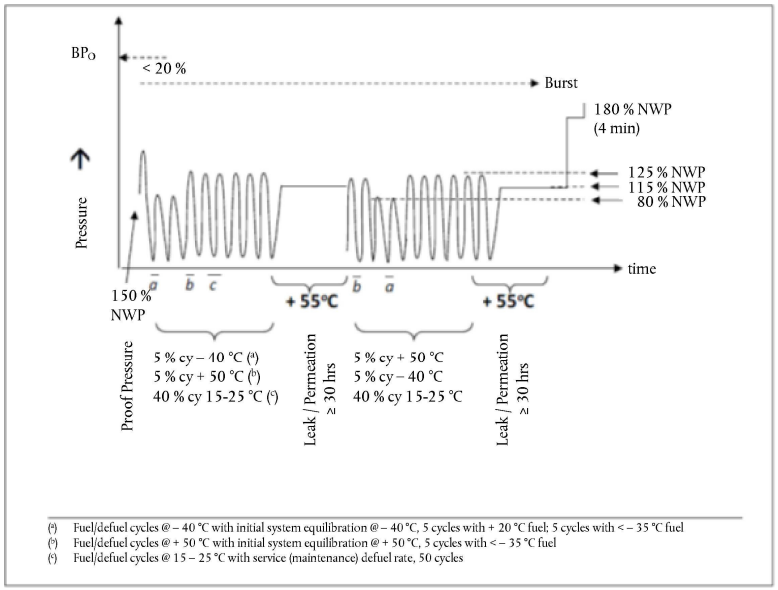
- Purpose – Secure leak free parking such that no fire may be possible (0.028 mg/sec needed to support a flame=
- Qualification – Permeation rate less than 0,005 mg/sec (3,6 Nml/min),

R134 workflow

- Test 4 – Verification tests (hydraulic/pneumatic)

  -Subtest 2, Ambient and extreme temperature gas pressure cycling test

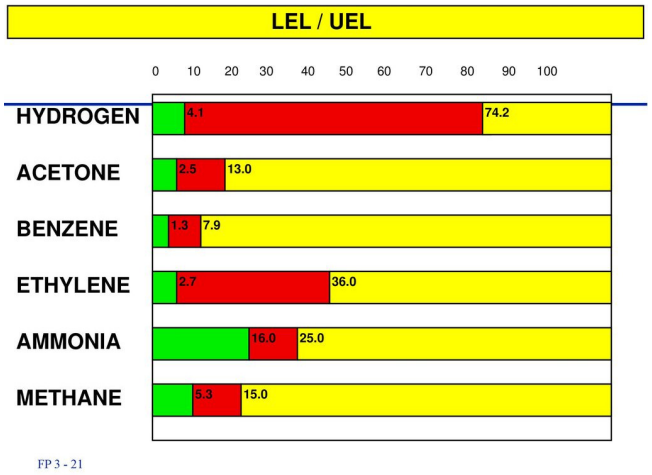
  250 cycles + 250 cycles from -40° to +50°C
  Measure permeation



- Purpose – Secure leak free parking such that no fire may be possible (0.028 mg/sec needed to support a flame)
- Qualification – Permeation rate less than 0,005 mg/sec (3,6 Nml/min),

Fire/explosion risks

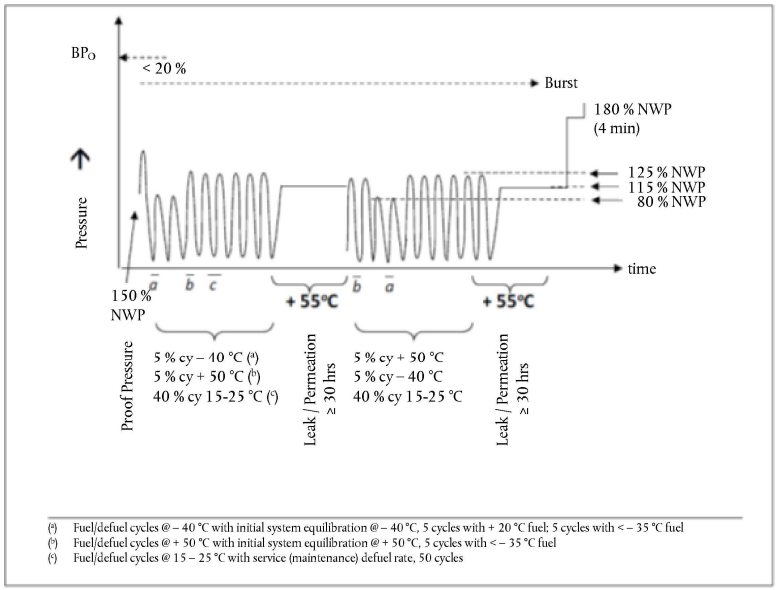
- Hydrogen, H_2
  - Flamable and explosive in concentrations from 4 to 75%
  - LEL – Lower Explosion Limit UEL – Upper Explosion Limit



R134 workflow

- Test 4 – Verification tests (hydraulic/pneumatic)

  -Subtest 3, Residual proof pressure test (hydraulic)

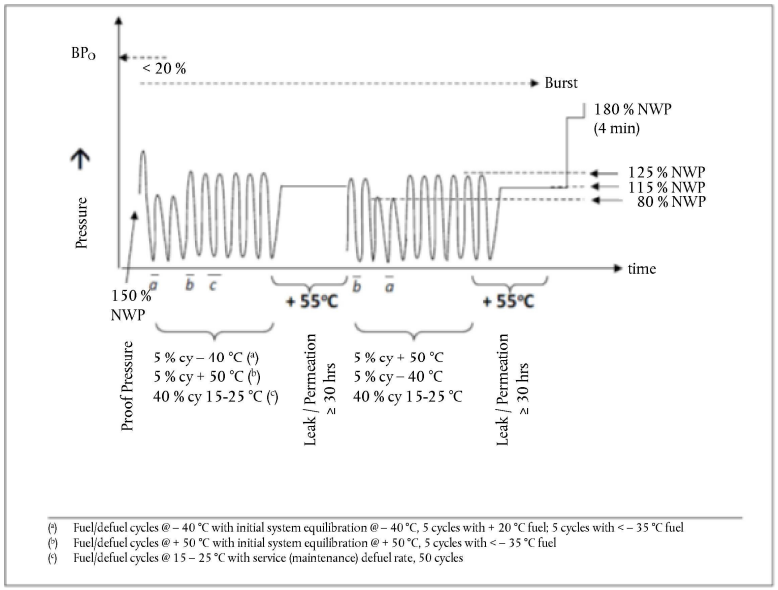


- Purpose – Subject the tank for a overpressure caused by a malfunctioning fueling station
- Qualification – 180% NWP for >4 minutes w/o burst

R134 workflow

- Test 4 – Verification tests (hydraulic/pneumatic)

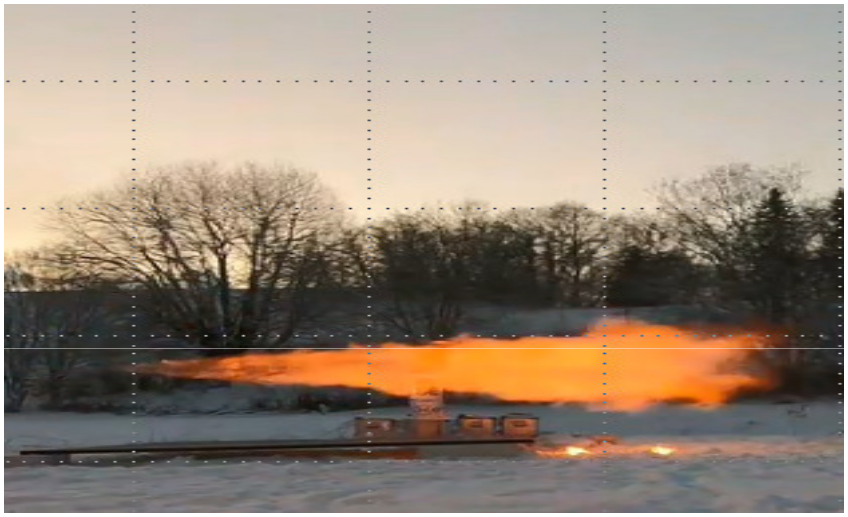
  -Subtest 4, Residual proof pressure test (hydraulic)



- Purpose – Secure a ±10% manufacturing variability to secure 25 years of ruprure resistance at NWP
- Qualification – Burst >80% BP_0

R134 workflow

- Test 5 – Performance in fire



- Purpose – Secure a safe beahaviour if exposed to fire
- Qualification – A TPRD shall release the contained gases in a controlled manner w/o rupture according to LBB criteria

Lessons learned

- Regulations are designed for 25 years operation
- 150 000 Swedish ”miles” of pressure cycling
- Qualification in the range of -40 to 85°C
- 25 years of full-fill parking
- Leak rate below level that can sustain a flame
- Abuse from handeling included
- Environmental factors taken into account
- Safe behaviour during fire

Tank test facility in Borås ?

The pre-studies are focusing on:

-R134 qualification **including** hydrogen tests

-Batch testing

-Tanks up to at least 450 liter capacity

-NWP pressures of at least 700 bar

Communicate your needs !

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Qualification of hydrogen tanks for vehicles

Regulations and legislations

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Andreas har jobbat på RISE sedan 2004 och på enheten för miljötålighet sedan 2018. Han har en civilingenjörsexamen, arbetar som senior ingenjör och är ansvarig för driften och utvecklingen av enhetens mekaniska labb i Borås vid sidan av att driva ett FoU-team.
Just nu är han engagerad i byggnationen och drifttagandet av det sk SEEL-labbet i Borås där batterier under 2023 ska kunna abusetestas. För att ytterligare möta behoven som kommer av elektrifiering utvärderas möjligheterna att bygga en resurs för att kvalificera trycktankar för vätgas. Andreas är en av kompetenserna i grupperingen på RISE som driver detta arbete.