HyTransfer

Final Webinar slides

This is an extended set of slides.

Slides not presented during the (live) Final Webinar are marked accordingly.

This presentation summarizes the key findings and results from the HyTransfer project.

This project is co-financed by European funds from the Fuel Cells and Hydrogen Joint Undertaking under:

FCH-JU-2012-1 Grant Agreement Number 325277

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

The project partners would like to thank the EC for establishing the fuel cells and hydrogen framework and for supporting this activity.

Version 1.1

This slide was not shown during the (live) Webinar.

Note for the reader

HyTransfer

The Webinar was followed by more than 60 stakeholders including representatives from various car manufacturers, the gas and petrol industry, gas tank manufactures, infrastructure providers, representatives from US, Japanese and European institutions such as NREL, DOE, HySUT and the European Commission. The Webinar was broadcasted to a TC 197 (hydrogen technologies) workshop organized by JRC. Here about 25 representatives from various countries followed the Webinar.

Within the HyTransfer project fast hydrogen transfer was investigated by modelling and experimental validation. A significantly improved understanding of temperature conditions within the involved tanks and tank systems was created by an extended experimental campaign in combination with thorough thermodynamic modelling and calculations. Based on this new knowledge, improvements in hydrogen refuelling can be proposed.

Various different protocol designs and elements are possible, each with a different impact on pre-cooling requirement, refuelling speed, final SOC and/or final tank temperature. The HyTransfer consortium jointly decided to investigate a very ambitious, new and innovative protocol that combines major benefits in all of the above mentioned single areas of improvement. This “HyTransfer approach” is presented on the following slides. **It is now up to the relevant RCS bodies, SAE and other involved stakeholders to implement the results into RCS to the extent international consensus can be achieved.**

In the coming weeks, project reports with further information and details will be published on the HyTransfer.eu webpage.

The HyTransfer consortium
(Dec. 16th, 2016)

Please send questions to coordinator@HyTransfer.eu.
The questions will be forwarded to the relevant project partner(s).

This slide was not shown during the (live) Webinar.

Final Webinar

HyTransfer

December 7th, 2016

Today's presentation

	Topic	Speaker	Company
1	HyTransfer in a nutshell	Jan Zerhusen	Ludwig-Bölkow-Systemtechnik
2	Goals and overall approach	Frédéric Barth	H2Nova for Honda R&D Europe
3	Experimental campaign	Baptiste Ravinel	Air Liquide
4	Thermal models & results	Thomas Bourgeois	Air Liquide
5	New protocol proposal	Frédéric Barth	H2Nova for Honda R&D Europe
6	New protocol tables	Thomas Bourgeois	Air Liquide
7	Techno-economic impact	Jan Zerhusen	Ludwig-Bölkow-Systemtechnik
8	Recommendations to industry	Clémence Devilliers	Air Liquide
9	Recommendations to RCS	Randy Dey Frédéric Barth	CCS Global Group H2Nova for Honda R&D Europe

Coordination | Industry | Research & Testing | Regulations, Codes & Standards | Funding

HyTransfer

Pre-Normative Research for Thermodynamic Optimization of Fast Hydrogen Transfer

- **Project duration:** June 2013 to December 2016 (43 months)
- **Budget & funding:** 3.1 M€ of which 1.6 M€ FCH JU funding
- **Main objective:** Develop and experimentally validate an optimized approach for fast filling of compressed hydrogen.
- **Project partners:**

Coordination	Industry	Research & Testing	Regulations, Codes & Standards	Funding
ludwig bölkow systemtechnik	AIR LIQUIDE; HONDA The Power of Dreams; HEXAGON COMPOSITES	European Commission; INSTITUT P' CNRS - UPR 3346; TESTNET ENGINEERING	CCS GLOBAL	FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

- **Homepage:** HyTransfer.eu

Goals and overall approach

Speaker: **Frédéric Barth**

H2Nova for Honda R&D Europe

HyTransfer project goals

- Aim: Improve *process control requirements* in order to allow further optimization of the refuelling process

Areas of optimization

- Fuelling duration
- Level of cooling
- Freedom for process control
- Energy consumption

Benefits

- Improved customer experience
- Improved HRS throughput
- Improved HRS reliability
- Reduced CAPEX
- Reduced OPEX

- How: through the investigation of *optimization opportunities*

- Outcome: “HyTransfer approach” leading to a new refuelling protocol proposal

Investigated optimisation opportunities

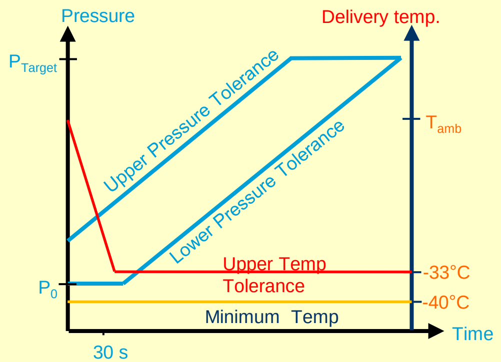
Current approach | New approach

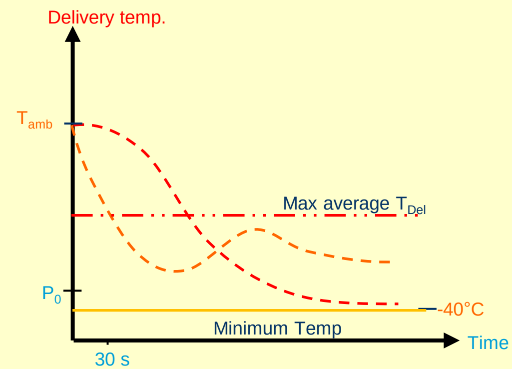
1. Less cooling and shorter fuelling duration

Current approach		New approach
Application of 85°C limit to *gas*	⇨	**Focus on *material* temperature**

2. Less constraint on process control

Current approach		New approach
Strict limits on T_{Del} and P_{fill}	⇨	**Only average deliv. temp. is limited**





3. Better adjustment to actual need

Current approach		New approach
T_{Del} < -33°C required all the time	⇨	T_{Del} adjusted to ambient temperature

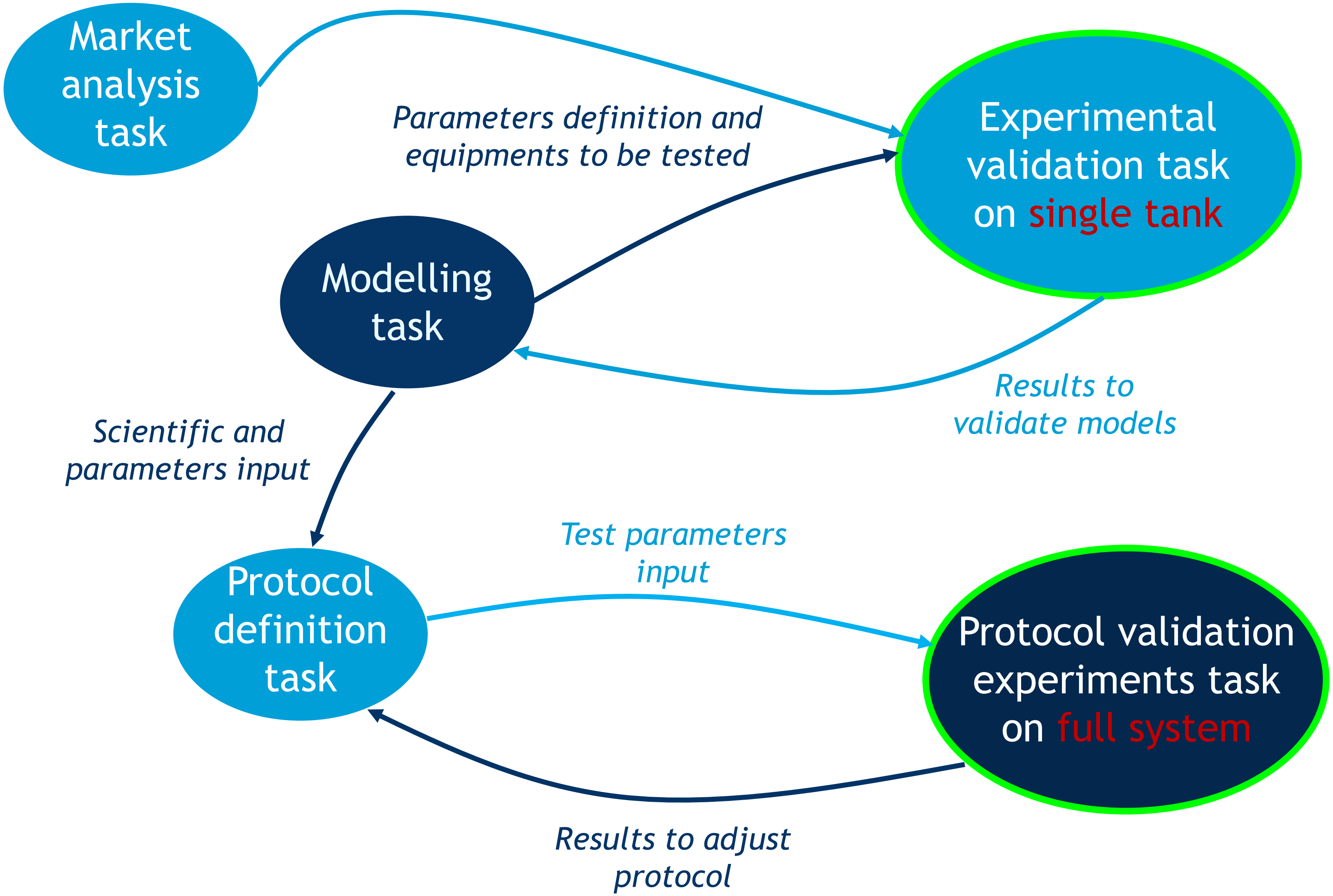
Opportunity investigation and new protocol development steps

1. Development of models predicting both gas and material temperatures
2. Experimental validation of models through filling tests
3. Analysis of thermal behavior and protocol optimization opportunities
4. Development of a new protocol approach implementing the optimization opportunities, using the validated models
5. Experimental validation of the new protocol concept on a tank system
6. Techno-economic analysis: evaluation of the new protocol’s impact on performance and costs
7. Recommendations for Industry and RCS

Experimental campaign

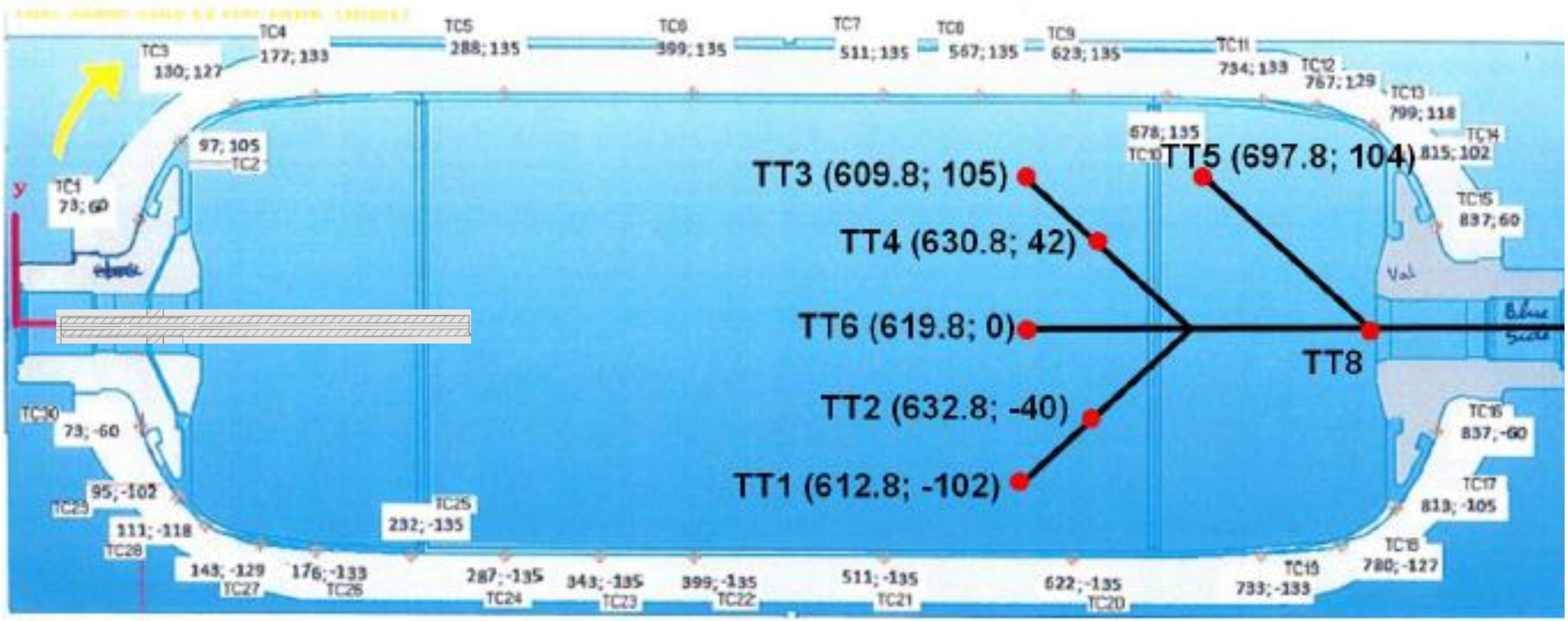
Speaker: **Baptiste Ravinel**
Air Liquide

Experimental tasks in the project



- Short & Large tanks / Type III & Type IV
- Injection diameter sizes
- Initial pressure
- Initial ambient temperature
- Tank inlet gas temperature
- Average mass flow
- Temperature & Pressure profiles

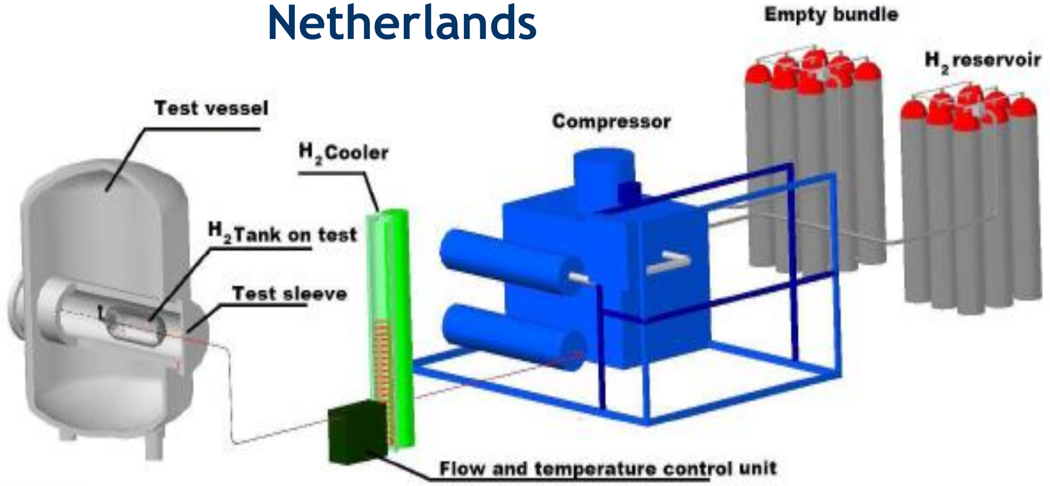
- Thermocouple positions



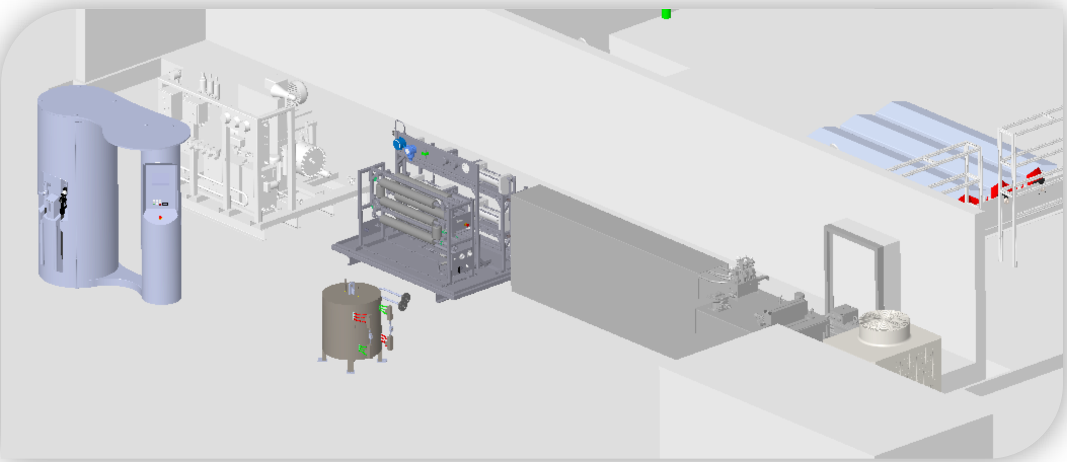
- Injection diameters :
    - 3 mm
    - 6 mm
    - 10 mm (no injector)
    - 4x 3mm radial

- 3 test facilities
- More than 40 fuelling tests
- More than 40 defuelling tests

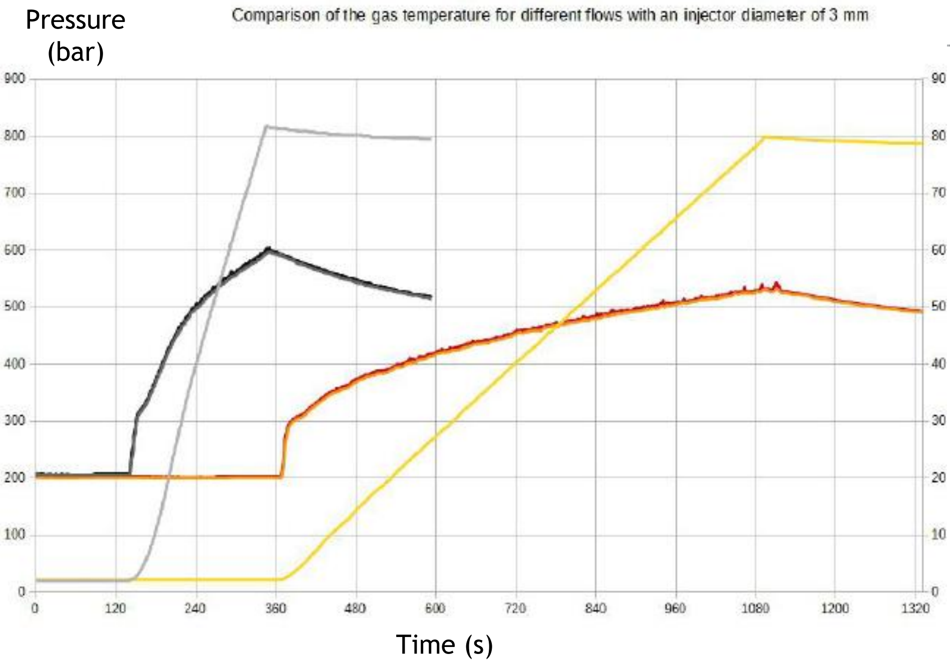
Joint Research Center
Netherlands

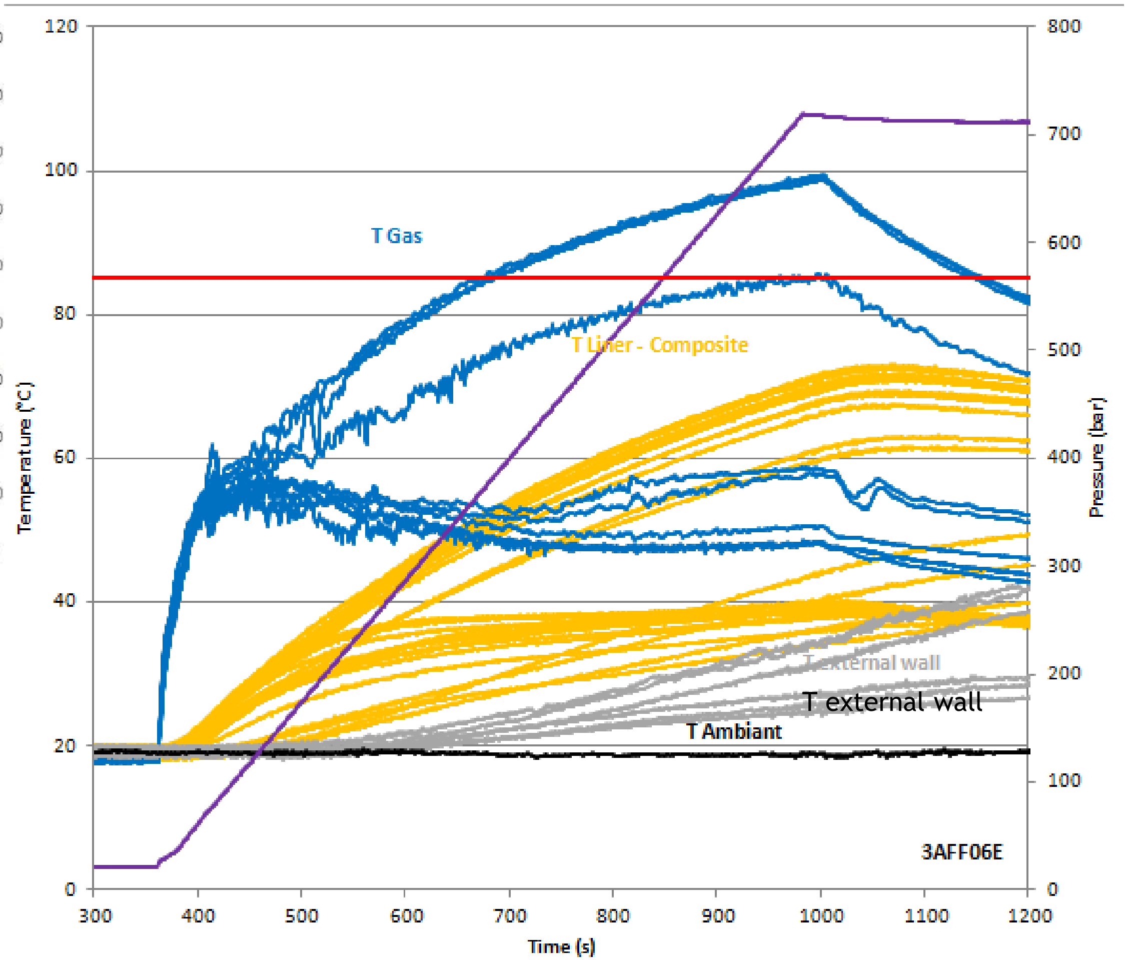


Air Liquide aT
France



Single tank experiments - Results

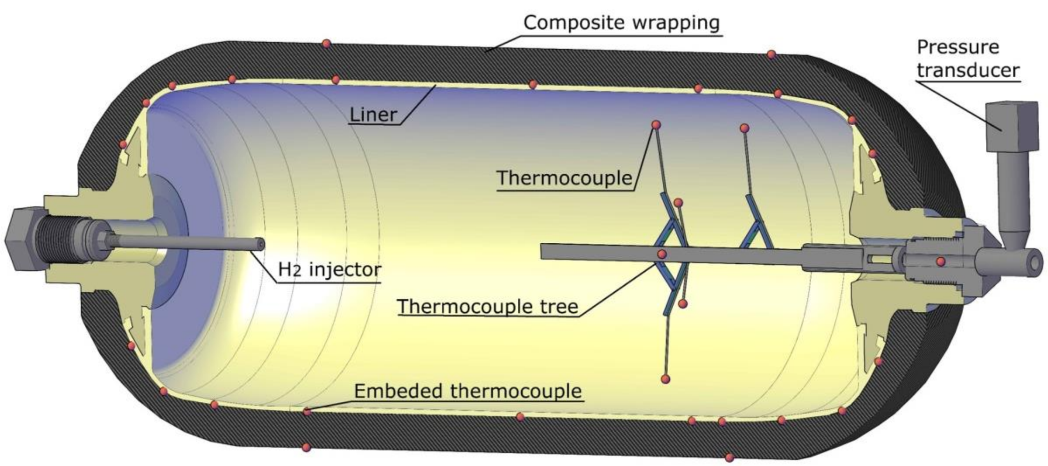




- Identification of stratified and homogeneous temperature distribution
- Temperature at different positions

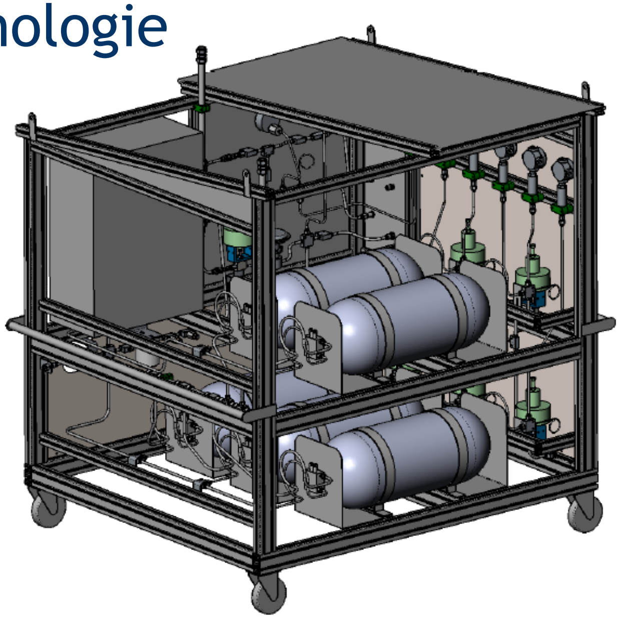
HyTransfer

- Good agreement with simulations
- Good consistency between test laboratories
- Parameters influence identification
- Fast fuelling and other investigations
- Injection diameter influence on heterogeneous or homogeneous conditions
- Liner thermal barrier



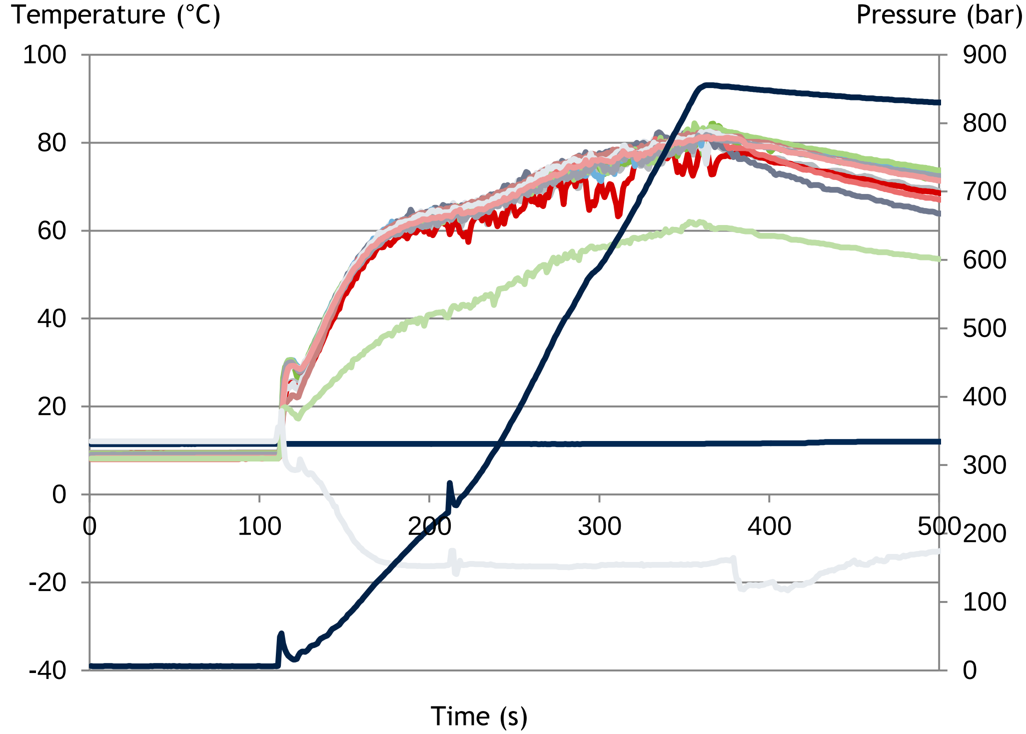
European Commission

- CHSS like test bench + station like testing facility
- 4 x 36L Type IV tank
  + 1 x 40L Type III tank
  (1.4 to 7.4 kg capacity)
- Test performed at Energie Technologie



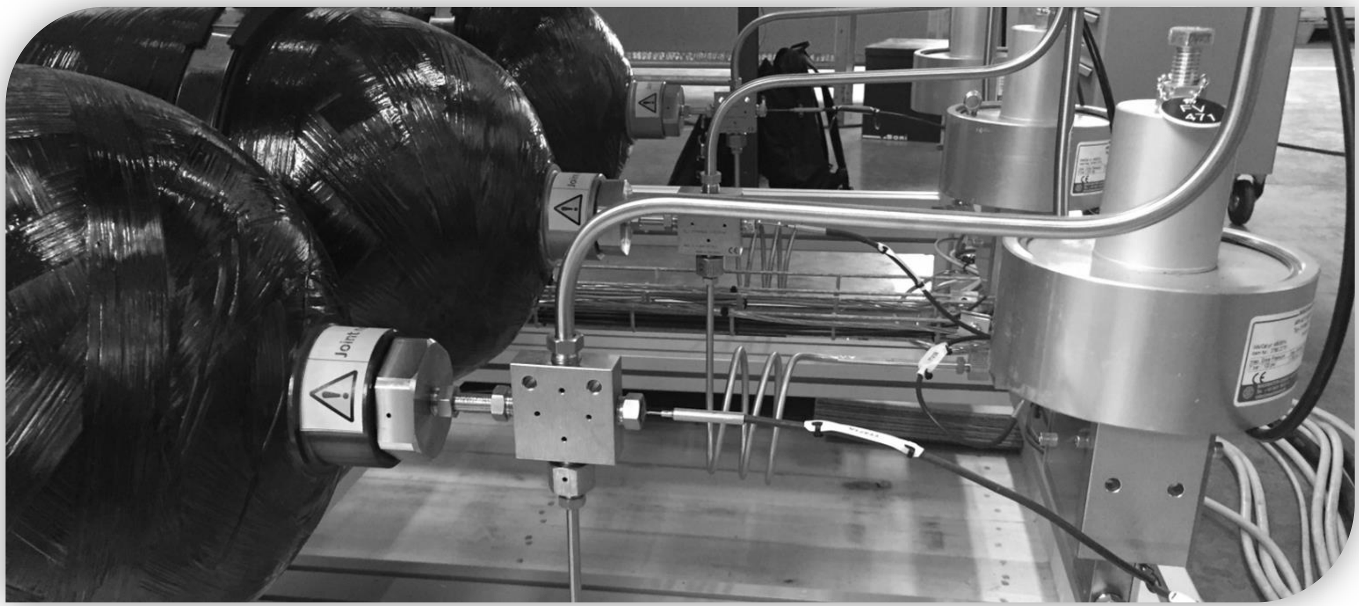
Full system experiments - Test campaign

Objectives	Experiment number (Exp#)	Test number according to procedure (Test#)	Pipe length	Initial pressure	Ambient temperature	Average gas dispenser temperature (T05040)	End of fill criterion: Final pressure at (P05039)
Kv measurement	1	1	short	5 bar	10°C	-14	875
	2	2	short	200 bar	10°C	-14	875
	3	4	long	200 bar	10°C	-14	875
	4	3	long	5 bar	10°C	-14	875
Wait for 2 days for calculation results							
Reference test	5	5	long	5 bar	30°C	-35	875
Influence of pipe length	6	6	short	5 bar	30°C	-32	875
Influence of initial conditions (Tamb and Pinit)	7	15	short	600 bar	10°C	0°C	822
	7 bis	15bis		5 bar	10°C	-18	875
	8	7		50 bar	30°C	-27	875
	9	10		200 bar	30°C	-5	875



More than 20 fuelling tests

- Good agreement with simulations expectations
- Overall consistency even with experimental uncertainties
- Large range of parameters tested
- Feedback for protocol and model improvement
- CHSS + station like testing in addition to single cylinder testing



Thermal models & results

Speaker: **Thomas Bourgeois**
Air Liquide

- Thermodynamical modeling
  - Numerical solution of energy and mass balances
  - Pros:
    - Very fast simulations (~1 min)
  - Cons:
    - Provides average gas temperature, and surface average wall temperature

1. Thermodynamical modeling
SOFIL: « Software for Filling »

Gas in the tank:

- Homogeneous temperature and pressure
- Energy balance

$$m\, c_p \frac{dT_g}{dt} = V\beta T \frac{dP}{dt} + k_g\, S_{int}\left(T_l - T_g\right) + \dot{m}\left(h_{in} + \frac{v_{in}^2}{2} - h_g\right)$$

- Equation of state of real gases

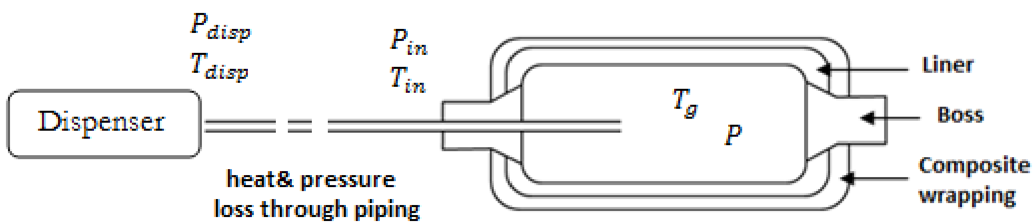
$$P\,V = n\,R\,Z\left(T_g, P\right)\,T_g$$

Station& vehicle piping:

- Heat loss

$$\dot{m}\left(h_{disp} + \frac{v_{disp}^2}{2}\right) = \dot{m}\left(h_{in} + \frac{v_{in}^2}{2}\right) + \phi_{gas \rightarrow pipe}$$

- Pressure loss



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In the tank wall:

- Radial temperature gradient
- Heat equation

$$\rho_w c_{p,w} dV \frac{\partial T_w}{\partial t} = \lambda_{w,r+dr} \left.\frac{\partial T_w}{\partial r}\right|_{r+dr} S_{r+dr} - \lambda_{w,r} \left.\frac{\partial T_w}{\partial r}\right|_{r} S_r$$

Internal heat exchanges:

$$Nu_{Dint} \equiv \frac{D_{int} k_g}{\lambda_{gas}} = a\, Ra_{Dint}^{\ \ 0.352} + c\, Re_{d_{in}}^{\ \ 0.67}$$

Initial & boundary conditions:

$$T_g(0) = T_0$$

$$T_w(0) = T_0$$

$$P(0) = P_0$$

T_{amb}

...

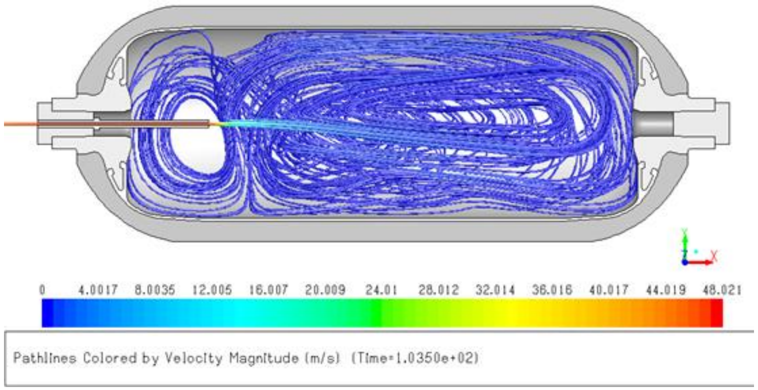
In the tank bosses:

- Homogeneous temperature
- Energy balance

$$m_b\, c_{p,b} \frac{dT_b}{dt} = k\, S_{b,int}\left(T_g - T_b\right) + k_a S_{b,ext}\left(T_{amb} - T_b\right)$$
$$+ S_{b,ext} \Phi_{rad,b}$$

Ref: (Bourgeois, Ammouri et al., 2015) (Bourgeois, Brachmann et al., 2016)

- Computational Fluid Dynamics (Air Liquide aT, JRC)
  - Numerical solution of Unstationnary Reynolds Averaged Navier-Stokes equations (URANS): CFX / ANSYS
  - Pros:
    - Very refined 3D simulations
    - Provide local temperature fields in the gas, liner, composite
  - Cons:
    - Time-demanding simulations: ~ 2 days for a filling simulation ; ~ 2 weeks for defueling simulation
  - Example of results: filling of type IV 36 l tank



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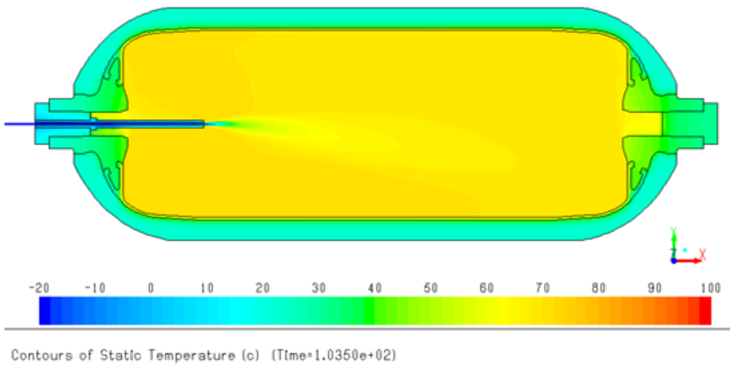

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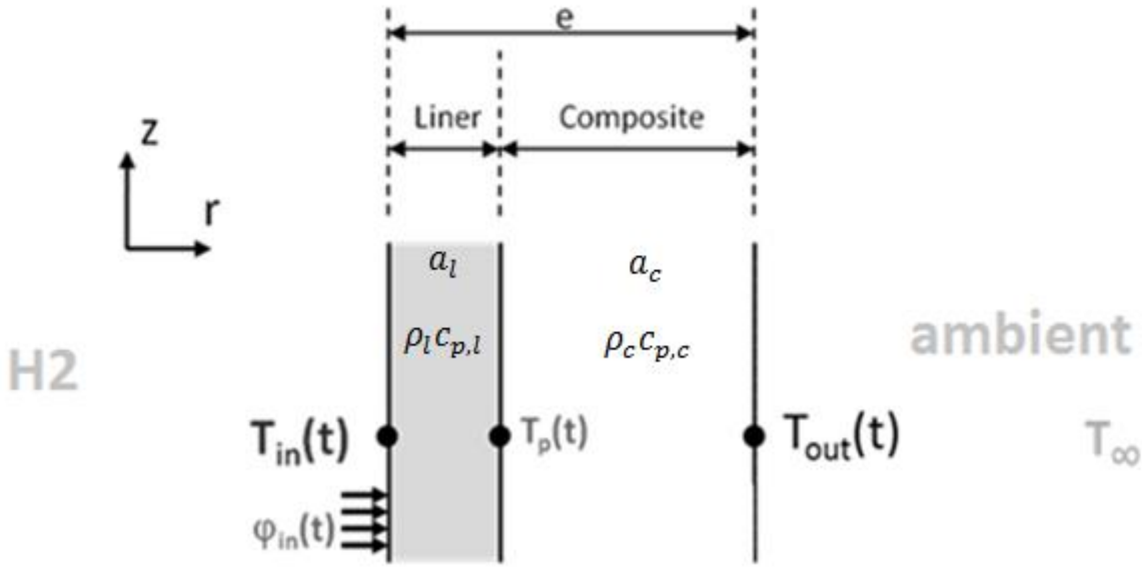
Ref: (Melideo&Baraldi, 2014) (Zaepffel et. al, 2016)

- Estimation of inner temperature T_{in} or heat flux density φ_{in} thanks to temperature measurements at the liner-composite interface.
  - Model is based on the heat equation in the wall "only", not the flow field of gas



(© CNRS)

  - Pros: fast & very precise information on the temperature of the liner in contact with the gas
  - Cons: no information on the flow field inside the gas
  - Ref: (Ruffio, 2011) (Maillet, 2000)

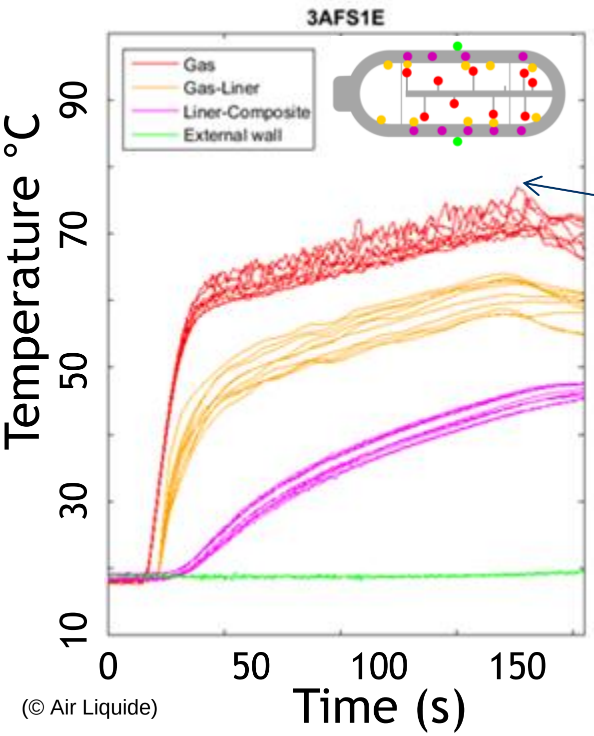
Thermal models & results

Speaker: **Thomas Bourgeois**
Air Liquide

HyTransfer

- Horizontally filled tanks with H_2 with a one-hole axial injector
- Type IV 36 l : 3 minute filling with Tinlet = -20°C

Injector with 3 mm internal diameter



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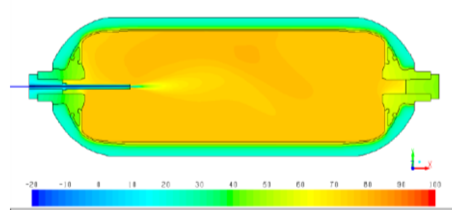
Max gas temperature = 78 °C



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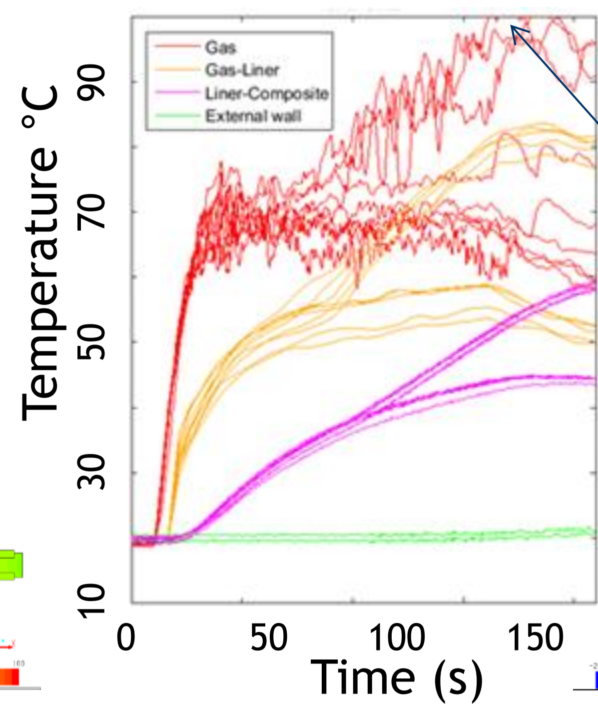
Injector with 10 mm internal diameter



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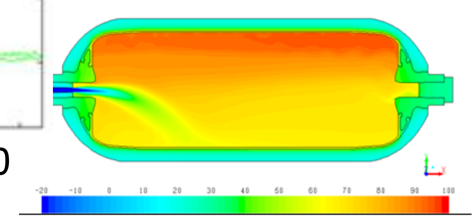
Max gas temperature $\boxed{=103°C}$



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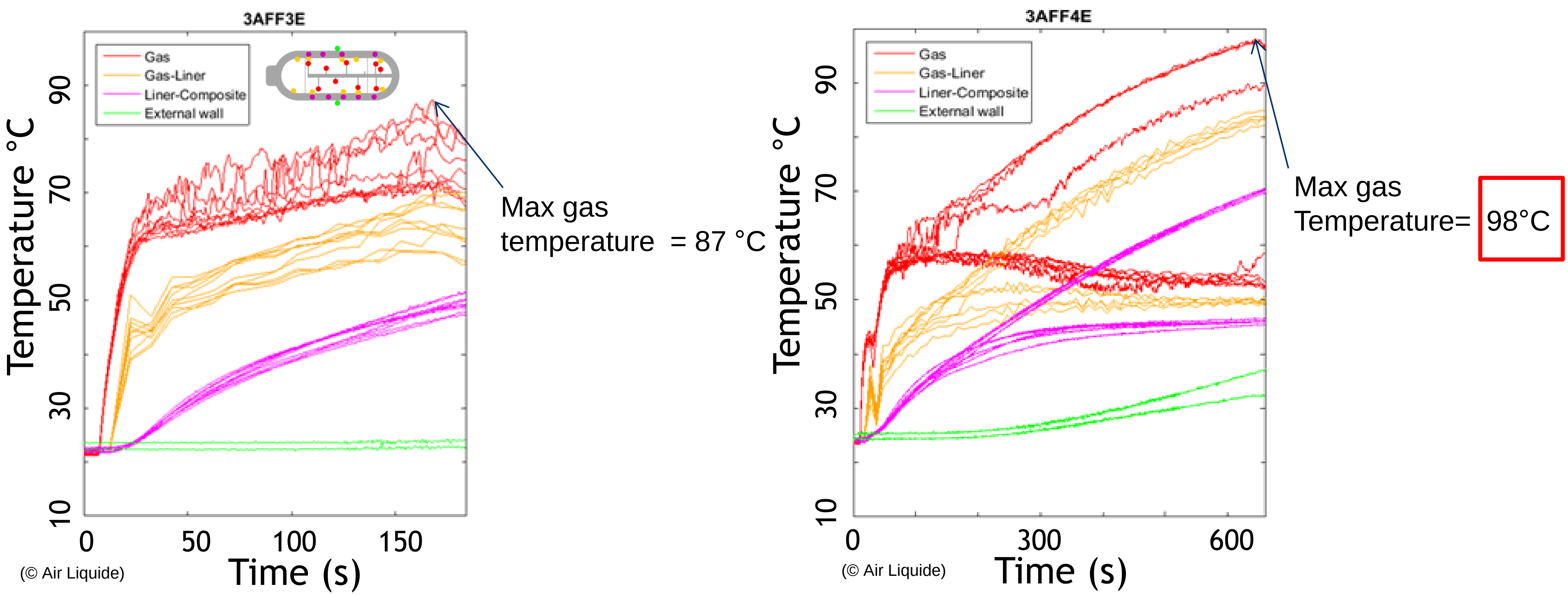
Ref :(Bourgeois, Brachmann et al., 2016)

- Type IV 36 l: filling with Tinlet = -20 °C, 6 mm injector

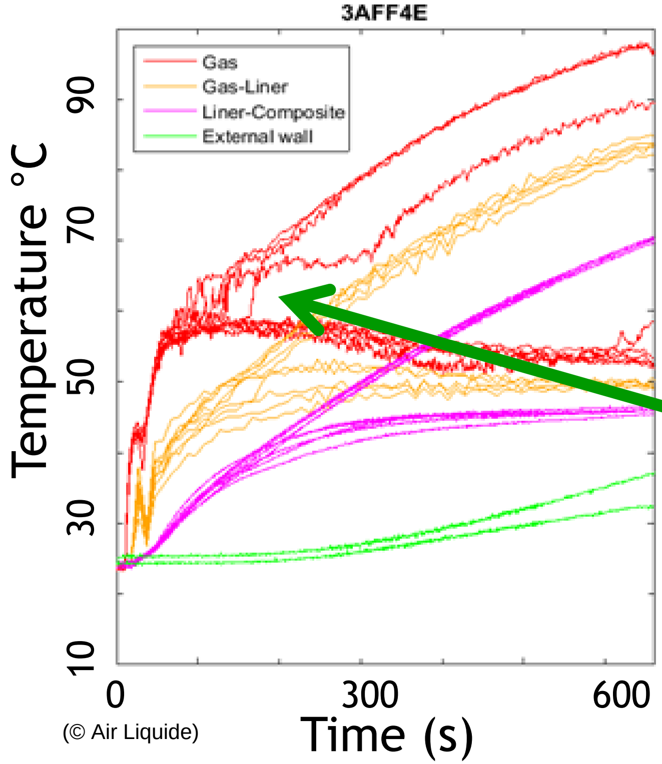
3 minutes filling to 700 bar

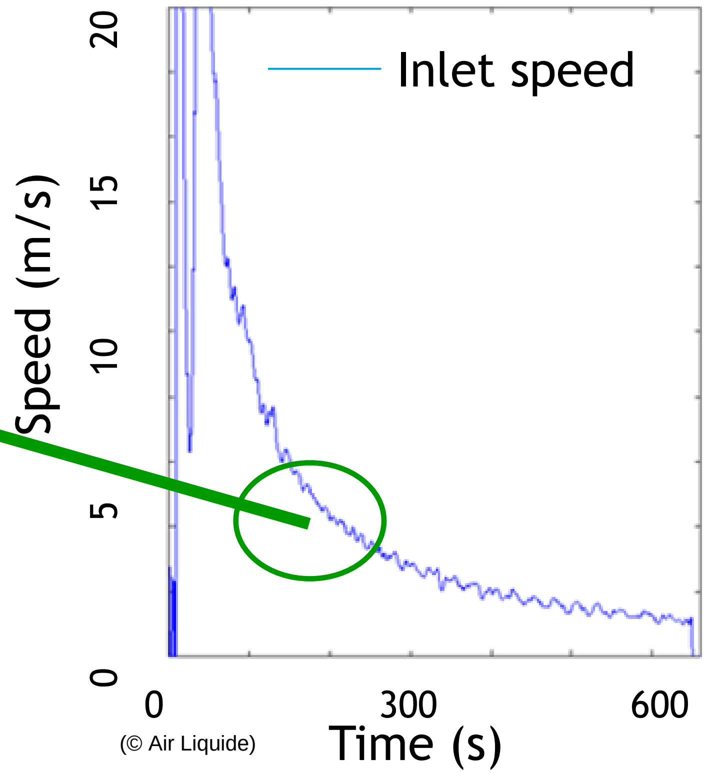
11 minutes filling to 700 bar



Ref: (Bourgeois, Brachmann et al., 2016)

- Inlet speed above 5 m/s → homogeneous temperature
- Inlet speed below 5 m/s → start of stratification (Terada, 2008)





Ref: (Bourgeois, Brachmann et al., 2016)

$$v_{inlet} = \frac{4\dot{m}}{\rho_{inlet}\pi d^2}$$

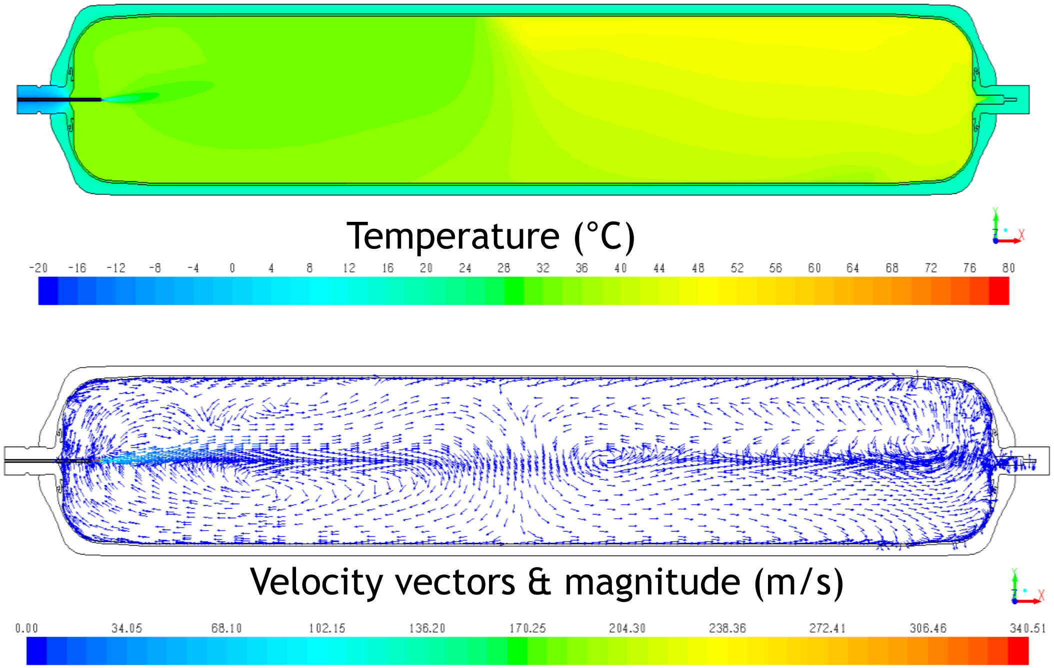
Start of stratification

Tank	Gas	Working pressure	Type	L/D	Mass flow rates	Inlet diameter	Inlet speed < 5m/s criterion
36L (HyT)	H2	700 bar	IV	2.4	2 to 8 g/s	3 to 10 mm	Valid
40L (HyT)	H2	700 bar	III	2.7	2 to 8 g/s	3 to 10 mm	Valid
65L (Terada, 2008)	H2	350 bar	IV	2	1.8 to 9.1 g/s	4.5 to 10 mm	Valid
90.5L (AL)	H2	700 bar	IV	1.6	4.4 to 8.2 g/s	22mm	Valid
531L (HyT)	H2	700 bar	IV	5.9	2 to 8g/s	3 to 25 mm	Valid

Ref: (Bourgeois, Brachmann et al., 2016)

- Wide range of 5 m/s criterion validity

2nd phenomenon : horizontal temperature gradient



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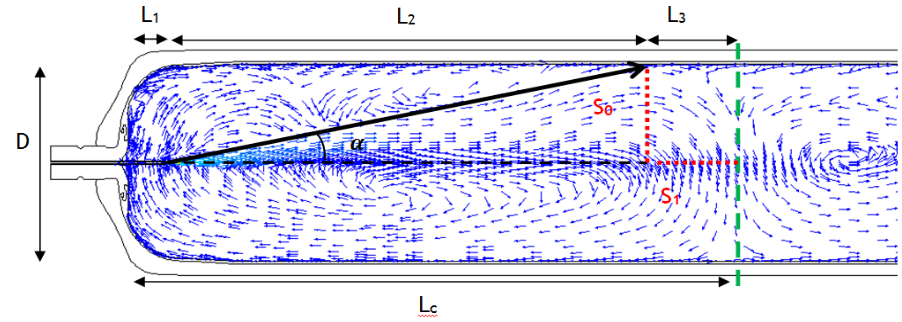


$$L_c \equiv L_1 + L_2 + L_3 \approx L_{inj} + 3D\ (\pm 0.6D)$$

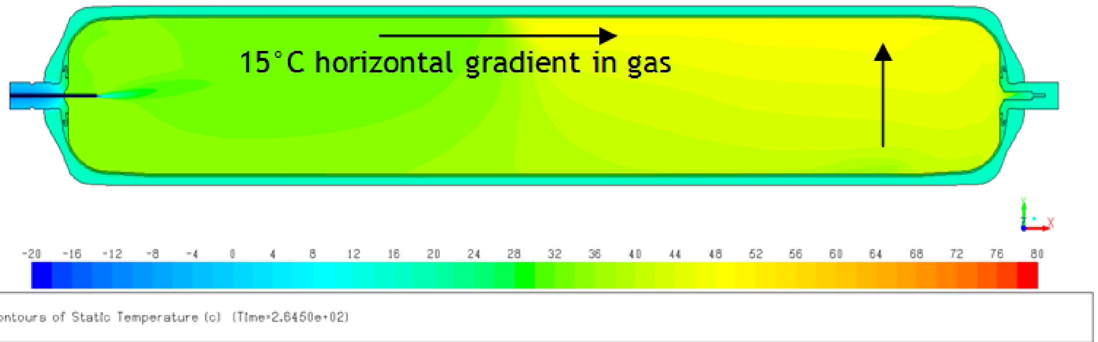
Ref: (Bourgeois, Brachmann et al., 2016)

- Horizontal temperature gradient appear only for “long tanks” defined by $L > L_{inj} + 3D$

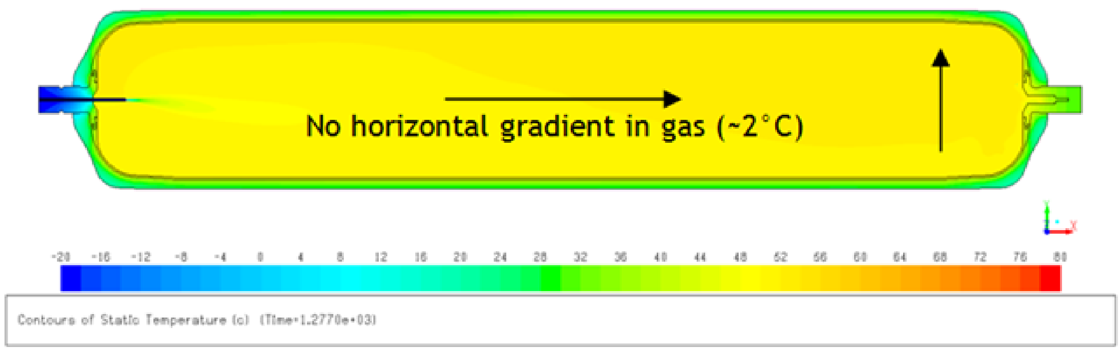
Verified for a H2 filling of a type IV 531 l tank with L/D=5.9, mass flow rates from 2 to 8 g/s, and injectors from 3 to 25 mm ; N2 filling of a type IV 48 l tank with L/D=6.6, mass flow rates from 2 to 8 g/s, and injector of 6 mm

2nd phenomenon : horizontal temperature gradient

V_{inlet} ~ 300 m/s



V_{inlet} ~ 40 m/s



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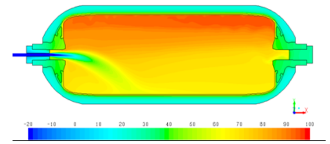
- Change of regime at inlet speed ~ 100 m/s

Verified for a H_2 filling of a type IV 531 l tank with L/D=5.9, mass flow rates from 2 to 8 g/s, and injectors from 3 to 25 mm ; N_2 filling of a type IV 48 l tank with L/D=6.6, mass flow rates from 2 to 8 g/s, and injector of 6 mm

- Horizontally filled tanks with H_2 with a one-hole axial injector.
  - Stratification (vertical temperature gradient)



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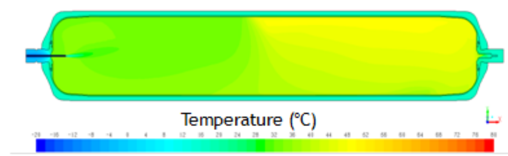
    - Start of appearance of stratification for v_{inlet} < 5 m/s
    - Valid on for all studied tanks (short & long tanks)
  - Horizontal temperature gradient



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    - Horizontal temperature gradient observed only for long tanks: $(L-L_{inj})/D>3$
    - Appearance of gradient for v_{inlet} > 100 m/s
    - Decrease of gradient for v_{inlet} < 100 m/s

$$v_{inlet} = \frac{4\dot{m}}{\rho_{inlet} \pi d^2}$$

Domain of validity of different criteria presented in previous slides.
(Bourgeois, Brachmann et al., 2016)

SOFIL - Heat transfer coeficient - type III 40L

- **Deduced from measurements:**

$$k_g = \frac{\dot{m}h(T_{in},P_{in}) - {d(m.u(T_g,P))}/{dt}}{S\left(T_g - T_w(r = r_i)\right)}$$

- **Correlation:**

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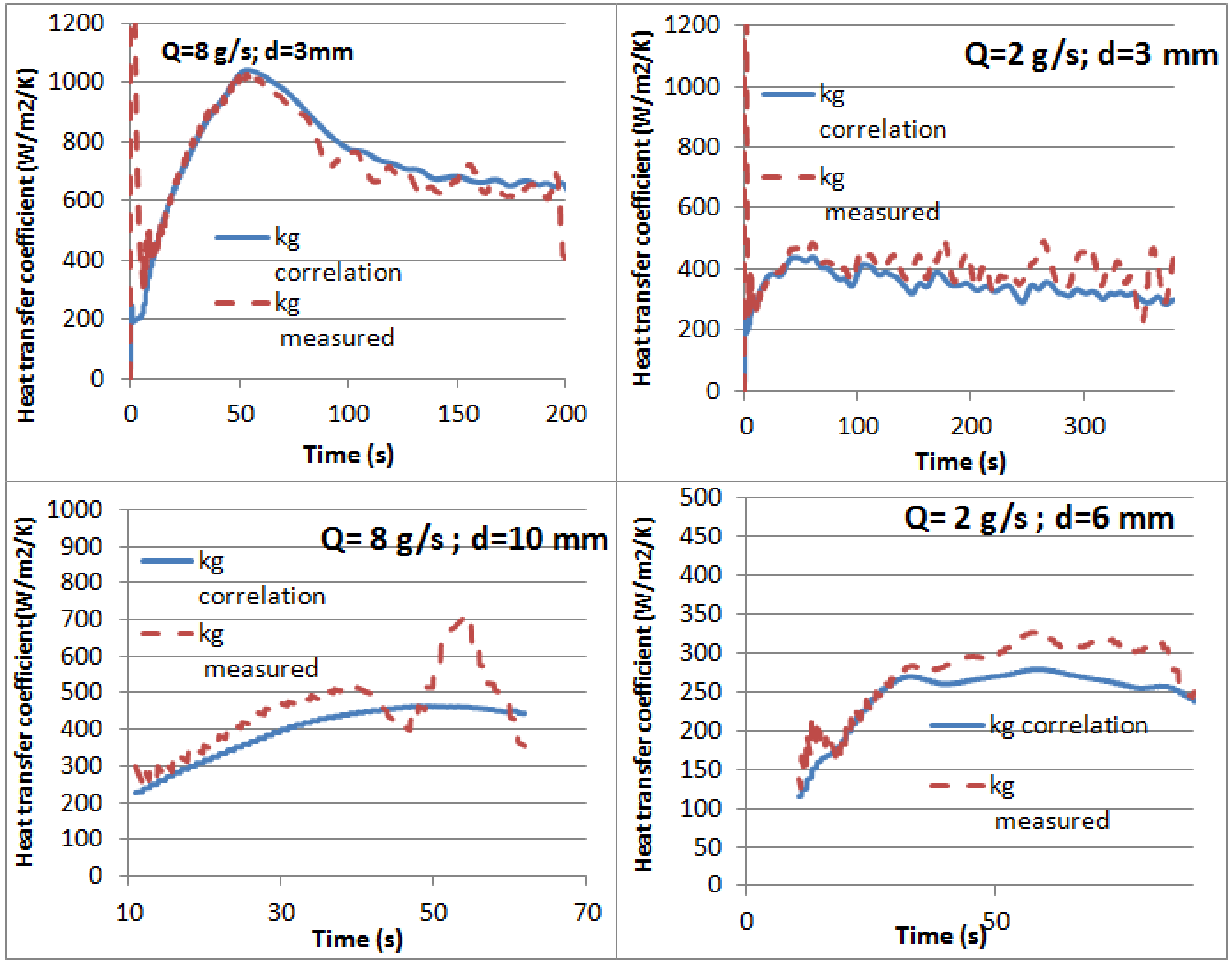
$$Nu_{D_{int}} = 0.17\, Re_d^{0.67}$$



(Bourgeois, Brachmann et al., 2016)

Validity

- Tempreature homogeneous conditions
- horizontally filled tanks; $3\ mm < d < 10\ mm$ $2{,}4 < \frac{L}{D} < 2{,}7$

$2.6 \times 10^4 < Re_d < 7.1 \times 10^5$

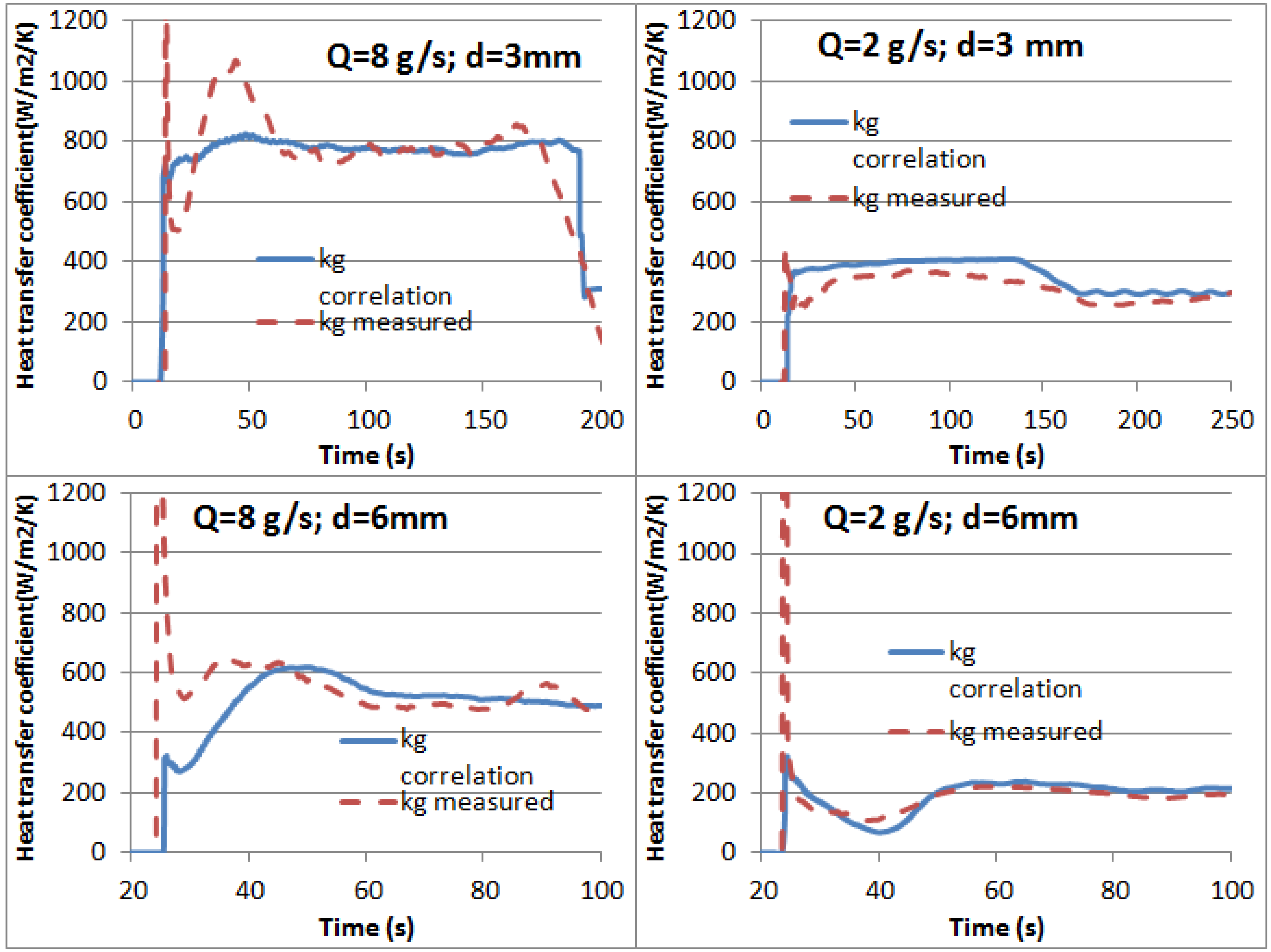
SOFIL model validation
Heat transfer coeficient – type IV 36 l

- Deduced from measurements:

$$k_g = \frac{\bar{\varphi}}{\left(T_g - T_w(r = r_i)\right)}$$

- Correlation:

$$Nu_{D_{int}} = 0.17\, Re_d^{0.67}$$



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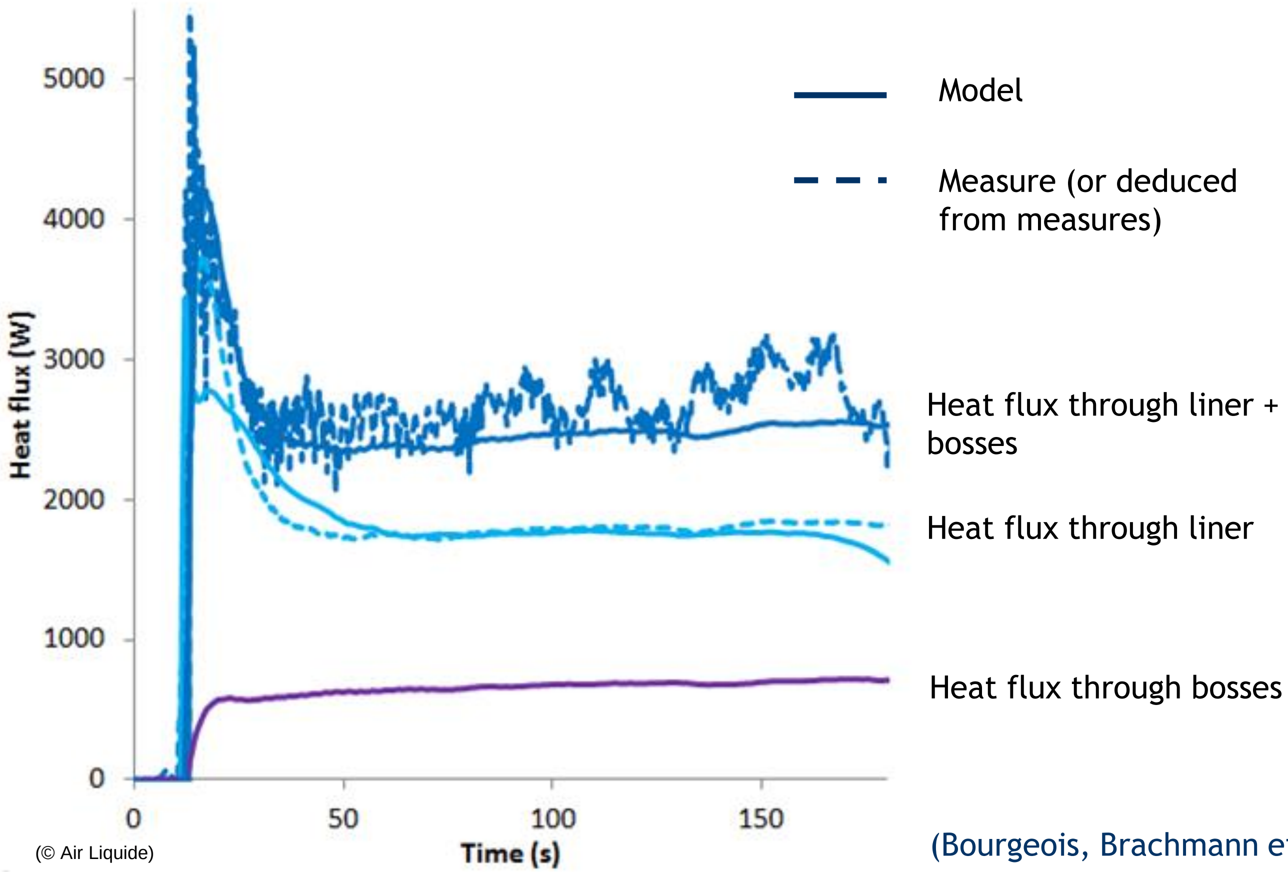
(Bourgeois, Brachmann et al., 2016)

Validity

- Temperature homogeneous conditions
- horizontally filled tanks; $3\,mm < d < 10\,mm$ $2{,}4 < \frac{L}{D} < 2{,}7$
  $2.6 \times 10^4 < Re_d < 7.1 \times 10^5$

Type IV - impact of bosses



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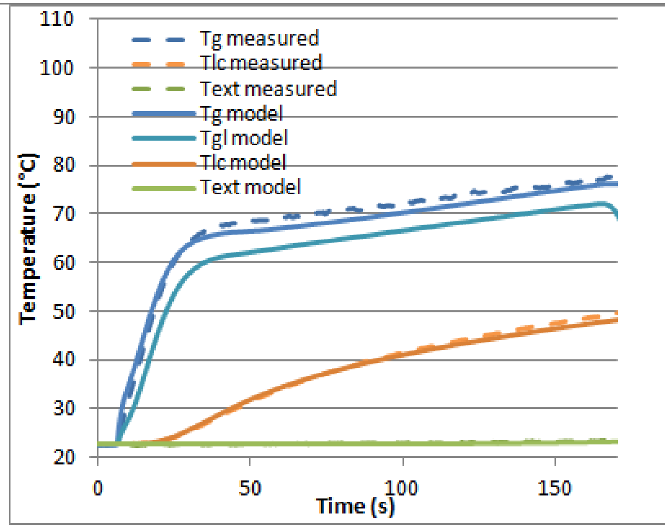
(Bourgeois, Brachmann et al., 2016)

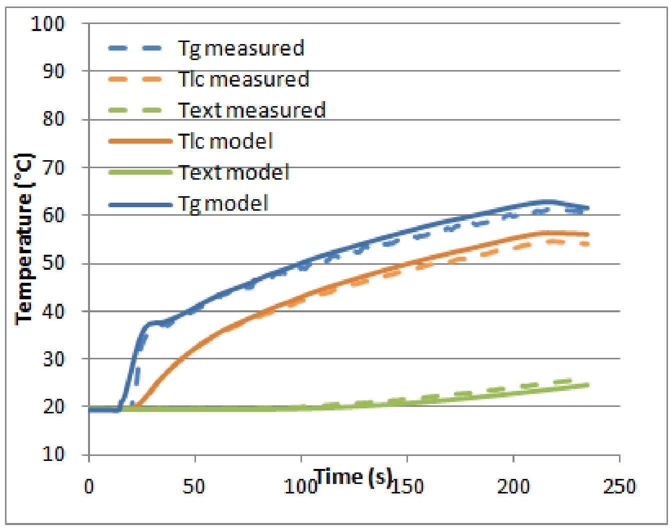
- Heat flux passing through the bosses is not negligible
  - 23% of total heat flux passing through wall on a 3 min 36 l type IV filling

SOFIL validation - single tanks

Type IV 36 l



Type III 40 l

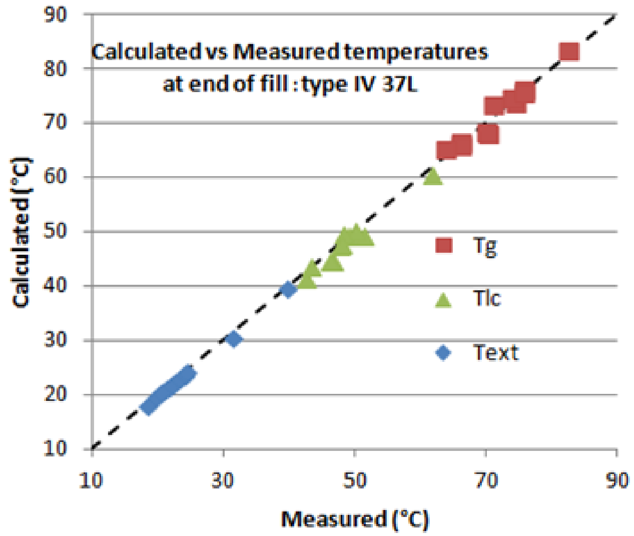


Agreement on whole temperature profile

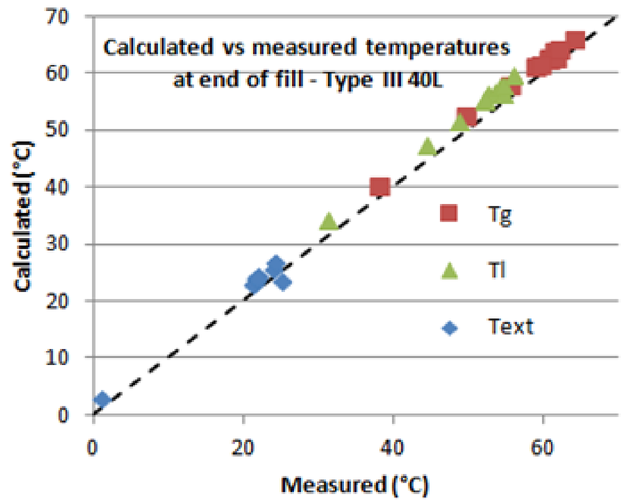
(Bourgeois, Brachmann et al., 2016)

Model comparison to experimental measures for gas; liner-composite and external temperatures tank filled from 20 to 750 bar in 180 seconds with -20°C inlet temperature.

Type IV 36 l



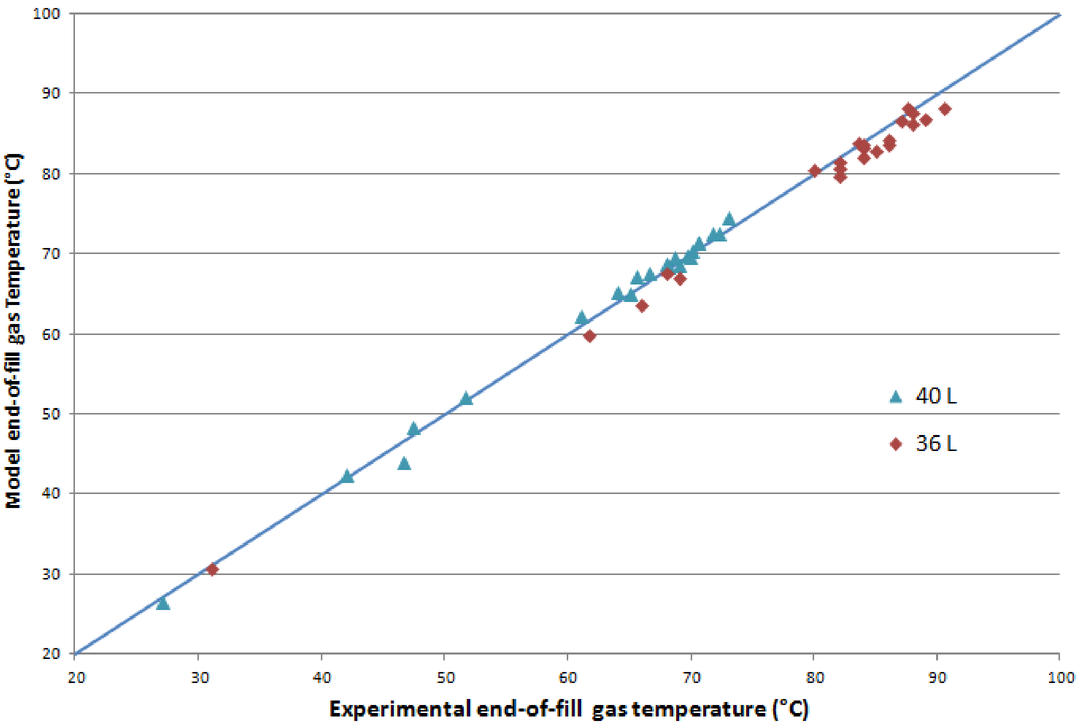
Type III 40 l



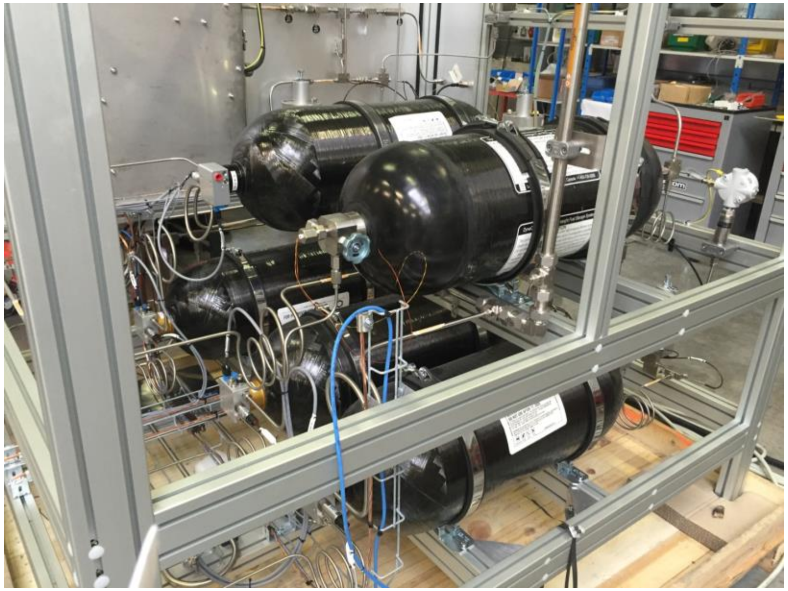
Agreement on all 22 temperature-homogeneous experiments

(Bourgeois, Brachmann et al., 2016)

SOFIL validation - piping & vehicle tank system



Model temperature obtained with SOFIL model (global heating piping)



(© Air Liquide)

Agreement on all 19 experimental end-of-fill temperatures

- SOFIL model permits to determine delivery temperatures, and therefore cooling demand, such that a maximum end-of-fill gas or wall temperature is not exceeded

- **Bourgeois, T., Ammouri, F., Weber, M.,** & Knapik, C. (2015). Evaluating the temperature inside a tank during a filling with highly-pressurized gas. *International Journal of Hydrogen Energy*, *40*, 11748-11755.
- **Brachmann, T., Barth, F., Bourgeois, T., Ammouri, F., Acosta-Iborra, B., Ravinel, B., . . . Saury, D.** (2016). Optimization of hydrogen vehicle refueling requirements. *WHEC*. Zaragoza.
- **Bourgeois, T., Brachmann, T., Barth, F., Ammouri, F., Baraldi, D., Melideo, D., . . . Lemonnier, D.** ((sent, under review) 2016). Optimization of hydrogen vehicle refueling requirements. *International Journal of Hydrogen Energy*.
- **Melideo, D., & Baraldi, D.** (2015). CFD analysis of fast filling strategies for hydrogen tanks and their effects on key-parameters. *International Journal of Hydrogen energy*, *40*(1), 735–745.
- Menter, F., Garbaruk, A., Smirnov, P., Cokljat, D., & **Mathey, F.** (2010). Scale-Adaptive Simulation with Artificial Forcing. Dans *Progress in Hybrid RANS-LES Modelling* (pp. 235-246). Springer.
- Ruffio, E. (2011). Estimation de paramètres et de conditions limites thermiques en conduction instationnaire pour des matériaux anisotropes. (I.-E. (http://www.theses.fr/2011ESMA0019), Éd.) These.
- **Zaepffel, D., Mathey, F., Bourgeois, T., & Ammouri, F.** (2016). CFD analysis of the filling process of a H2 vehicle tank. *World Hydrogen Energy Conference*. Zaragoza.

New protocol proposal

Speaker: **Frederic Barth**
H2Nova for Honda R&D Europe

Key concepts: Hot Case and Cold Case

HyTransfer

- The values of the parameters determining the final temperature inside the vehicle tank are unknown.
- Therefore, two theoretical extreme cases are agreed upon.

Hot Case situation

Combination of assumptions leading to the highest temperature at end of fill

Parameter	Worst case
Tank capacity & vessels	Tank composed of a **single Type 4** vessel
Piping heat capacity and pressure drop*	**Highest** possible thermal mass **Highest** possible pressure drop
Initial conditions inside tank – knowing Tamb	**Highest** possible (Hot Soak) temp. **Lowest** possible initial pressure
Applied filling conditions	**Highest** allowed delivery temp **Quickest** allowed fill

Cold Case situation

Combination of assumptions leading to the lowest temperature at end of fill

Parameter	Worst case
Tank capacity & vessels	Tank composed of **multiple Type 3** vessels
Piping heat capacity and pressure drop	**Lowest** possible thermal mass **Lowest** possible pressure drop
Initial conditions inside tank – knowing Tamb	**Lowest** possible (Cold Soak) temp. **Highest** possible initial pressure
Applied filling conditions	**Lowest** allowed delivery temp **Slowest** possible fill

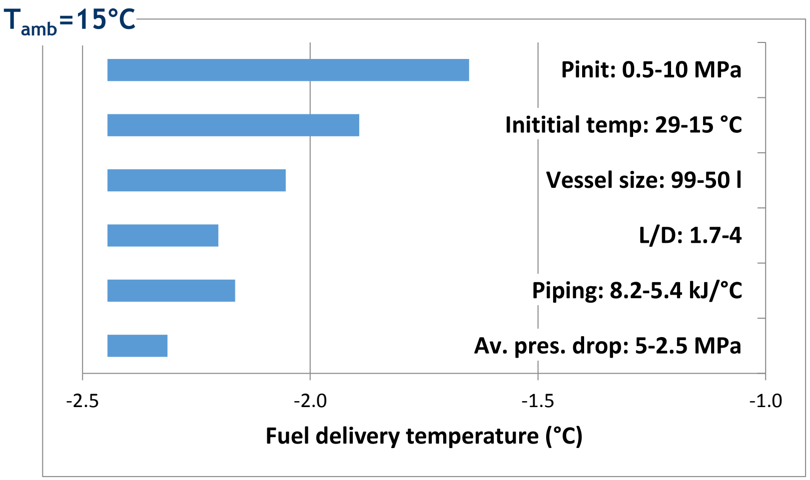
- a Hot Case situation is assumed *for all fills* to determine required means for avoiding overheating
- a Cold Case situation is assumed *for all fills* to determine required means for avoiding overfilling

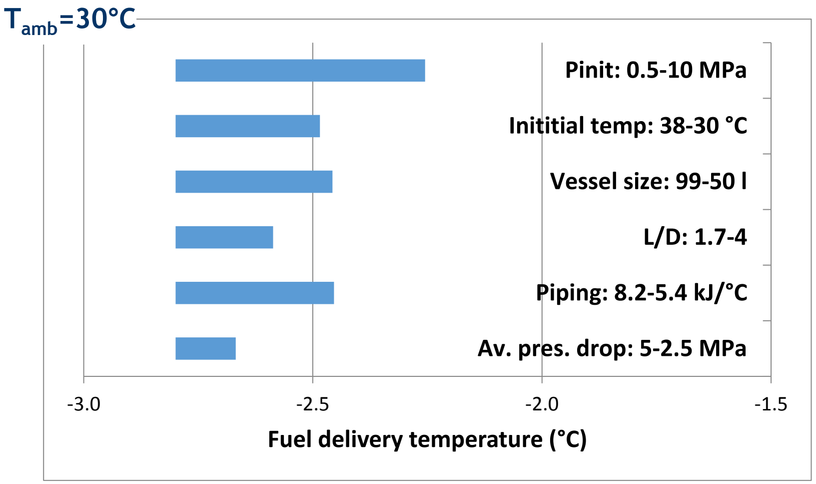
*Downstream of point where fuel delivery conditions are specified = hose break-away

The Hot Case adds up many conservative assumptions

Each Hot Case assumption contributes to lowering the required fuel delivery temperature, T_{Del} , compared to that needed in typical situations.

Sensitivity of required T_{del} to each Hot Case assumption



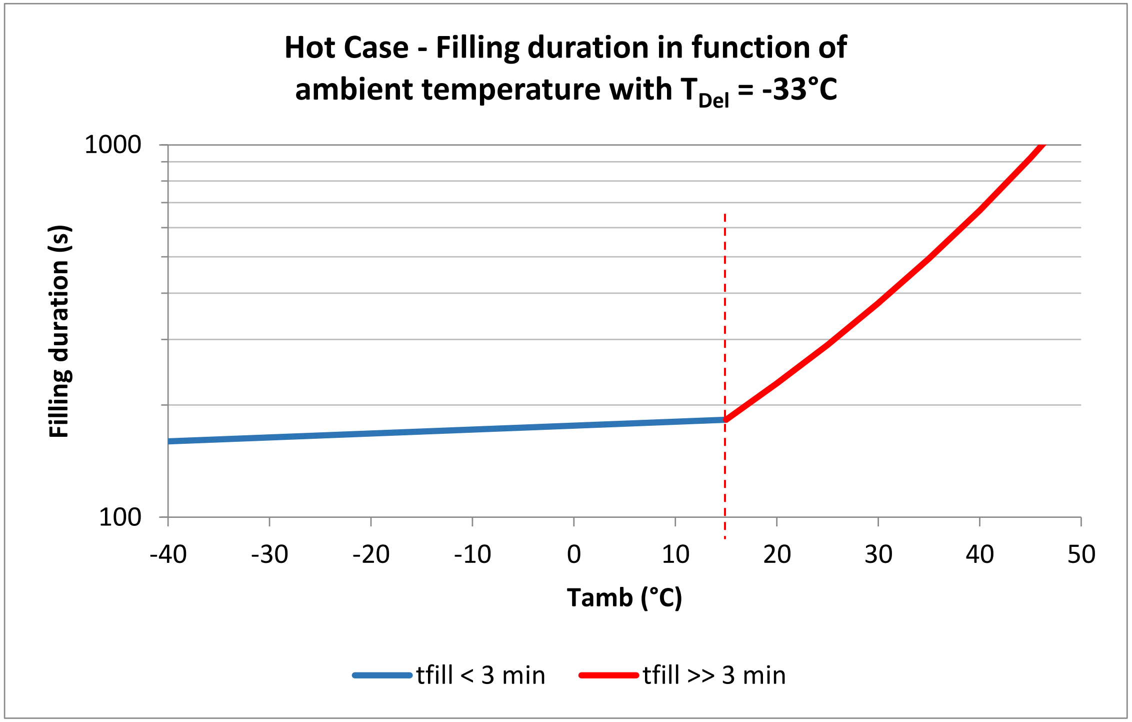


The stacking of conservative assumptions has a large cumulated impact on the level cooling applied *all the time*.

→ a high level of cooling is systematically applied in order to achieve *nominal end-of-fill conditions* for a theoretical situation *that will practically never occur*.

Targeting 100% SoC - i.e. a 85°C gas temperature - for the Hot Case results in long fuelling durations

Assumed fuel delivery temp (SAE 2601): T_{Del} = - 33°C
Process control target: $T_{Gas} \leq$ 85°C for Hot Case



Beyond 15°C, the filling duration needed to keep $T_{gas} \leq$ 85°C for the Hot Case increases exponentially

Opportunity 1:

Apply “de-rated” conditions for the Hot Case

- Proposed new filling criterion for the Hot Case:

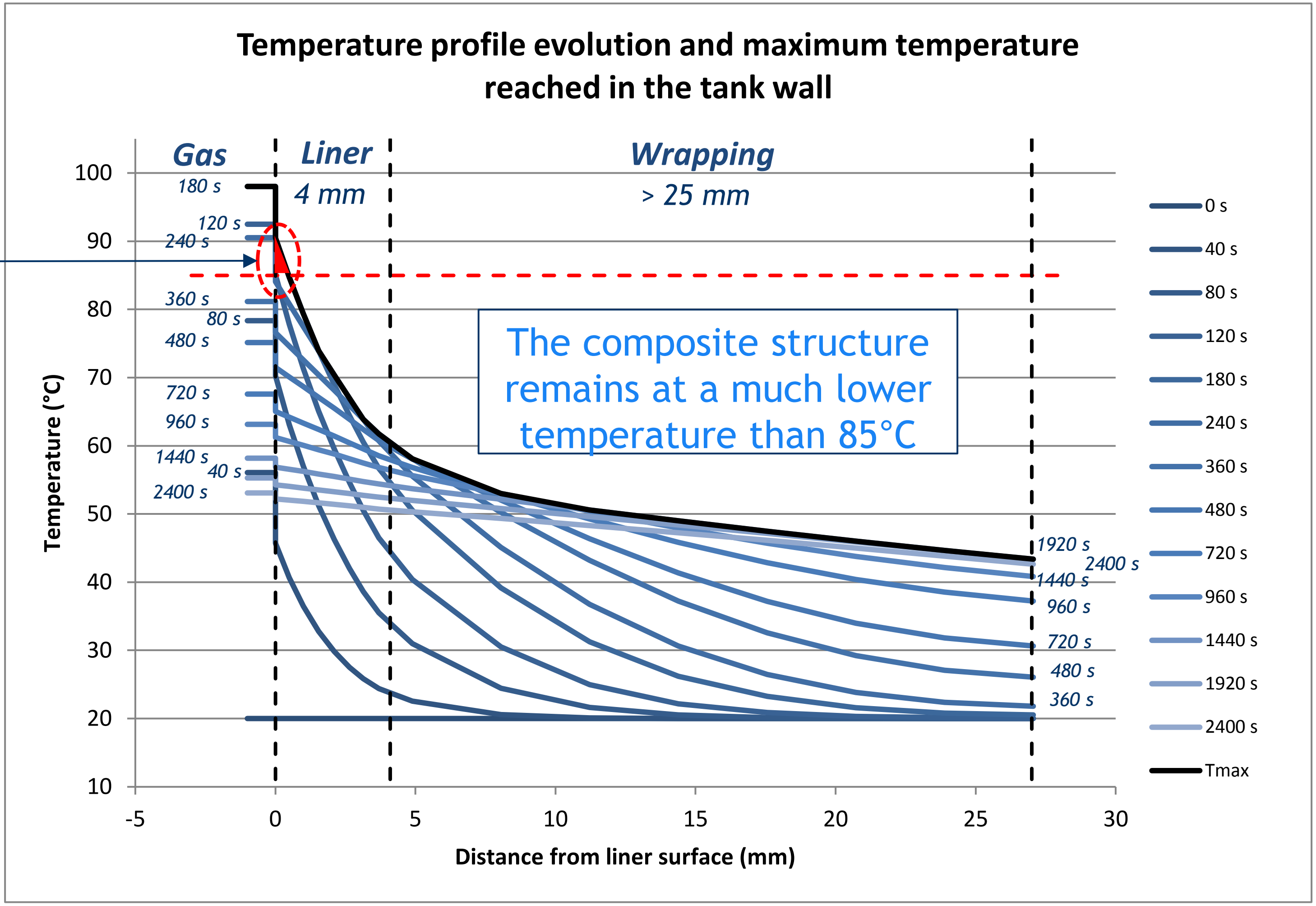
  Allow the temperature to temporarily exceed 85°C by accepting the SoC to be limited to 97% at the max delivery pressure of 87.5 MPa

- Taking into account the pressure drop defined for the Hot Case, this corresponds to a peak gas temperature of 98°C.

Impact on material temperature ?

Opportunity 1:
Apply “de-rated” conditions for the Hot Case

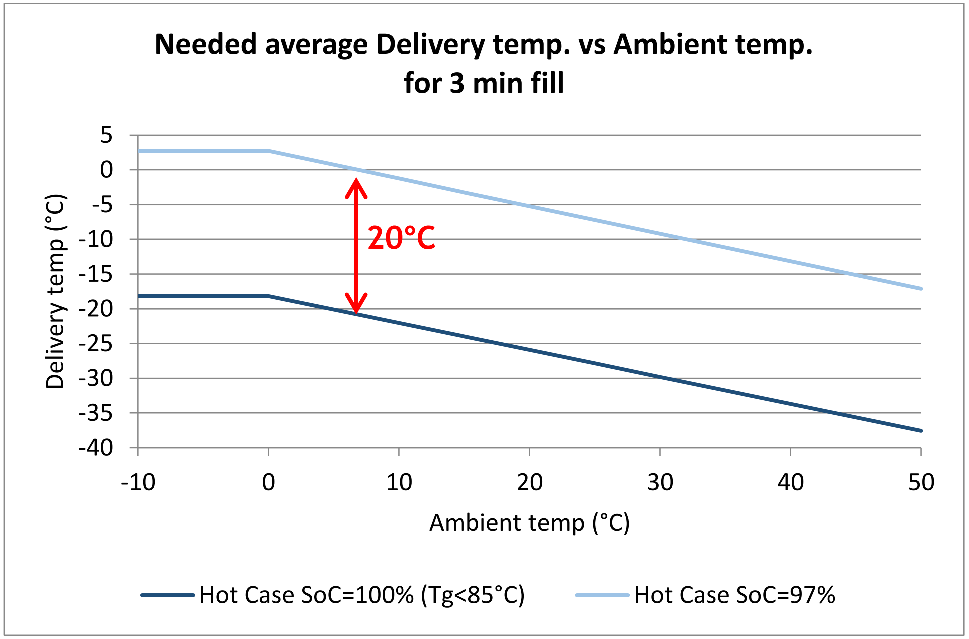
Only a very small amount of material is exposed, during less than 2 min, to temperatures above 85°C, without exceeding 95°C

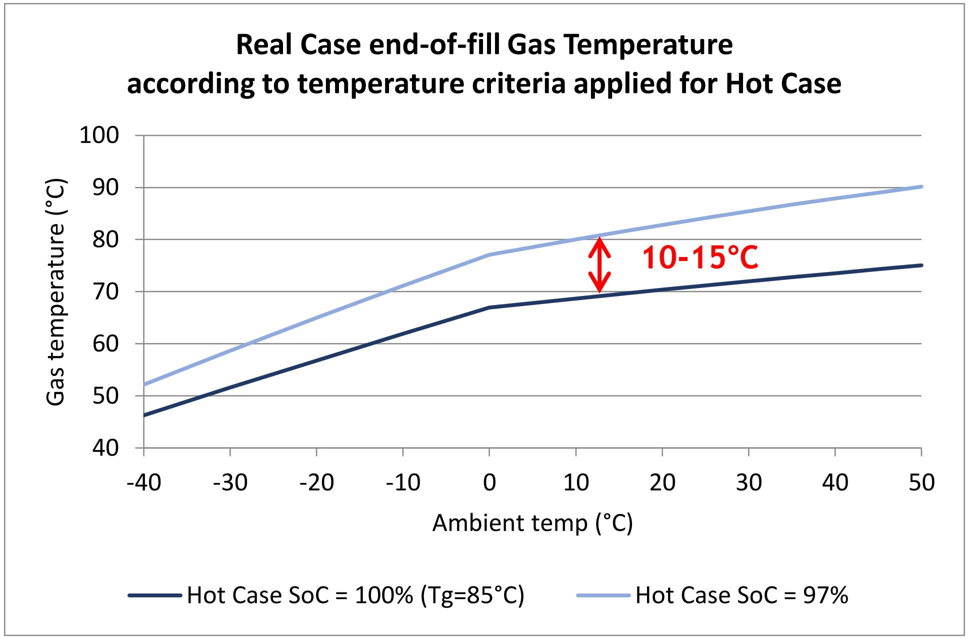


No change needed to 85°C temperature for tank design qualification testing!

Benefits of accepting "de-rated" conditions for the Hot Case (SoC of 97% at delivery pressure of 87.5 MPa)

- The average delivery temperature can be increased by about 20°C, allowing fills can be carried out in 3 minutes or less *in all cases*.
- Although end-of-fill temperatures will be increased by 10 to 15°C, the gas temperature will very likely not exceed 85°C in practice – so tanks will still be filled to 100%.





Charts show calculations done for HEX 37 l tanks with SAE Hot Case assumptions regarding initial conditions and piping.
Real case assumptions : Initial pressure = 10 MPa, Initial temp. = Ambient temp. , Piping heat capacity and pressure drop equal reduced by 50% compared to Hot Case assumptions.

The impact on material temperatures of the new Hot Case fill criterion is acceptable – key arguments

- Only the liner can encounter temperatures above 85°C – in such an event, this will last less than 2 minutes, and these temperatures will not exceed 95°C.
- The only possible detrimental effect of increasing the peak temperature from 85°C to 95°C in the liner material is acceleration of creep.
- Tank qualification includes maintaining a pressure of 88 MPa at 85°C for 1000 h. For the thermoplastic materials used, in a situation of liner creep, these testing conditions generate more creep than an exposure to 95°C during 2 min at each fill over tank lifetime (<30 h assuming a Hot Case situation at each and every fill).
- The material behaviour above can be ensured by specifying a minimum Vicat Softening Temperature of 110°C.
  Note: pressure increases the VST.
- All the other components (bosses, including the boss-liner interface, on-tank valve) will see slightly higher temperatures than today (increase <10°C); however these temperatures will remain well below 85°C.
- These components are all tested to 85°C during hydraulic cycling tests.

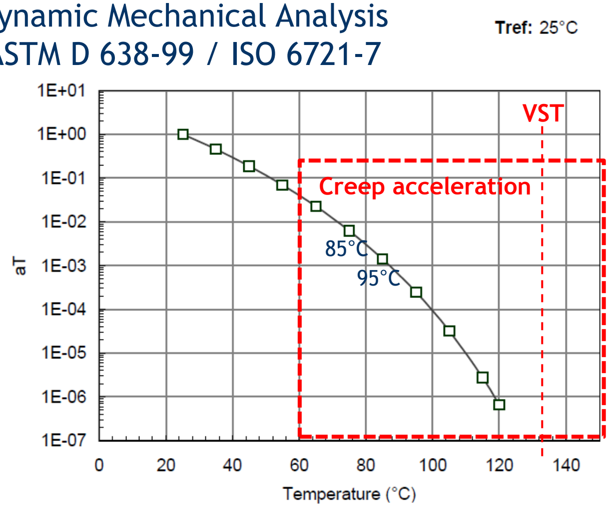
Viscoelastic behaviour of semi-crystalline thermoplastics
Example of HDPE

Temperature shift factor for HDPE - example

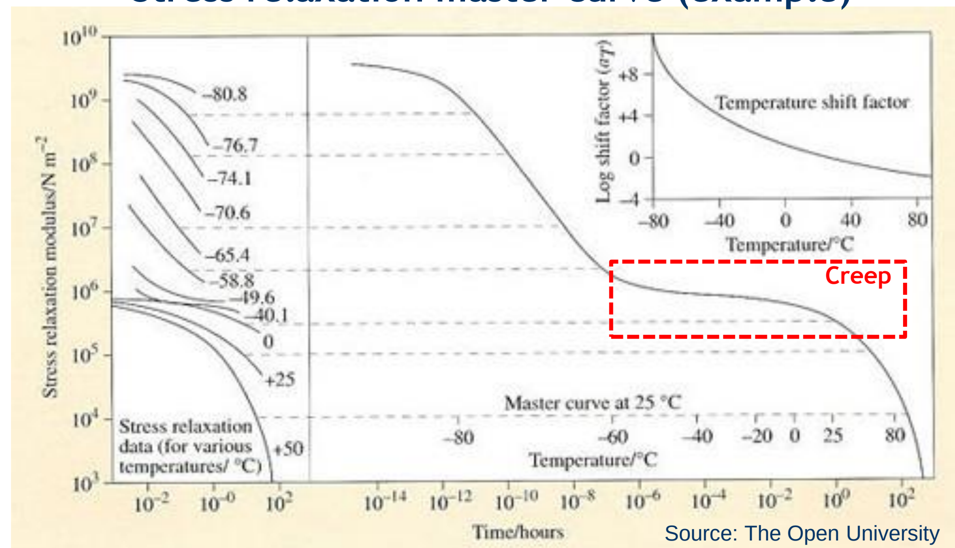
a_T vs Temperature

Dynamic Mechanical Analysis
ASTM D 638-99 / ISO 6721-7

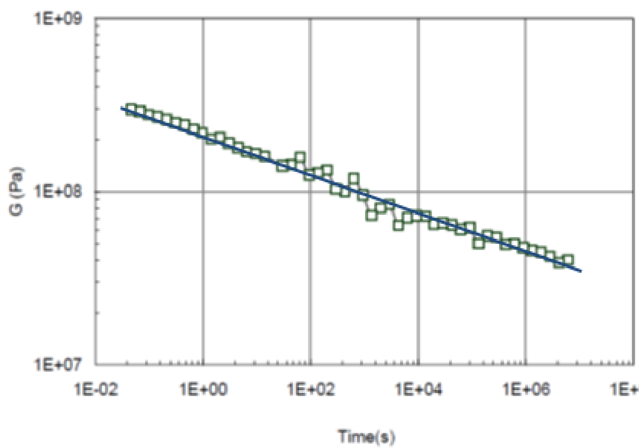
Temp °C	aT
25	1.00E+00
35	4.60E-01
45	1.90E-01
55	7.02E-02
65	2.27E-02
75	6.26E-03
85	1.42E-03
95	2.50E-04
105	3.22E-05
115	2.76E-06
120	6.63E-07



Stress relaxation master curve (example)



Relaxation vs. Time Mastercurve



RESULT OF ANALYSIS

176 h @ 95°C is needed to have the same creep as for 1000 h @ 85°C

T (°C)	a_T	t (h)
85	1,42E-03	1000
95	2,50E-04	176
103,6	4,29E-05	30

Creep acceleration in HDPE resulting from a 10°C temperature increase

T (°C)	a_T	$a_T(T\text{-}10°C)/a_T(T)$
85	1,42E-03	4
95	2,50E-04	6
105	3,22E-05	8
115	2,76E-06	12

The temperature must be within 15°C of VST (135°C), to have creep accelerate by a factor > 33 (1000/30) as a result of a 10°C increase.

Analysis of potential impacts of the proposed new criterion (1/2)

HyTransfer

Question	Analysis
Effect on H_2 permeation ?	- The steady state permeation rate approximately doubles with a temperature increase of 10-15°C. - However, an additional temperature elevation of 10-15°C lasting only 2 minutes will not significantly impact the amount of H_2 permeated, since the permeation response time is much greater (hours to days).
Effect on other on-tank components ?	- Valve, PRD and seals are qualified for operation at up to 85°C. - These components are all part of the metallic valve-boss assembly in thermal contact with the cold delivered gas; the maximum temperature they reach during fueling is therefore much lower than 85°C (typically 30°C lower than the gas temperature) and not significantly impacted by the gas temperature inside the tank. - The main effect of the new criterion is that these components will not be exposed to the low delivery temperatures (<-33°C) currently applied and will be operated at temperatures closer to ambient.
Impact in case of non-homogenous gas temperature ?	- Non-homogeneous temperatures need to be prevented already today through requirements on injection conditions or on-tank valve qualification. - Shorter filling durations resulting from the new criteria reduce the likelihood of stratification, however higher max temperatures (by 10-15°C) can be expected also if stratification does occur. - This increases the importance of ensuring, by design of the in-tank valve, that stratification is avoided during 3 minutes fills.

This slide was not shown during the (live) Webinar.

Analysis of potential impacts of the proposed new criterion (2/2)

Question	Analysis
Impact on the liner-boss junction ?	- Due to their thermal capacity, the maximum temperature reached by the bosses is typically 30°C lower than the maximum gas temperature. The temperature at the liner-boss junction at both ends therefore does not exceed the qualification test temperature of 85°C.
Impact on liner aging ?	- The maximum amount of time that the liner could be exposed to temperatures between 85°C and 95°C is about [30] hours over tank lifetime. - Semi-crystalline thermoplastics such PA and HDPE are chemically stable and not susceptible to degradation from exposure to temperatures up to melt temperature.
Impact on the high temperature detection in the vehicles ?	- In normal refueling conditions, the bulk gas temperature may reach up to 98°C at end of fill. - The set point of the high temperature detection in the vehicles will need to be increased (e.g. to 98°C), otherwise the fueling process will be aborted before the target SoC is reached in situations closed to the Hot Case. - Sensor accuracy requirements would remain unchanged.
Impact on probability of exceeding the actual liner temperature limit ?	- The application of the new criterion leads to a general increase of end-of-fill temperatures of 10-15 °C; however achieving the needed level of cooling will be simpler and therefore more reliable than today (limit on average delivery temperature, rather than imposition of a temperature profile).

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Recommended adjustments to existing tank qualification requirements

- Liner material specification

  In EU reg. 406/2010, increase the minimum liner material Vicat softening temperature specification from 100°C to 110°C, in order to keep a difference of at least 15°C with the maximum liner surface temperature that could be reached (95°C):

  - *The softening temperature of polymeric materials from finished liners shall be determined based on the A50 method in ISO 306.*
  - *The softening temperature shall be ≥ 110 °C.*

OR

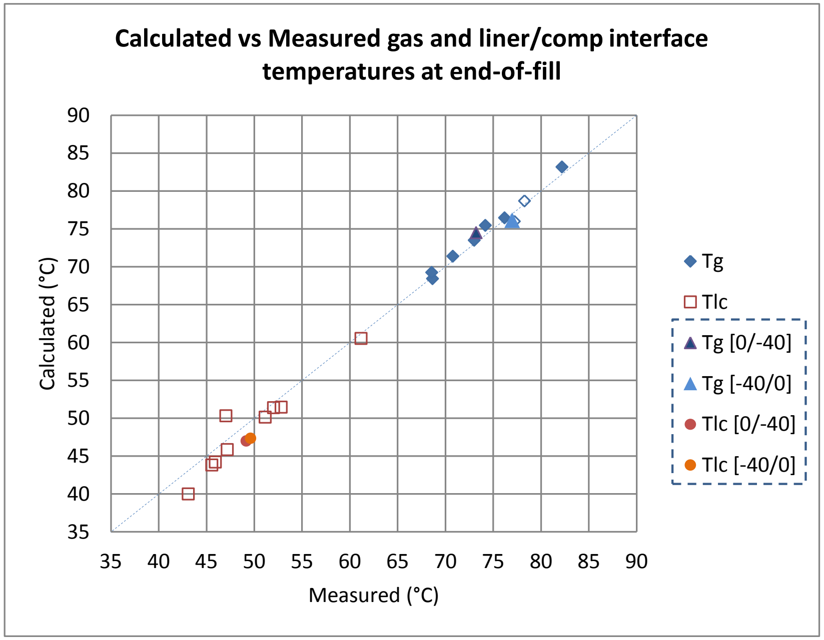
- Tank design verification test

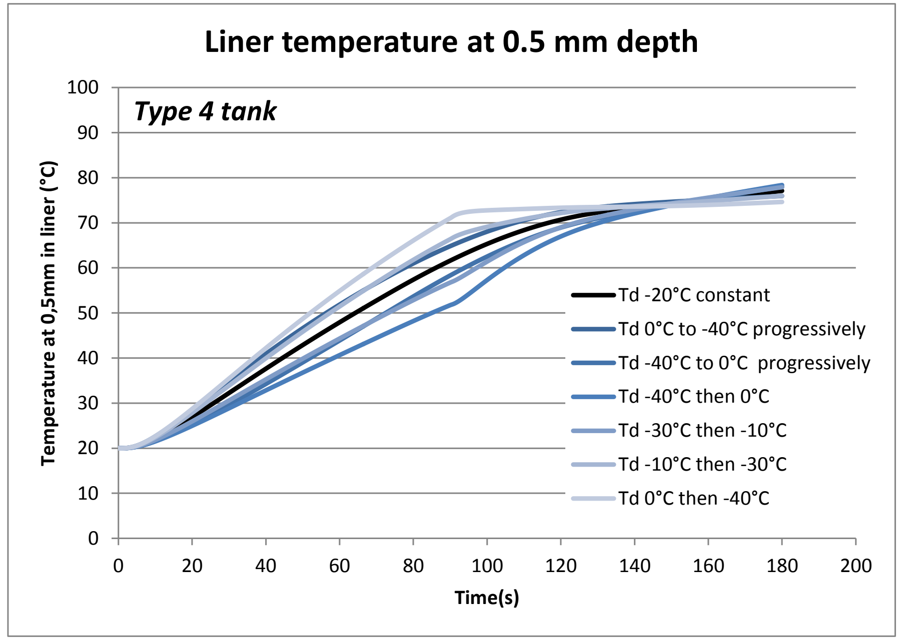
  Adjust the gas cycling test (required by EU reg. 79/2009, UN ECE R134, and ISO/CD 19881) in order to demonstrate that the tank withstands gas pressure cycling with a peak gas temperature of at least 98°C.

Currently used liner materials comply with the modified material specification. Furthermore, the above changes are not expected to significantly reduce the choice of eligible liner materials, since the tanks are anyhow tested for *continuous* operation to up to 85°C.

Opportunity 2:
Specification of mass averaged filling temperature only

- Experimentally verified observation: for fast fills of a given duration, the end-of-fill temperatures can be adequately predicted in a given tank knowing only the initial conditions and the mass averaged filling temperature.





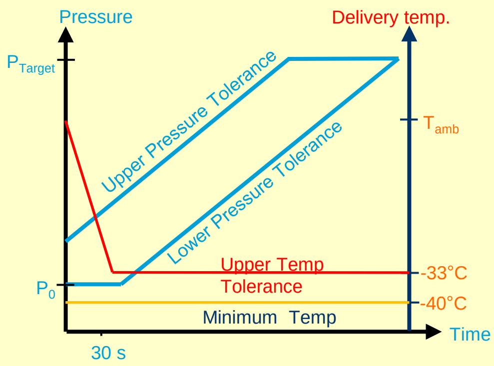
→ For ensuring that gas or material temperature will not exceed 85°C, only the mass averaged filling temp needs to be specified, not the filling temperature profiles.

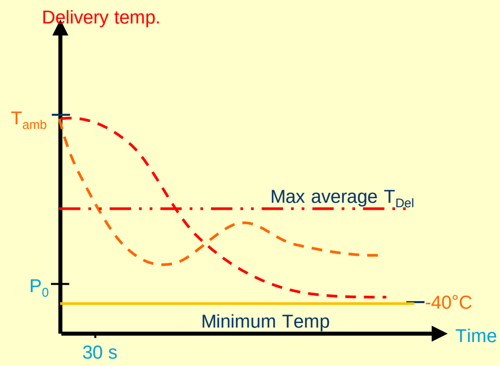
Op. 2: Practical benefits of specifying only the average filling temperature

P_{Fill} & T_{Del} profile specified

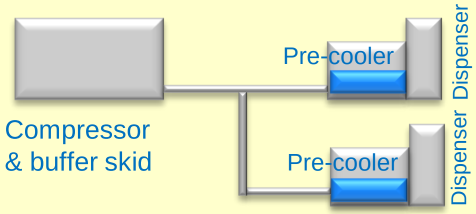
Only max average T_{Del} specified

Process control

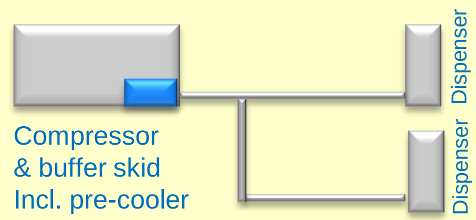




System integration



Pre-cooling needs to be located close to dispenser to be able to control T_{Del}
Large thermal capacity required



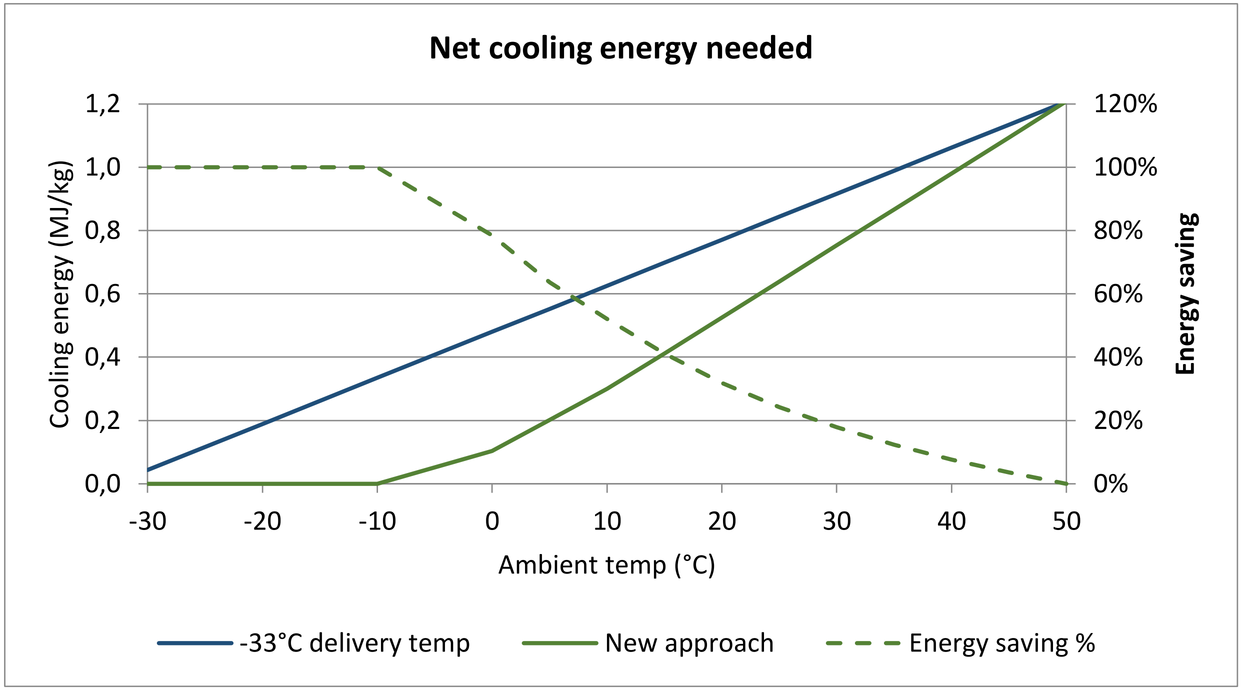
Benefits

- More freedom on filling temperature profile
- Less control needed of initial HRS conditions

- Integration of cooling and compression in a single skid
- Heat exchanger may have a smaller thermal capacity

HyTransfer

- Potential impact on the net cooling energy needed:



- Energy losses <u>in standby</u> are also reduced in similar proportions

Main ingredients of the new protocol proposal

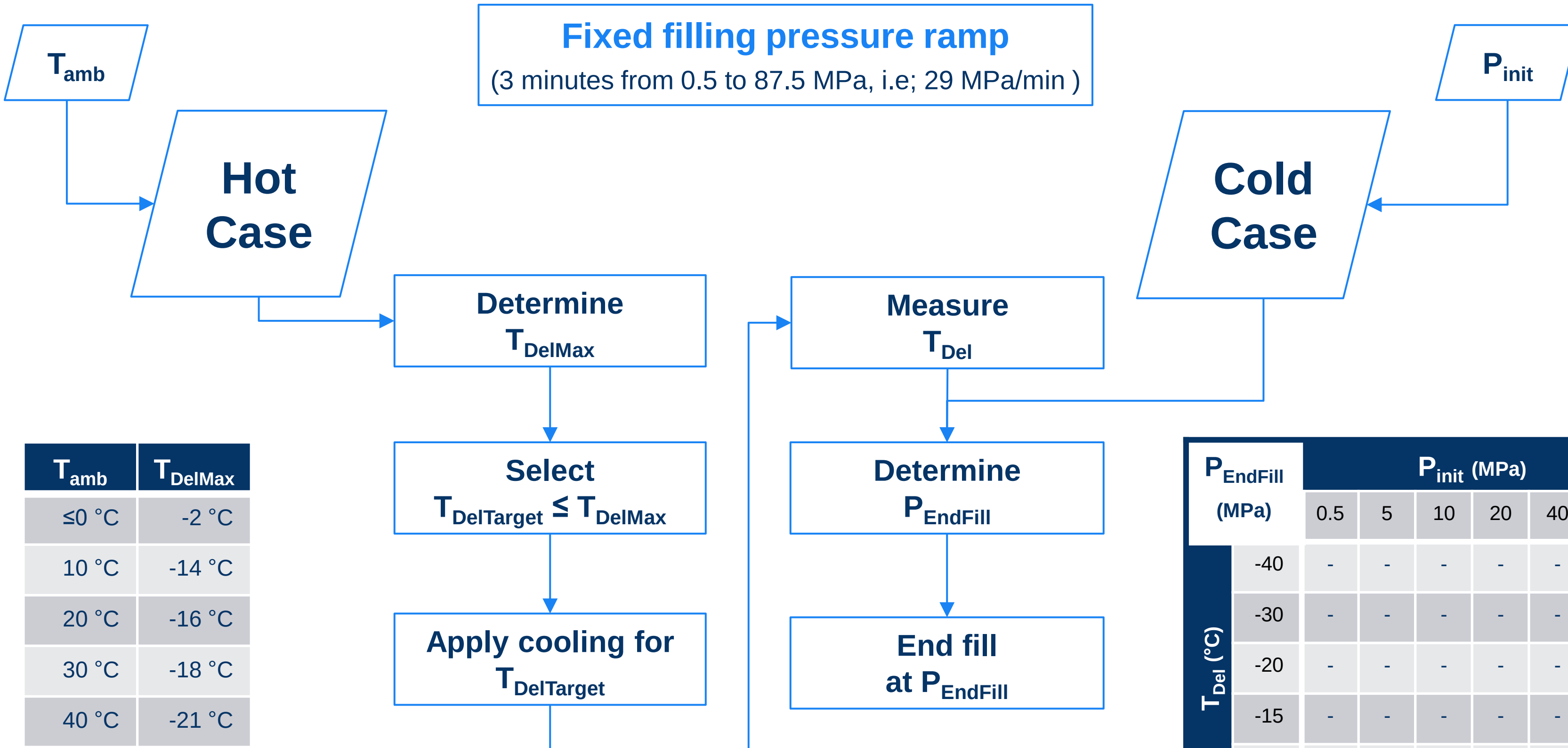
1. New end-of-fill criteria for the Hot Case
2. Fixed filling pressure ramp rate
3. Specification of the mass averaged delivery temperature only
4. Adjustment of the delivery temperature to the ambient temperature

Protocol definition items impacted by the new protocol proposal

Item	Sub-item	Definition
Location in the station where the delivery pressure and temperatures are specified		Just upstream of break away
Normal operating boundaries of the vehicle tank	Pressure limits	1,25 x Nominal fill pressure
	Max temperature limit	Peak gas temp of 98°C at the end of fill No change to 85°C temp of tank qualification tests
	Min temperature limit	-40°C
	Max state of charge (SoC)	107% for the Cold Case
"Hot Case" (HC) and "Cold Case" (CC) definition	Piping heat capacity and pressure drop	Actual heat capacity and pressure drop of the HRS may be taken into account.
	HC initial pressure	0.5 MPa, whatever the actual initial pressure
	All other HC and CC parameters	Same as SAE J2601
Fuel delivery boundaries	Maximum mass flow rate	60 g/s
	Minimum delivery temperature	-40°C
	Delivery pressure profile	Constant pressure ramp rate
	Delivery temperature profile	Only the mass averaged temperature is specified
Fuel delivery parameters	Delivery pressure ramp rate	Fixed: 29 MPa/min
	Delivery temperature	Variable: maximum value in function of T ambient

Proposed HyTransfer fuelling protocol - Simplified flow chart

Shown for fuelling without communications



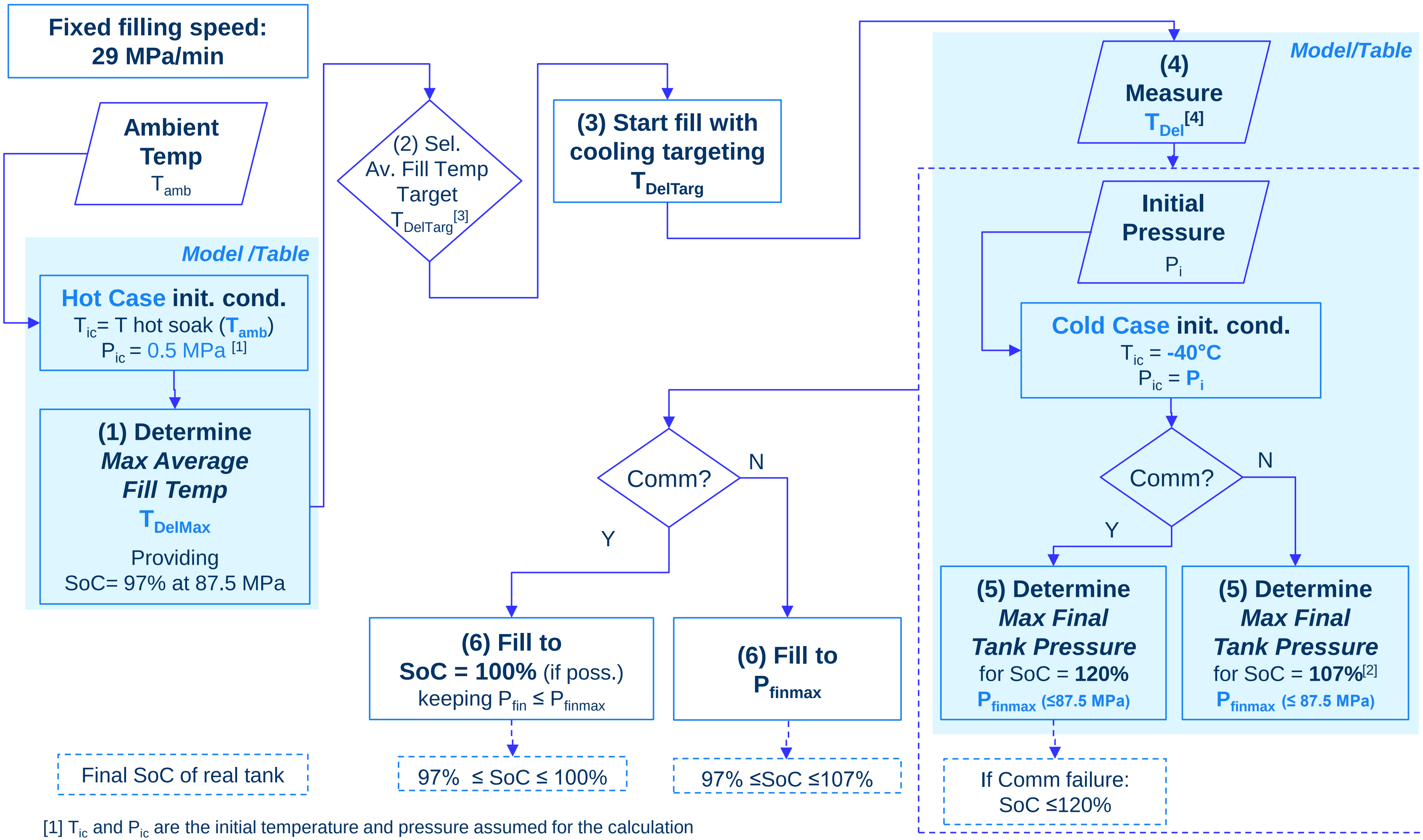
T_{amb}	T_{DelMax}
≤0 °C	-2 °C
10 °C	-14 °C
20 °C	-16 °C
30 °C	-18 °C
40 °C	-21 °C
50 °C	-23 °C

$P_{EndFill}$ (MPa)		P_{init} (MPa) 0.5	5	10	20	40	70
T_{Del} (°C)	-40	-	-	-	-	-	-
	-30	-	-	-	-	-	-
	-20	-	-	-	-	-	-
	-15	-	-	-	-	-	-
	-7	-	-	-	-	-	-

Tamb: ambient temperature
T_{DelMax}: maximum mass averaged delivery temperature
$T_{DelTarget}$: mass averaged delivery temp.target selected by the HRS
T_{Del}: mass averaged delivery temp actually applied by HRS

P_{init}: Iinitial pressure
$P_{EndFill}$: end-of-fill pressure

Proposed HyTransfer fuelling protocol - Flow chart



[1] T_{ic} and P_{ic} are the initial temperature and pressure assumed for the calculation
[2] When SoC ≤ 107%, tank pressure will not exceed 87,5 MPa if temperature is raised to a maximum ambient temp. of 50°C
[3] $T_{DelTarg}$, must be lower than T_{DelMax}
[4] continuously throughout fill

This slide was not shown during the (live) Webinar.

New protocol tables

Speaker: **Thomas Bourgeois**
Air Liquide

Example of table 4-7 kg with no communication (extract of protocol)

Ambient temperature (°C)	Maximum mass-averaged delivery temperature (°C)
-40	-11
-30	-11
-20	-11
-10	-11
0	-12
10	-14
20	-16
30	-18
40	-21
50	-23

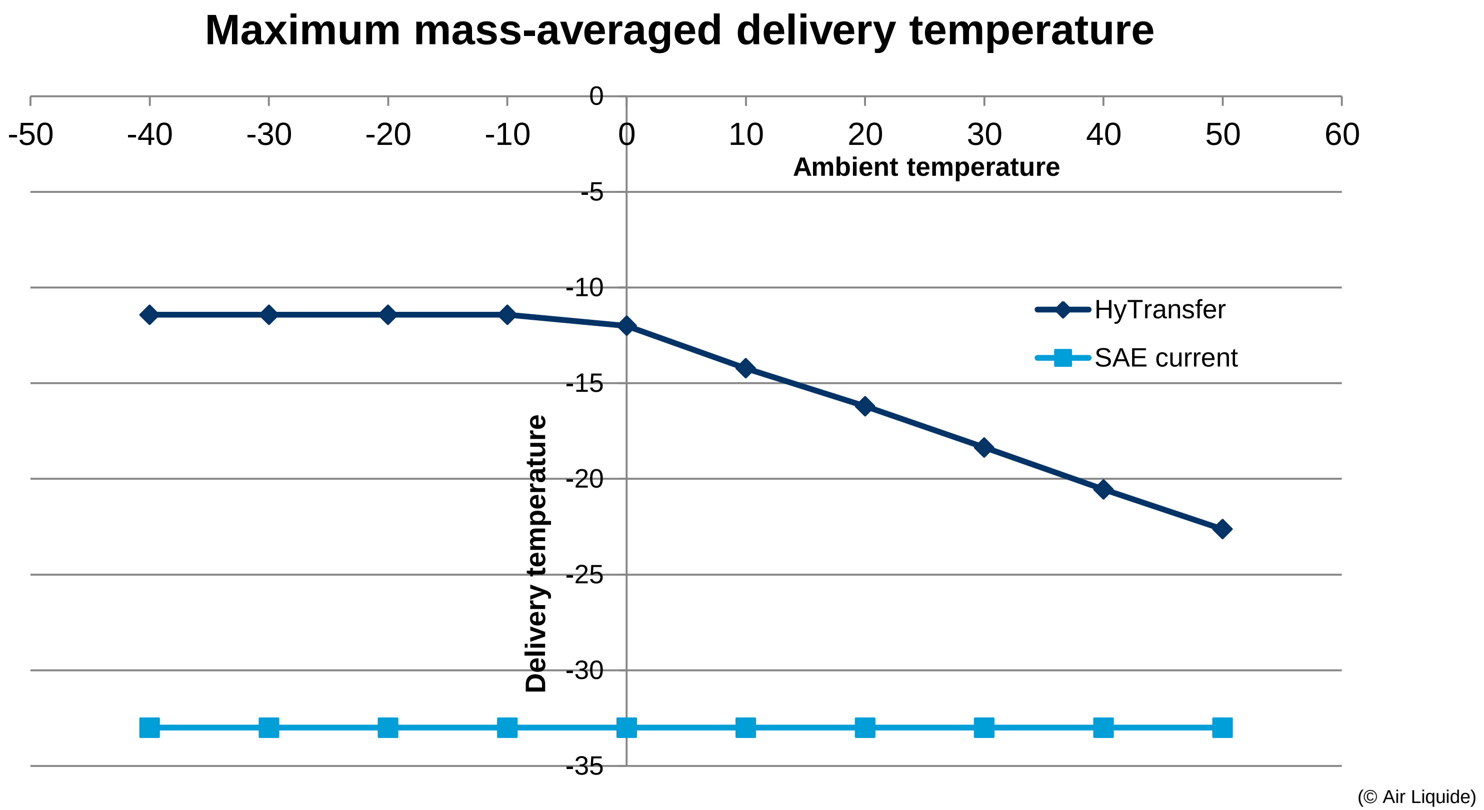
Final fillling pressure (bar) — Ambient temperature 20°C

Average delivery temperature (°C)	Initial pressure (bar)								
	5	**20**	**50**	**100**	**200**	**300**	**400**	**500**	**600**
-40	848	847	843	837	824	810	795	779	761
-30	857	855	852	847	835	818	801	783	763
-20	865	863	860	853	841	827	807	787	766
-10	875	873	868	862	848	834	816	793	769
0	875	875	875	869	855	840	824	799	773
10	875	875	875	875	859	843	827	804	775

Disclaimer: These tables are preliminary. They should not be used "as is" on a station. Further additional validation of the proposed protocol should be performed before being usable in a hydrogen station."

- Modelling hypotheses and validation steps will be detailed in HyTransfer deliverables D3.3, D3.4
- Hot and cold case assumptions used here (piping, etc.) will be detailed in HyTransfer deliverable D5.1
- Mass-averaged temperatures presented are those that should be respected at the end of filling. For high ambient temperatures, not only this, but mass-averaged temperature limits at different filling times will be provided.

Example of table 4-7 kg with no communication



- These first results permit to do a technico-economic evaluation of the HyTransfer approach

Techno-economic impact

Speaker: **Jan Zerhusen**

Ludwig-Bölkow-Systemtechnik

Scope of the techno-economic impact analysis

Analyze the impact of an improved refueling protocol on:

- Refueling performance
  (fueling time)
- Pre-cooling requirements and impact on costs
  (CAPEX and OPEX, fuel costs)
- Energy requirement and resulting CO_2-emissions
- FCEV user experience
  (Queuing probability and queuing time e.g. @ peak hours)

Out of project scope:

- Impact on the vehicle and/or vehicle components

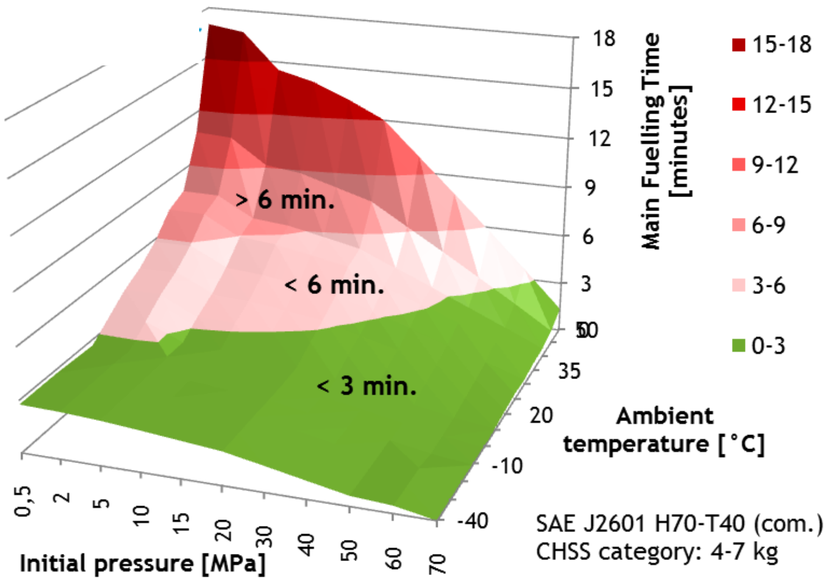
Benchmark fueling protocol:

- SAE J2601 H70-T40 (communication fueling)

Direct comparison of protocols' fueling performance

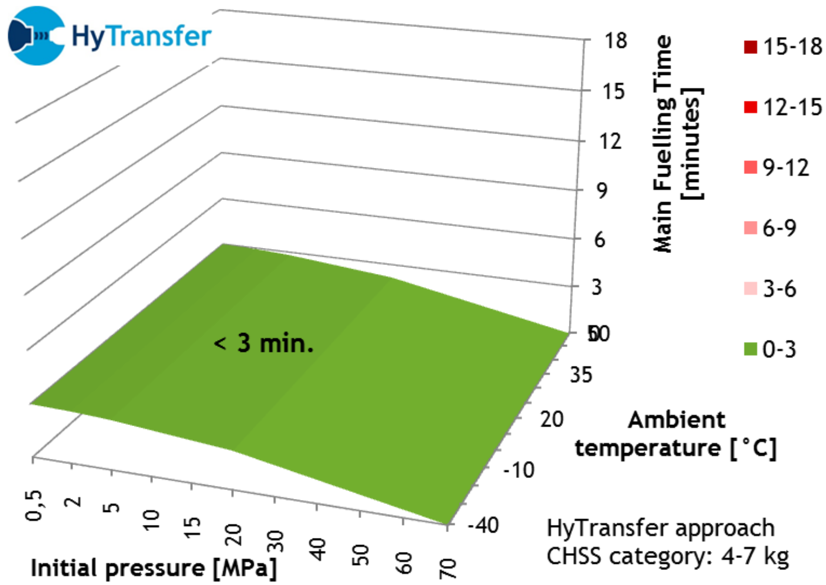
SAE J2601 H70-T40 (com. fueling)

Protocol leads to long fueling durations at high ambient temperatures and low initial vehicle tank pressure



HyTransfer approach

This new approach always assures a fueling time of 3 minutes or below

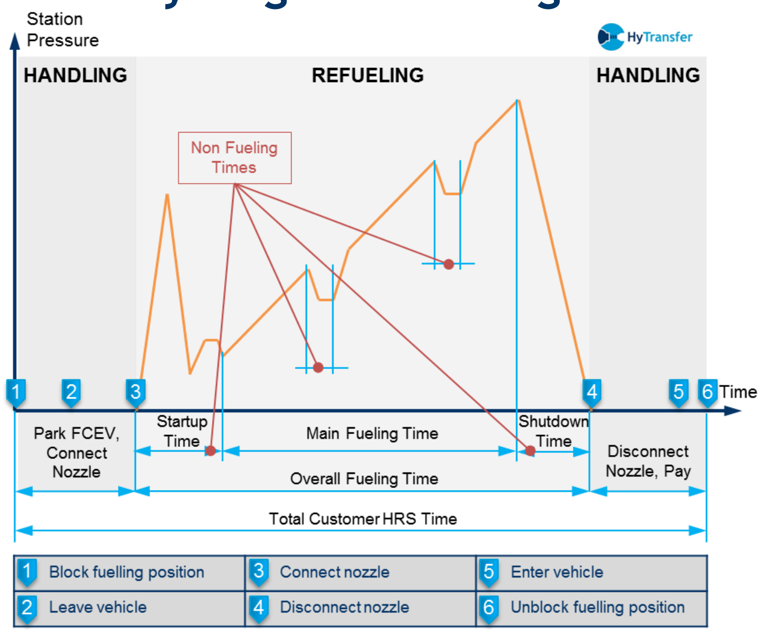


- Significant improvement for ambient temperatures above 10°C
- Fueling time with HyTransfer approach independent of ambient temperature

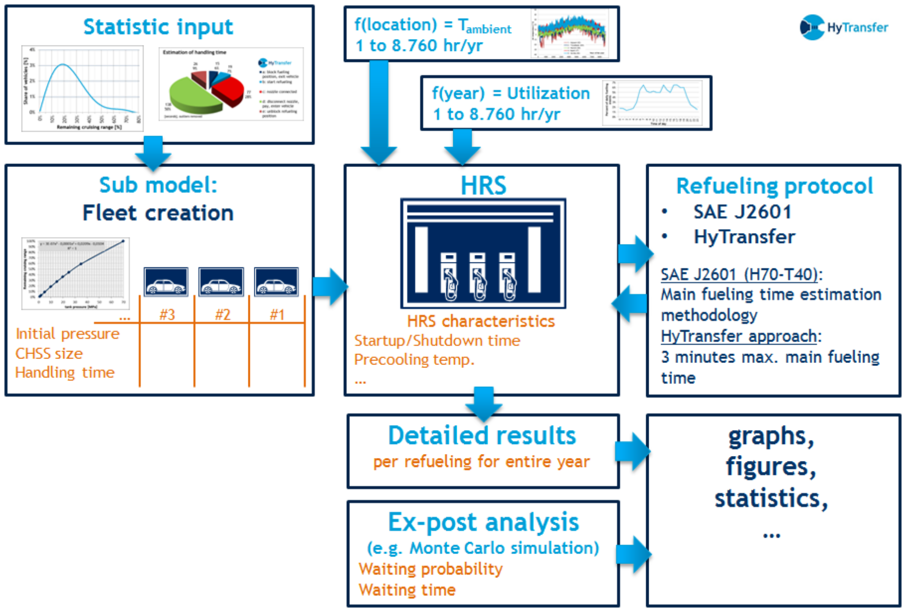
Methodology impact analysis

- Impact evaluation based on simulation:
  - HRS operation for one year (hourly temperature profiles, defined FCEV fleet)
  - 3 different European locations (hot, mild and cold climate conditions)
- Two stages of commercialization considered:
  - Early market: 2020, small HRS @ 20% of nominal capacity utilization
  - Advanced market: 2030+, medium HRS @ 70% of nominal capacity utilization

Hydrogen refueling



Simulation model



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Results (1/2): Impact of reduced pre-cooling requirements

A reduced pre-cooling requirement significantly reduces investments for and operating costs of a pre-cooling unit. Comparison of requirements:

- SAE J2601 H70-T40: **fix** pre-cooling temperature for all fuelings (-33 to -40°C)
- HyTransfer approach: average pre-cooling temp. **adapted** to ambient temp. needs (-7 and -23°C for ambient temp. between -40 and 50°C, respectively)

	Unit	Improvement (compared to SAE J2601)	
Scenario:		Early market [a]	Advanced market [b]
Reduced investment (pre-cooler)	%	-40%	
Saved electricity (pre-cooling) [c]	kWh_{el}/kg_{H2}	-2.5	-0.7
Cost reductions [c] (mutually excluding)	€/kg_{H2}	-0.8	-0.2
	€/vehicle life [d]	-1,400	-360
	€/HRS/year	-12,000	-20,000
Reduced CO_2 emissions [c, e]	g_{CO2}/kg_{H2}	-1,338	-213

a) Early market = 2020, small HRS (200 kg/day) @ 20% utilization (of nominal dispensing capacity)
b) Advanced market = 2030, medium HRS (400 kg/day) @ 70% utilization (of nominal dispensing capacity)
c) Average value, results slightly different for hot, mild and cold climate locations
d) Based on 0.9 kg/100km and 200.000 km vehicle life;
e) Based on 2020: 535 g_{CO2}/kWh (DE 2015) and 2030: 304 g_{CO2}/kWh (DE 1990 -60%)

Results (2/2): Impact of reduced “Main Fueling Time”

- For a HRS using SAE J2601 H70-T40 protocol, critical hours in the year are when high demand meets high ambient temperatures.
- The following results are average values for the 5% (= 400 hours) most critical hours of a year:

	Unit	SAE J2601 (H70-T40)		HyTransfer approach	Improvement
Climate condition: [a]		hot	mild/cold	independent	
HRS dispensing capability [b]	Cars/hour/ dispenser	6.9	8.7	9.2	+5 to +33%
Average fueling time [c]	Minutes	5.3	3.6	3.2	–10 to –40%
Queuing probability [e, f]	%	63	54	51	-5 to -20%
Customer queuing time [d, e, f]	Minutes	6.9	5.9	5.5	-7 to -20%

a) Hot = southern Europe e.g. Spain; mild/cold = middle and northern Europe e.g. Germany, Finland
b) Fueling protocol and customer handling caused dispensing limit (unlike technical limitations)
c) Time between connecting and disconnecting nozzle (including 45s for HRS startup, shutdown and other non-fueling times (e.g. pressure pulse, leak check, hydrogen pressure bank switching,…)
d) Average waiting time for unoccupied dispenser
e) Queuing probability and queuing time depends on the total time a vehicle occupies a dispenser. This time also includes e.g. handling time and payment. As a consequence, the improvement of the fueling protocol is relativized in this number.
f) For this analysis, up to 6 vehicles per dispenser per hour have been considered (in accordance with H_2 mobility Germany specifications).

Key improvements enabled by new approach

Hydrogen fuel costs can be **reduced by 0.2 to 0.8 €/kg.**

- This translates into possible **savings for vehicle owners** between **25 to 90 €** on fuel costs per year.
- Alternatively a **HRS operator can increase profit** by up to **20,000 €** per year per station.

A **fueling time of max. 3 minutes can always be assured.** Significant improvement especially for hot climate zones (e.g. southern Europe) and during peak demand hours:

- **HRS operators can sell** up to **33% more hydrogen** per dispenser
- Vehicle users' refueling experience is significantly improved by
  - 20% reduced probability that dispenser is occupied by other vehicle
  - 20% reduced waiting time until next free dispenser is available
  - 40% shorter fueling time

This slide was not shown during the (live) Webinar.

HyTransfer

Main beneficiaries:

FCEV users	HRS operators	General public / others
Fast fueling	Increased peak performance	Improved energy efficiency
Lower fuel costs	Additional hydrogen sales	Reduced CO_2 emissions
Lower waiting probability (for unoccupied dispenser)	Reduced investment costs	Improved client experience
Shorter waiting times (for unoccupied dispenser)	Reduced operating costs	Improved technology acceptance
	Reduced HRS footprint	
	Expected increase of component reliability and lifetime*	

This slide was not shown during the (live) Webinar.

* Expected benefit, not investigated within this project

Recommendations to industry

Speaker: **Clémence Devilliers**
Air Liquide

- Which Industry is concerned by these recommendations?
  - OEMs / Integrators of tank system
  - Tank manufacturers
  - HRS manufacturers

1. Ensure homogeneous filling conditions (1/3):

– Why?

- **Filling protocoles are usually based on models that only predict average gas temperature**
- It prevents from hot spots / stratification, and therefore allows a **reduction of maximal gas temperature**
  - Difference between max and mean temperature less than 3°C: $T_{max\ gas} - T_{mean\ gas} < 3°C$
- It permits an optimization of filling protocol by increasing T_{del} of around 20°C

– How?

- Minimum gas velocity criteria (U) depending on the L/D ratio (short vs. long tank), ensured by fulfilling criteria on Q/d_{inj}^2 :

	Short tank : **$L-L_{inj} < 3*D$**	Long tank: **$L-L_{inj} > 3*D$**
Velocity criteria: - To prevent from **vertical gradient** - To prevent from **horizontal gradient**	**U > 5 m/s** No criteria	**U > 5 m/s** **U < 100 m/s**
Ratio **Q/d_{inj}^2**	$\frac{Q}{d_{inj}^2} > 314$	$314 < \frac{Q}{d_{inj}^2} < 1137$

With:
- **Q in kg/s** (H2 quantity filled in 3 minutes)
- **d_{inj} in m**

- It is recommended to adapt an injector on intank-valve with diameter (d_{inj}) depending on tank dimensions (L/D ratio) and capacity (m_{H2})

1. Ensure homogeneous filling conditions (2/3):

– Application:

Short Tank (L/D < 3)

Example: **36l tank** (Hexagon Lincoln)

- L/D = 2.4
- m_{H2} filled *(5-700 bar, 15°C)* = 1.53 kg
- Q = 8.5 10^{-3} kg/s (for a filling in 3 minutes)

- No vertical gradient :
  U > 5m/s ↔ d_{inj} < 5.2mm
- No horizontal gradient :
  Not applicable for short tank

Type IV - 36L
Hexagon Lincoln

Long Tank (L/D > 3)

Example: **531l tank** (Hexagon Lincoln)

- L/D = 5.9
- m_{H2} filled *(5-700 bar, 15°C)* = 22.4 kg
- Q = 1.24 10^{-1} kg/s (for a filling in 3 minutes)

- No vertical gradient :
  U > 5m/s ↔ d_{inj} < 19,9mm
- No horizontal gradient :
  U < 100 m/s ↔ d_{inj} > 10,4mm

Type IV - 531L
Hexagon Lincoln

1. Ensure homogeneous filling conditions (3/3):

– **False ideas:**

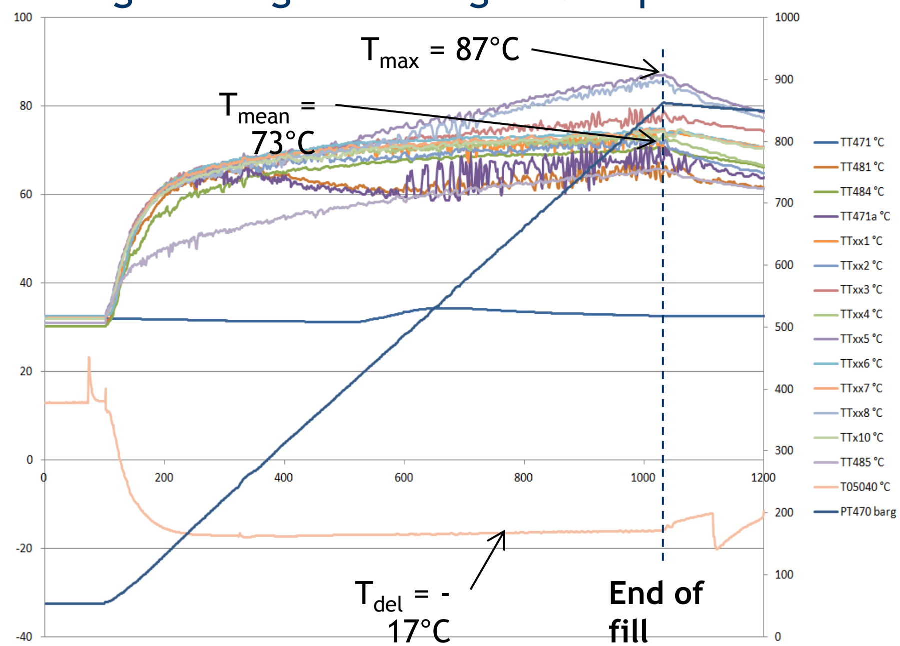
- « Increasing filling time (i.e. reducing filling pressurization ramp / flow rate) would reduce gas temperature »
  - **Not necessarily**: Mean temperature can be reduced, but stratification occurs and very high temperatures can be reached (up to 120°C depending on filling conditions)

– Remark:

- Stratification was observed during a filling according to SAE protocol

Filling conditions :
Table D30: **H70 / T20 / 7-10Kg Comm**

	SAE – Table D30	**Measured**
Pinit	50 bar	53 bar
Tamb	30°C	32°C
APRR	4,4 MPa/min = 0,73 bar/s	5,2 MPa/min = 0,87 bar/s
Ptarget	871 bar	866 bar



2. Demonstrate plastic liner material compatibility with respect to temperature limit of 95°C, by determining the Vicat softening temperature (VST)
   - VST must be greater than 110°C, i.e. 15°C above the maximal gas temperature reached by the liner surface (95°C), for the rare cases of Hot Case situation
3. OR: Perform a gas cycling test (as required by standards) with a peak gas temperature limit of 98°C.

3. Design HRS considering:
   - Reduced pressure losses:
     - HyTransfer calculation hypothesis:
       - Pressure losses of the vehicle remains unchanged compared to SAEJ (200 bar)
       - Pressure losses of the station **reduced of 100 bar**
         - » Hypothesis: 50 bar in HyTransfer (vs. 150 bar in SAE)
     - TOTAL : Pressure losses = 250 bar in HyTransfer calculations (350 bar in SAE)
   - Reduced thermal masses of components
     - Downstream to breakaway

Recommendations to RCS

Speaker: **Randy Dey**
CCS Global Group

Frédéric Barth
H2Nova for Honda R&D Europe

RCS recommendations

These recommendations are the result of consensus among the HyTransfer partners.

RCS recommendation #1:

This is the main RCS recommendation of HyTransfer – *uptake of the proposed HyTransfer refuelling protocol.*

It is recommended that the proposed refuelling protocol developed by the HyTransfer project in Europe be taken up by CEN and other international bodies. This is an important step towards meeting the interoperability requirements and timeline defined by the **Alternative Fuels Infrastructure Directive (AFID), 2014/94/EU, Annex II.**

RCS Recommendation #2:

This pertains to the Hot Case condition - *Liner material temperature rating.*

For the specific conditions and results for the Hot Case, it is recommended to allow the liner temperature to temporarily encounter 95°C.

It is recommended to specify a fuel delivery temperature allowing the gas temperature to reach 98°C in the rare event of a Hot Case situation. In actual situations, the gas temperature will generally not exceed 85°C with this fuel delivery temperature, and hence allow to achieve a 100% SoC.

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RCS Recommendation #2: (continued)

How to check/verify:

Liner material specification: According to existing requirements of # EU 406/2010, the Vicat softening temperature (VST) of the liner material should be rated 15°C over maximum temperature encountered. Therefore, for the maximum temperature that could be reached by the liner surface of 95°C, the liner material VST must be rated at 110°C minimum.

OR

Tank design verification test: Adjust the gas cycling test (as required by GTR 13 (sec 5.3.2 and Annex 3, sec 4.1), EU 406/2010 and ISO/CD 19881) to verify that the tank withstands pressure cycling with a peak gas temperature of 98°C.

RCS recommendation #3:

This pertains to the Hot Case condition – *prevention of temperature stratification.*

It is recommended that non-homogeneous gas temperature distribution (or stratification) be prevented.

How to check/verify:

<u>Specification</u> of injection conditions: The injection flow section in each vessel shall be such that injection velocity remains above 5 m/s throughout tank fill.

<u>OR</u>

Tank design verification <u>test</u>: In-tank valve testing on a reference tank in order to check that stratification is prevented when performing a 3 minute fill at constant pressure ramp rate from 0.5 MPa to 87.5 MPa.

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CEN/TC 268/WG5:

AFID calls out four hydrogen standards including Hydrogen Refuelling Stations, Fuel Specification, Refuelling Protocol and Refuelling Connectors to be in place in Europe by 31 December 2017.

In order to meet the timing imposed by the **AFID**, it is recommended to bring the proposed HyTransfer refuelling protocol to CEN to develop a Technical Specification (TS) as a first step on its way to an EN and ISO standard.

Path forward for the RCS recommendations

UNECE/WP29:

Some countries that are members of WP29 are considering round II in the revision of GTR 13 and the UNECE R134. So, it is timely that the HyTransfer recommendations regarding tanks, valves and sensors in vehicles be brought forward for their consideration.

EU/406/2010 and EC/79/2009:

Same as previous recommendation.

The proposed HyTransfer refuelling protocol is a new and innovative approach that will provide important benefits such as:

- Cost reduction of HRS construction (CAPEX) and operation (OPEX)
- Increased reliability and safety
- FCEV user experience

In recognition of the timeline of the **AFID**, it is recommended that a New Work Item (NWI) covering the proposed HyTransfer refuelling protocol be submitted by a Member State (MS) in Europe (for example – Germany via DIN) to CEN in order to develop a Technical Specification (TS) as an important first step.

In this way, the TS will give first hand experience using the proposed HyTransfer refuelling protocol and contribute to the further development of both, technology and standardization (EN, ISO...), in the coming years.

Thank you for listening!

Q & A Session

Please ask your questions via chat.

Today, we only have time to answer selected questions. Further questions and comments will be addressed and attached to today’s slides. You will receive the slides in the next days.

Questions received during/after the Webinar

- **Q: Does stratification only occur when using pre-cooled fuel delivery? And does the fuel delivery temperature effect the magnitude of the stratification?**
  A: No, stratification also appears with non precooled gas. We have been able to observe this on tanks filled with not precooled gas outside of the HyTransfer project.
  In principle, the fuel delivery temperature should not affect the magnitude of the stratification. This has not been verified experimentally, but we think that the magnitude of stratification is more affected by: the inlet speed of gas, the duration since the beginning of stratification, and the internal diameter of the tank. "

- **Q: One of the slides presented indicated that the new proposed protocol would achieve "Maximum State of Charge (SoC)" equal to 107% for non-communications. I'm wondering how this can be allowed and if it translates to exceeding 1.25 times the service pressure rating of the storage container (especially if 107% SoC is achieved at low ambient temperatures and then the vehicle is brought into a much warmer space)?**
  A: An SoC of 107% (if possible with the maximum filling pressure of 1.25 service pressure, i.e. 87.5 MPa) is technically acceptable for the Cold Case, because the pressure in a tank filled to 107% SoC with a filling pressure of up to 87.5 MPa - implying an end-of-fill temperature not exceeding 51°C - will not subsequently exceed this pressure outside of the fueling station, since 50°C is the maximum temperature that the tank will see in service independently of refueling.
  (Note: If the end the end-of-fill temperature for the Cold Case is greater than 50°C, then filling to 87.5 MPa will result in an SoC < 107%. Also in this case the pressure in the tank outside of the fueling station will not subsequently exceed 87.5 for the same reason.)

This slide was not shown during the (live) Webinar.

- **Q: One of the suggestions is to go to CEN and develop a new H2 fueling standard around the results of this study which later could become an ISO standard. Should there be another recommendation - bring the results of HyTransfer to the SAE J-2601 committee with the expectation of modifying the SAE J-2601 standard? Fueling standards are mostly harmonized today. Why is the HyTransfer team recommending a path that leads to divergent standards?**
  A: This is because SAEJ2601 already now cannot be reference from European legal documents like Regulations or Directives (see EU regulation 1025/2012) which has caused us significant problems in the development of ISO CD 19880-1 for the HRS layout in ISO/TC197 WG24. The latter cannot be referenced from the AFID and CEN has to develop an HRS standard which complies with the requirements of interoperability.
  In order to avoid the same mishap for the protocol, the suggestion is to develop a TS at CEN and then to forward it to ISO. You may be aware of that ISO these days plans to start a NWIP for an ISO 19880-7 for the refueling protocol, taking into account the SAEJ2601:2016 requirements, the MC formula and upcoming HyTransfer requirements. This is the way of harmonization taking into account the recent state of development on an international level: ISO.
  Formally SAE is not recognized as an international standard – although applied worldwide. If we want to have harmonized standards also being eligible to be taken up (referenced) by EU legislation via EN-adopted international standards, then the 'harmonization' has to happen as truly recognized global standards such as ISO or IEC.

- **Q: Why isn't one of the recommendations to modify SAE J-2601?**
  A: See answer above.

This slide was not shown during the (live) Webinar.

- **Q: Is the Hytransfer group planning on submitting their protocol to the CEN for standardization?**
  A: It is not planned that within the HyTransfer project any protocol is submitted e.g. to CEN for standardization. This is out of the scope of the project. The goal of the webinar was to present the most ambitious outputs of HyTransfer and thus open a discussion.

- **Q: Have you started to carry out a summary risk analysis on this new protocol? In the event of drift of the "Mass-Average delivery temperature", what are the potential consequences compared to the SAEJ 2601 protocol? What would be the recommendations for safety functions (again comparing with those of SAEJ2601)? In particular with regards to following the ramp rate corridor (which would be always the same for your protocol), with what margins?**
  A: We were not able to carry out this risk analysis within project because we were very busy up to the end with the finalization of the experimental program and the drawing up of the scientific results. This is undoubtedly one of the important points that remains to be dealt with for protocol definition.

This slide was not shown during the (live) Webinar.

Acknowledgement

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