Behaviour of liquid hydrogen tanks exposed to fire

Workshop No. 4
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Outline

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   Computational domain, setup and material properties
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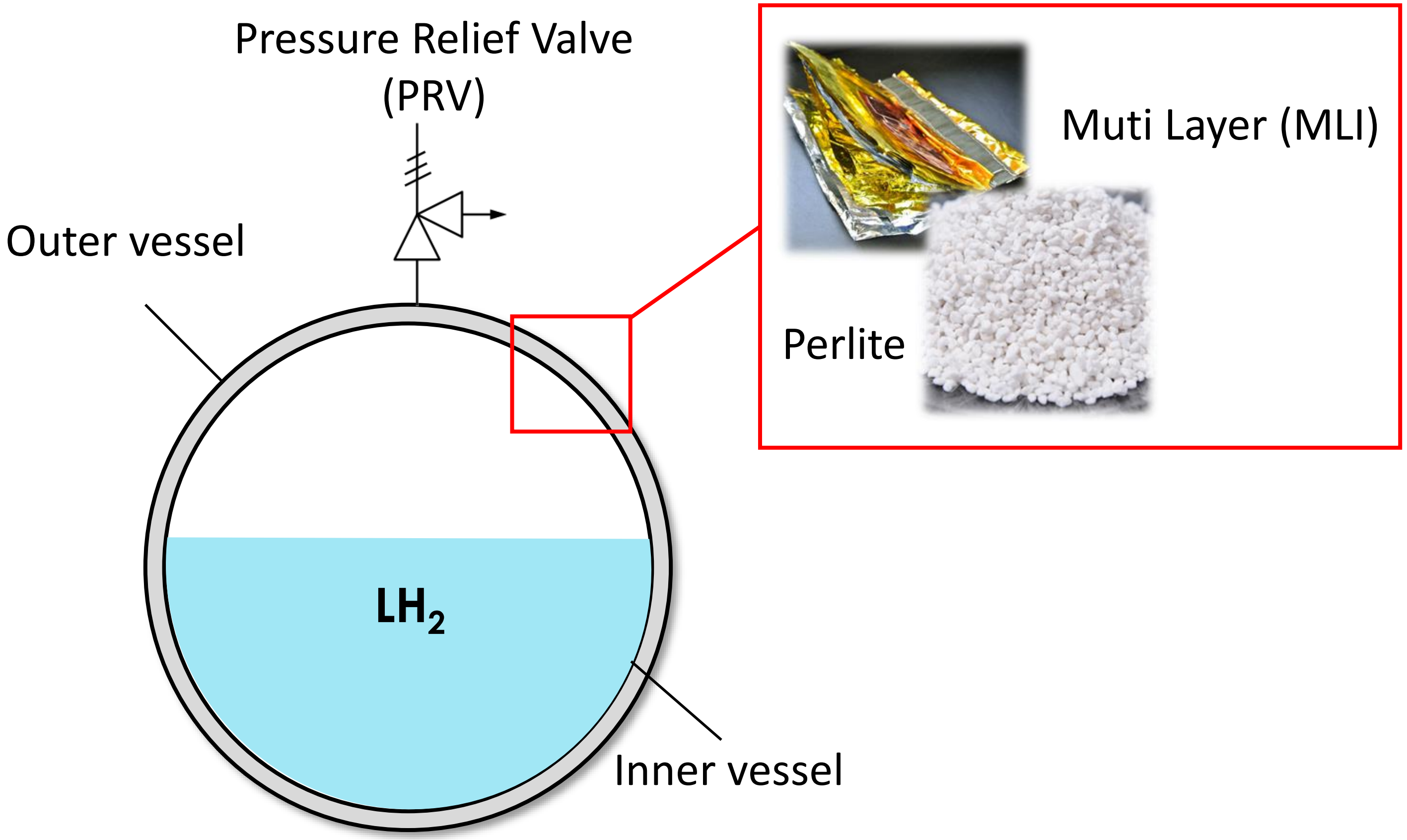
   Tank self-pressurization and time to failure
7. **Conclusions**
   Discussion and future development

Liquid hydrogen tanks exposed to fire

Thermodynamics and other phenomena

The **fire exposure** of a cryogenic storage component is one of the most critical accident scenario from a safety standpoint.



Liquid hydrogen tanks exposed to fire

Thermodynamics and other phenomena

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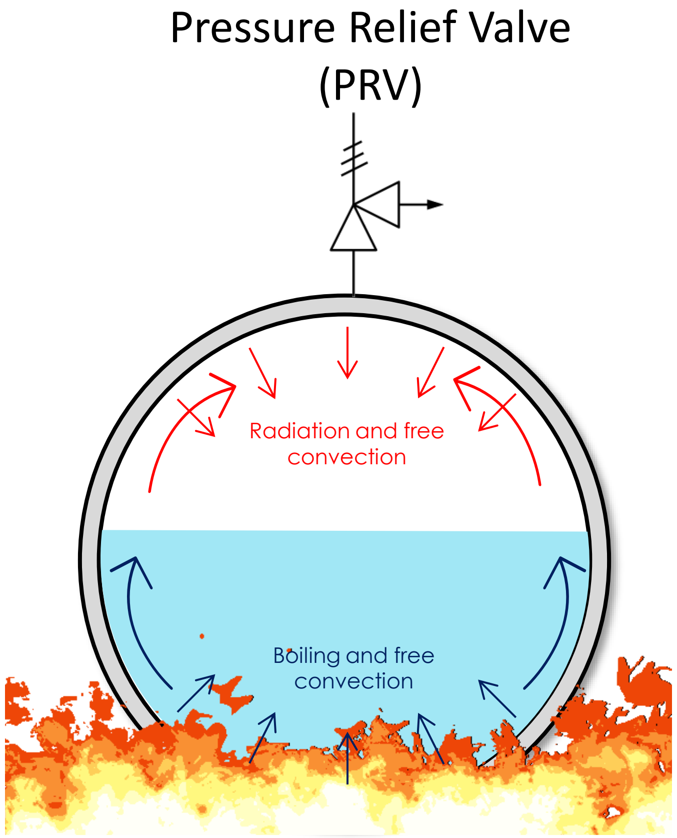

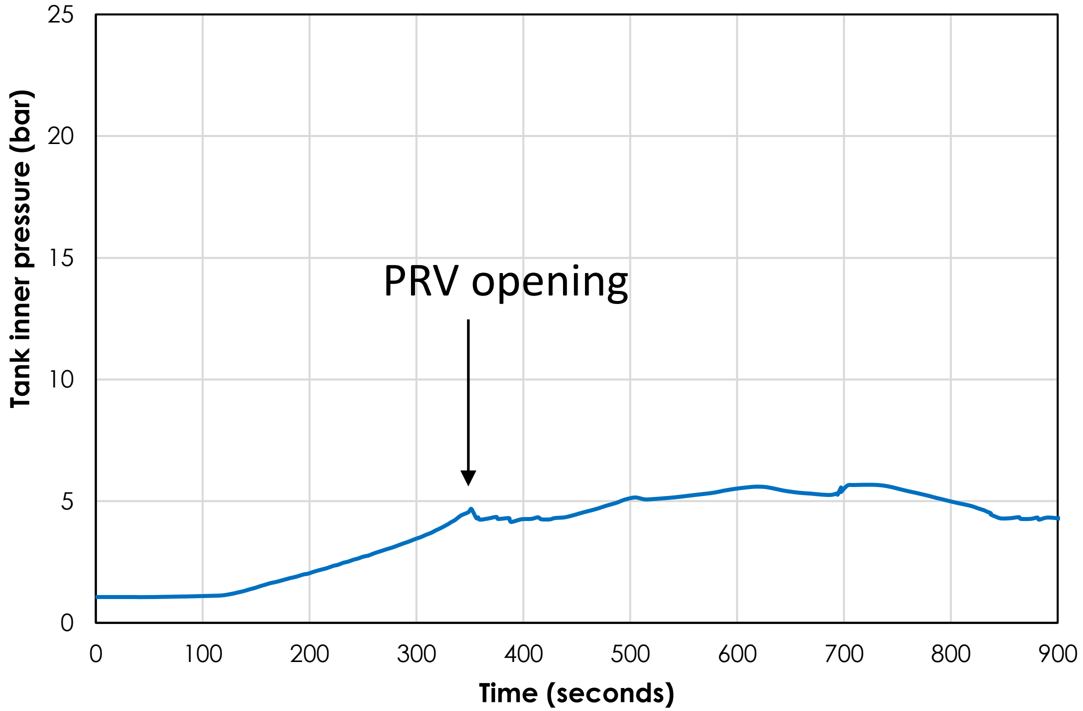

Liquid hydrogen tanks exposed to fire

Thermodynamics and other phenomena

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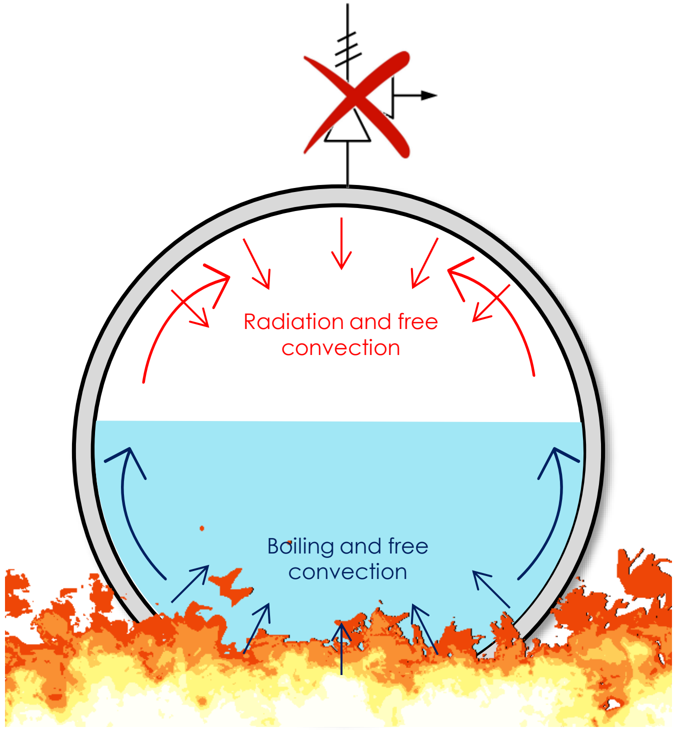

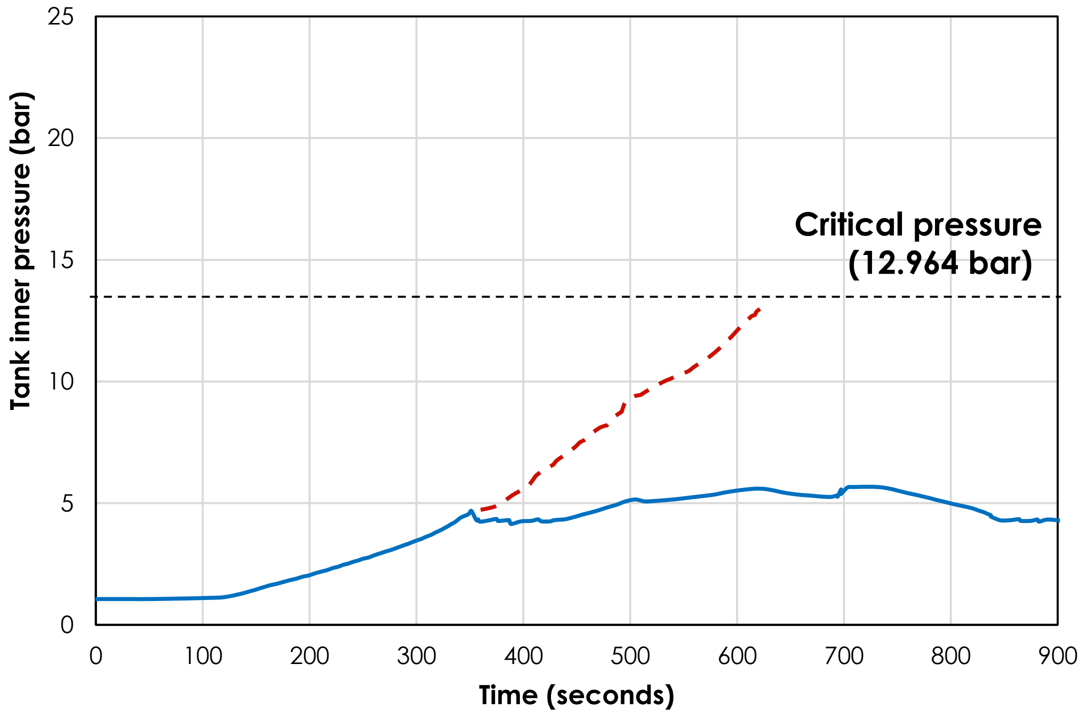

Liquid hydrogen tanks exposed to fire

Thermodynamics and other phenomena

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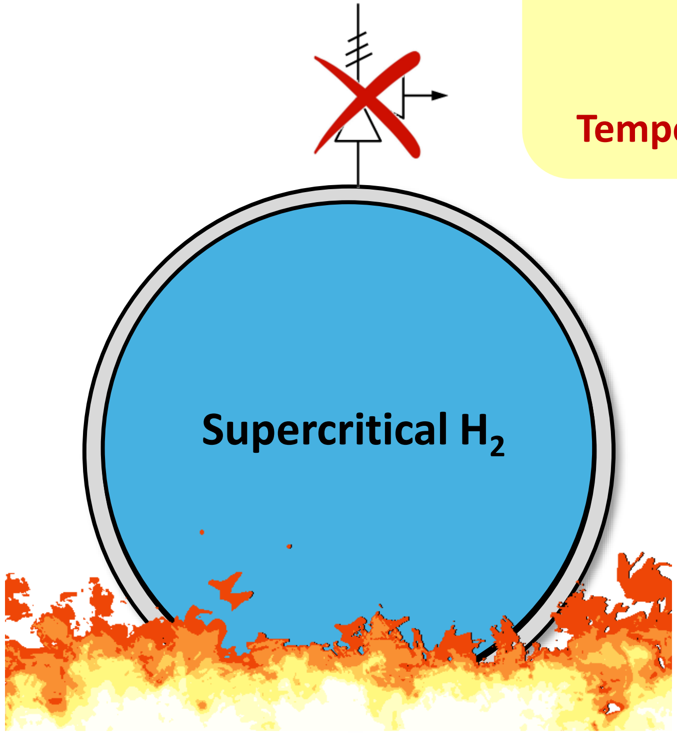
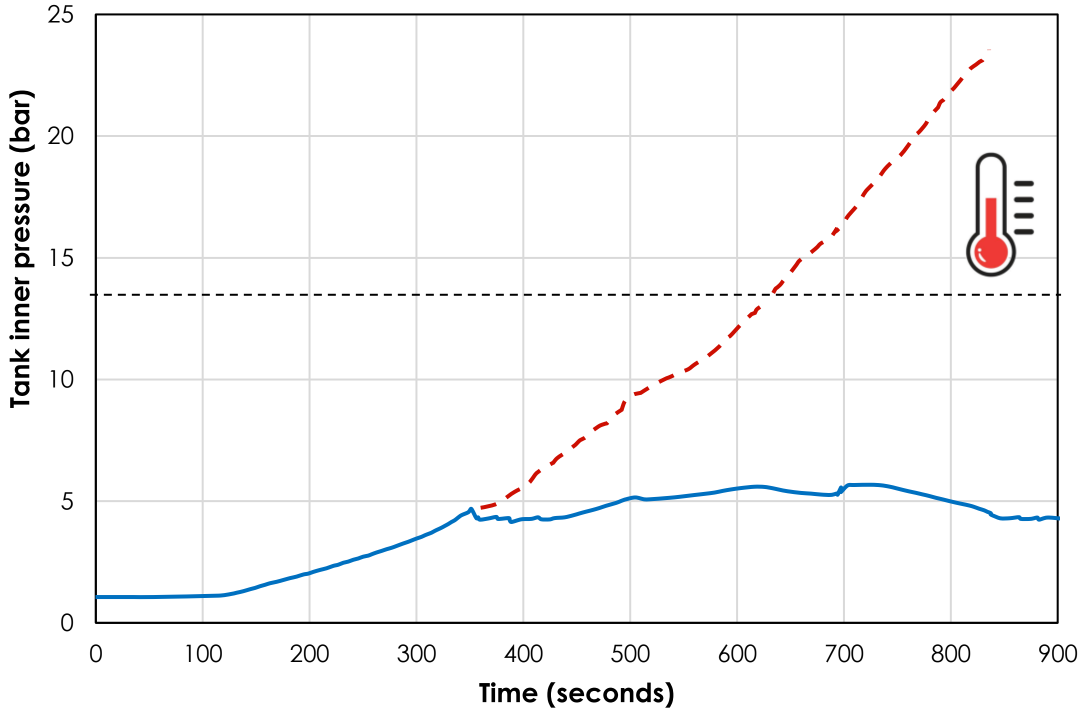


Pressure > 12.964 bar

+

Temperature > 33.145 K

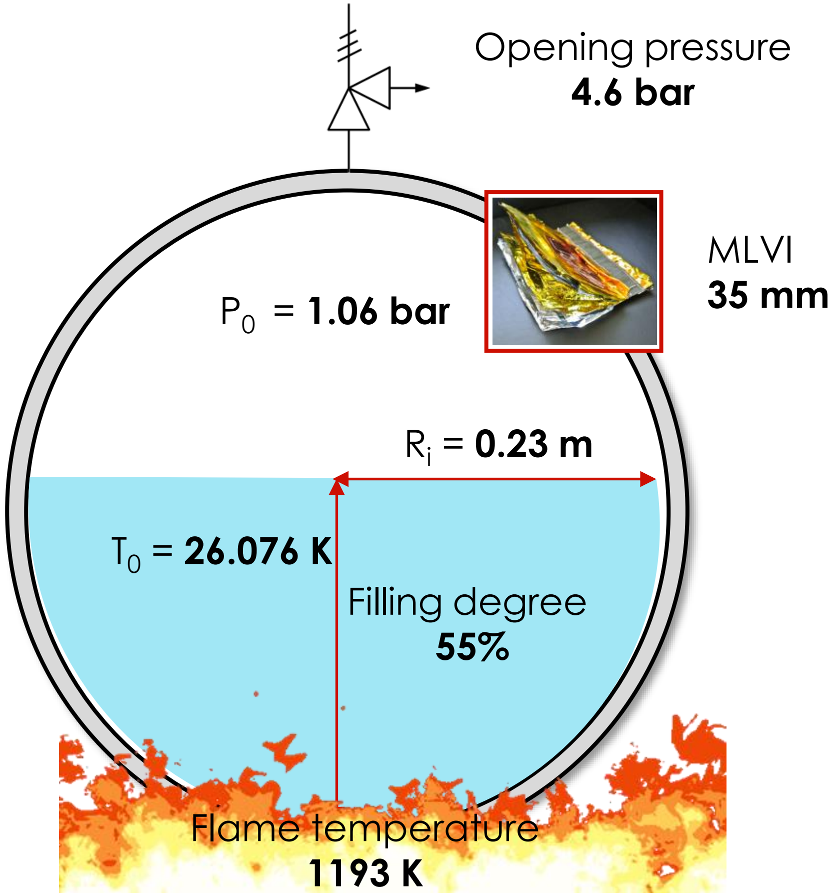


Reference fire test

Fire test from BMW

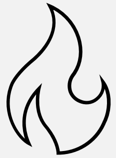
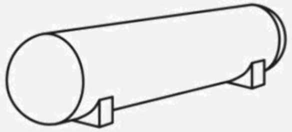
The fire test carried out by the **BMW Group** was considered as a reference to validate the model.

BMW Hydrogen 7



Goal

Tank behaviour during fire attack

Scenario =  **+** 

Q1: Which is the **pressure build-up** during the fire attack?

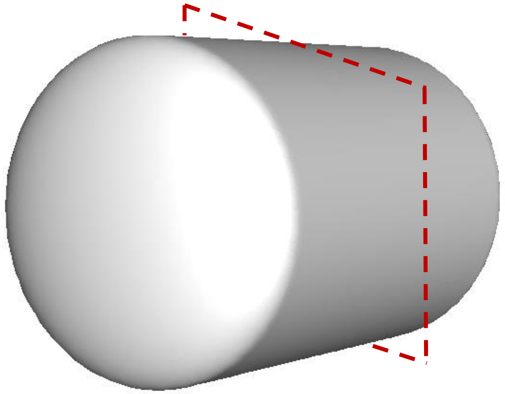
Q2: Which is the **time to failure** of the tank?

Time to Failure*:* time after the beginning of the fire after which the tank fails

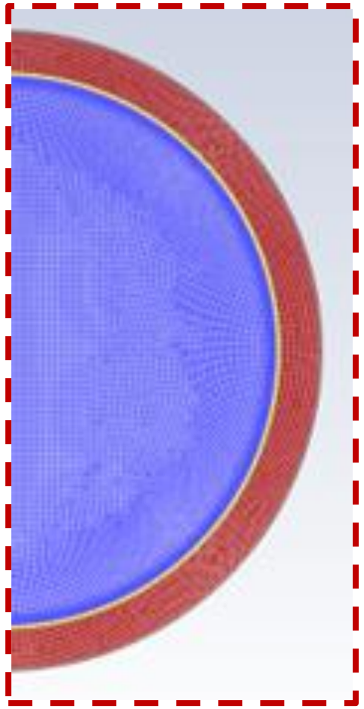
CFD model

Computational domain, setup and material properties

Real case:
3D tank



Model:
2D tank



Mesh features:

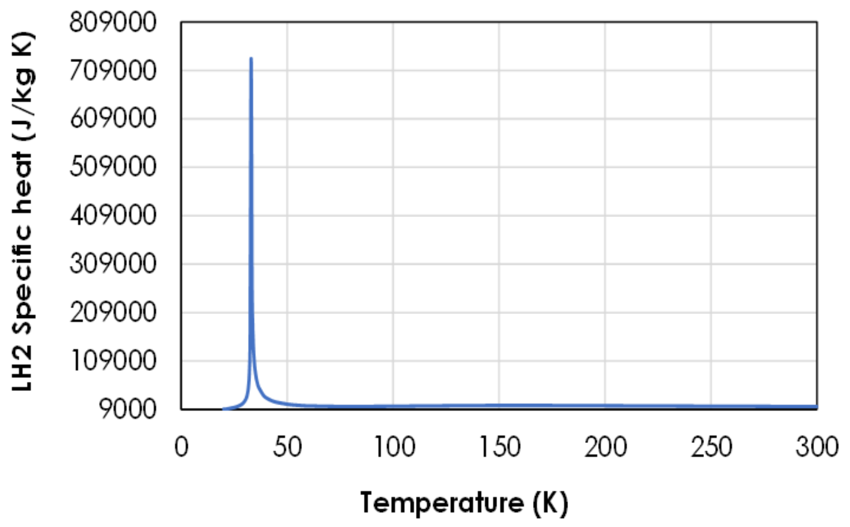
- ❑ Element size: 3 mm
- ❑ Inflation layers: 25 (fluid in contact with the inner wall)
- ❑ Cells: 17,029

CFD model

Computational domain, setup and material properties

Submodels

1. **Volume of Fluid (VoF) →** multiphase (liquid and gaseous hydrogen) modelling
2. **k-ω shear stress transport (SST) →** turbulence
3. **Lee model →** evaporation-condensation



Material properties

1. **Hydrogen →** piecewise linear functions of temperature
2. **Steel →** default values
3. **Insulation →** variable thermal conductivity

Case study

Assumptions

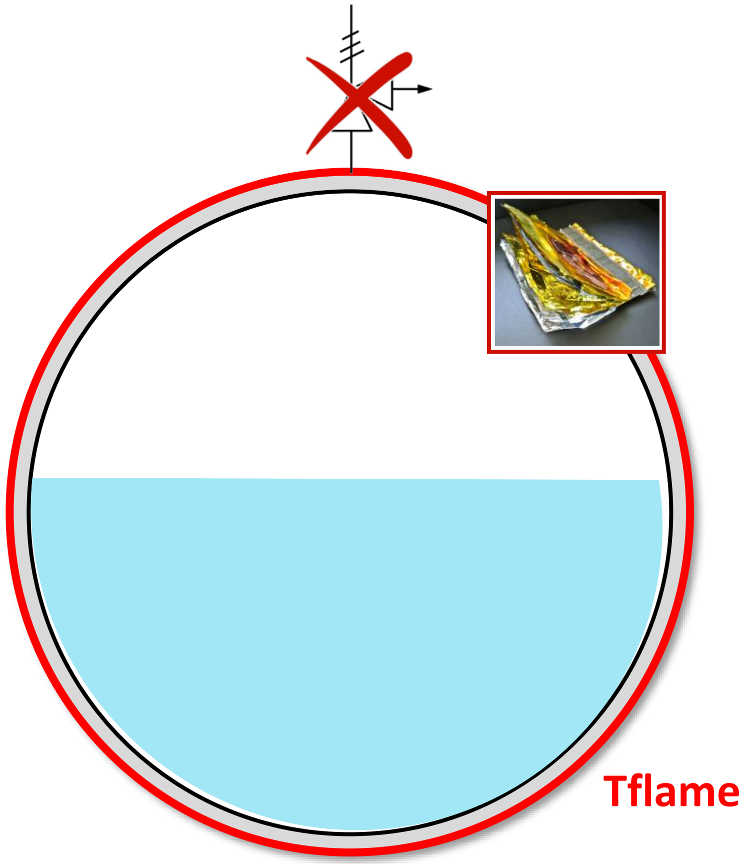
Initial conditions

1. **Pressure = 4 bar** (around PRV opening pressure)
2. **Hydrogen emperature =** Tsat

Additional conditions

1. **PRV** not working
2. **Inner shell →** 5083 Al alloy (Max σ_{amm} = 112.5 Mpa)
3. **Temperature at the outer tank wall =** Tflame (1193.15 K)
4. **Insulation performance**

$$k = \begin{cases} 1.5\, mW & t < 115\, s \\ 160\, mW & t \geq 115\, s \end{cases}$$



Results

Tank self-pressurization and time to failure

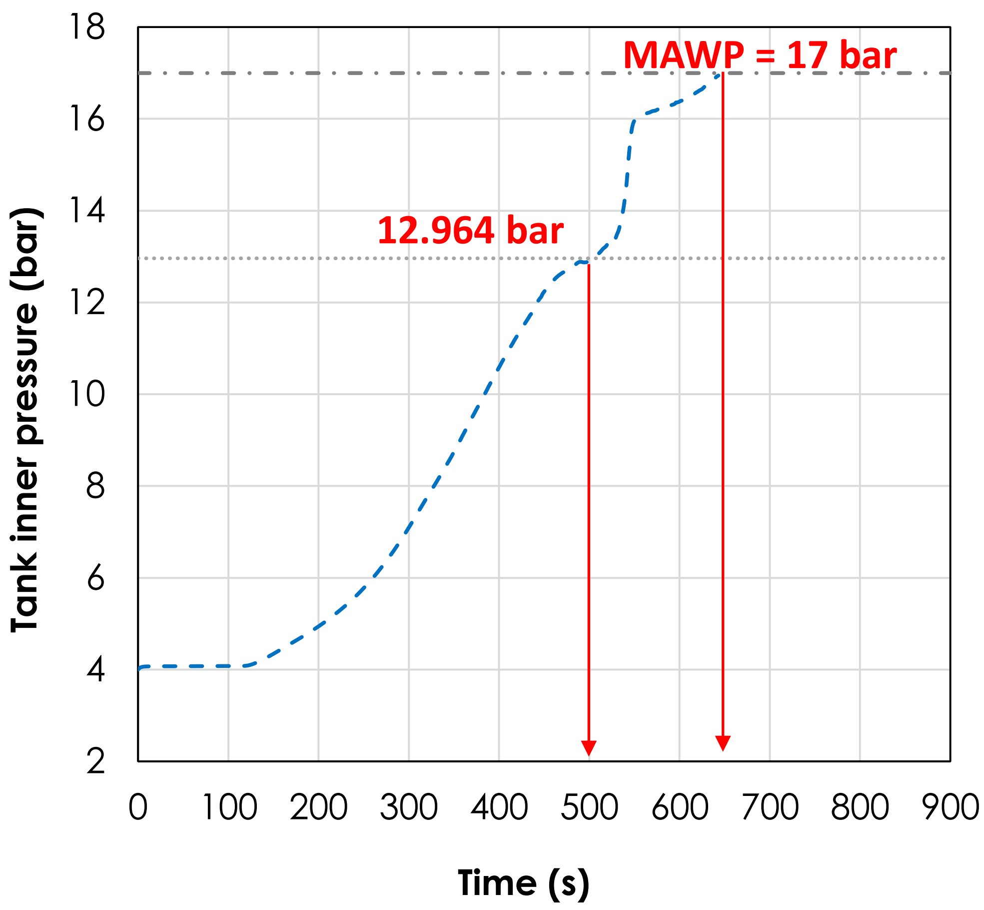
Q1: Which is the **pressure build-up** during the fire attack?

Q2: Which is the **time to failure** of the tank?

At **504 s** the inner pressure equals the critical pressure

At **643 s** the tank fails

The results of the model can be validated against the experimental data only for **subcritical conditions.**



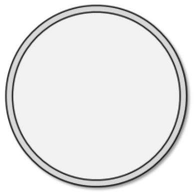
Results

Tank self-pressurization and time to failure

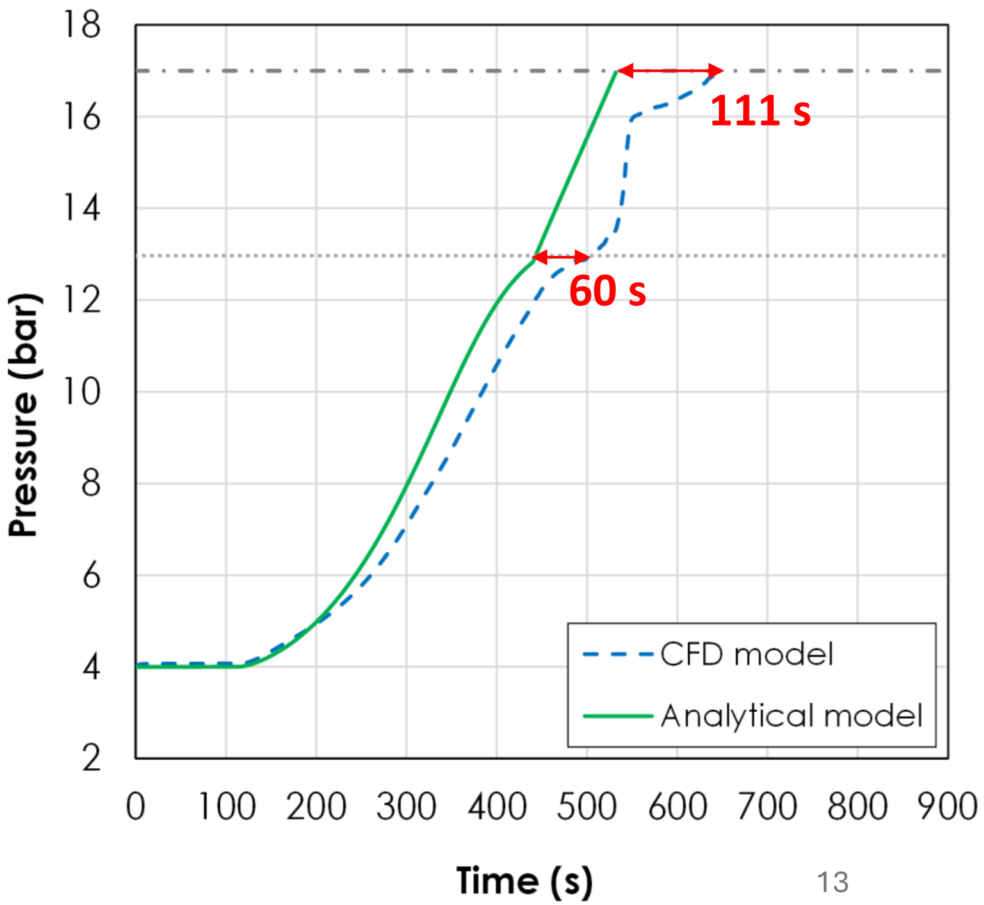
To verify the results in supercritical conditions, a comparison with a validated **analytical model** was performed.

Parameter	CFD model	Analytical model
Time to reach Pc	504 s	444 s
Time to failure	643 s	532 s

2D



3D



The small differences in the results can be attributed to the **different geometry**

Conclusions

Discussion and future development

The proposed model can simulate hydrogen behaviour in both sub- and **supercritical conditions**

The pressure trend shows anomalies after the **critical point**, probably due to the imported thermodynamic properties database for hydrogen

Improvement of the functions impelemented for **hydrogen properties** (accounting for pressure and temperature dependence)

Better definition of the insulation performance

Better characterization of the fire (engulfment level, flame temperature, etc.)

ELVHYS

Thank you for your attention

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UK Research and Innovation

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