Hyindoor

Pre normative research
on the indoor use of fuel cells and hydrogen systems

Pressure peaking phenomenon validation

Volodymyr Shentsov, Mike Kuznetsov, Vladimir Molkov

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New Energy World JU
fuel cells & hydrogen for sustainability

Outline

- Problem formulation
- Methodology
- The model and the nomogram for leak flow rate limit leading to 100% hydrogen accumulation in an enclosure with time
- Pressure peaking phenomenon (PPP) model and nomogram
- Nomograms for ‘safe’ pipe diameter (< 20kPa)
- Experimental facility and tests
- Validation of PPP
- Concluding remarks

Problem formulation

- H2 stored indoors as compressed gas @(350-700 bar)
- Even if **unignited**, the release of hydrogen has been shown to result in unacceptable overpressures indoors capable of destroying the structure
- Occurs in situation when H2 leak and vent size such that there will be only outflow through the vent
- The experimental results were absent
- The Karlsruhe Institute of Technology (KIT) carried out tests to confirm validity of University of Ulster theory

Methodology

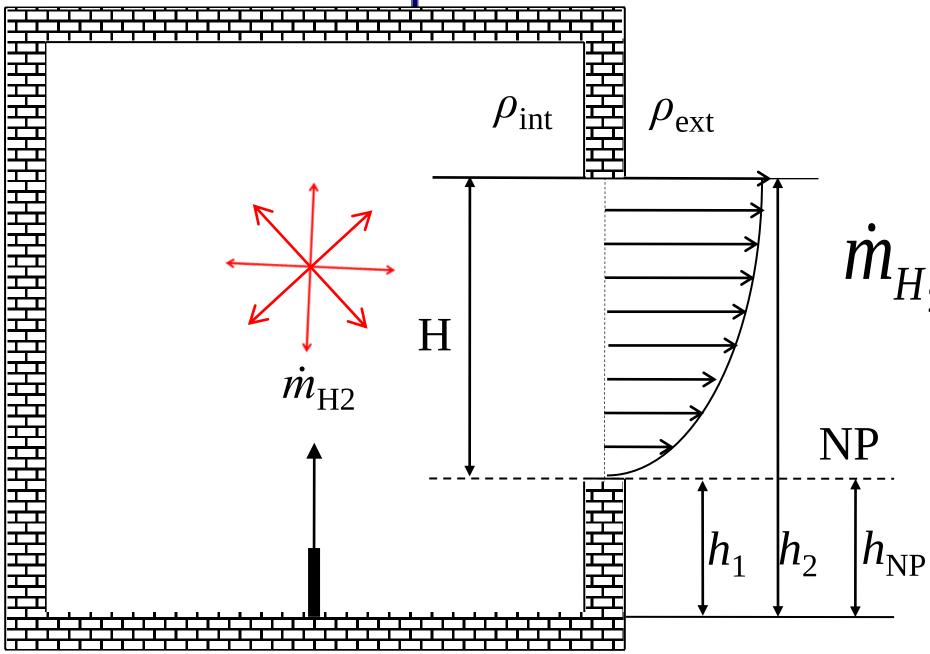
- Calculate the limit for PPP, (Molkov et al. 2014)
  - Use model/nomogram for 100% hydrogen accumulation
- In case of existence of PPP use the model or nomogram for calculating over-pressure in a garage resulting from an unignited release (PPP), (Brennan and Molkov 2013)
  - Model applicable for a known garage volume
  - Known vent area
  - Known release mass flow rate

V. Molkov, V. Shentsov, and J. Quintiere, "Passive ventilation of a sustained gaseous release in an enclosure with one vent," Int. J. Hydrog. Energy, vol. 39, no. 15, pp. 8158–8168, May 2014.

S. Brennan and V. Molkov, "Safety assessment of unignited hydrogen discharge from onboard storage in garages with low levels of natural ventilation," Int. J. Hydrog. Energy, vol. 38, no. 19, pp. 8159–8166, Jun. 2013.

100% accumulation limit

At the steady state, when hydrogen fully occupies the enclosure, $\dot{m}_{vent} = \dot{m}_{nozz}$ i.e. the mass flow into the enclosure equals the mass flow out.



$$\dot{m}_{H_2} = C_D A \sqrt{H} \cdot \sqrt{\frac{8g\rho_{\text{int}}(\rho_{ext} - \rho_{\text{int}})}{9}}$$

$$C_D = 0.6$$

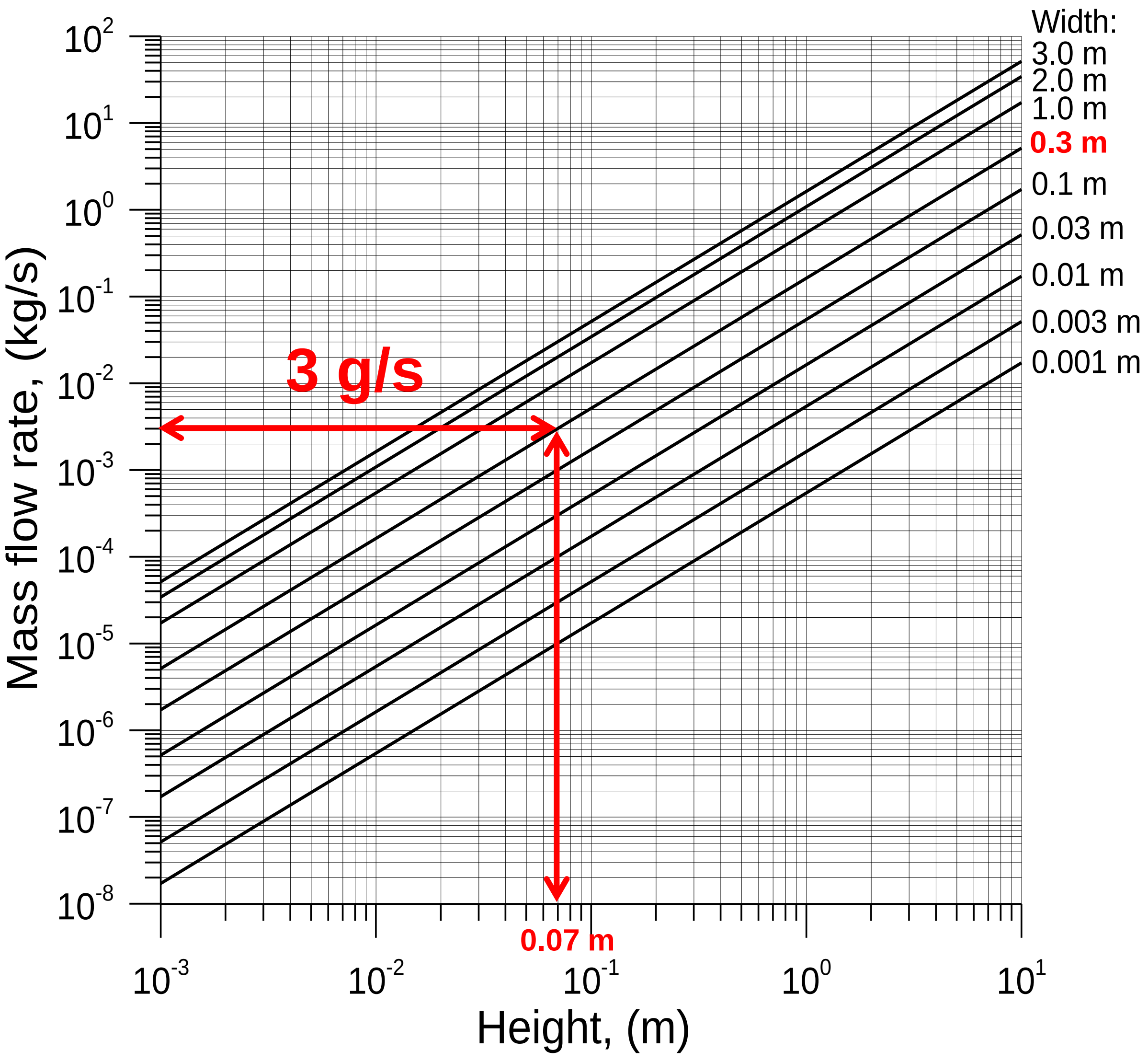
The lower limit of release flow rate that leads to 100% of hydrogen accumulation within an enclosure

(this limit has to be exceeded to apply the pressure peaking phenomenon)

Nomogram: 100% accumulation

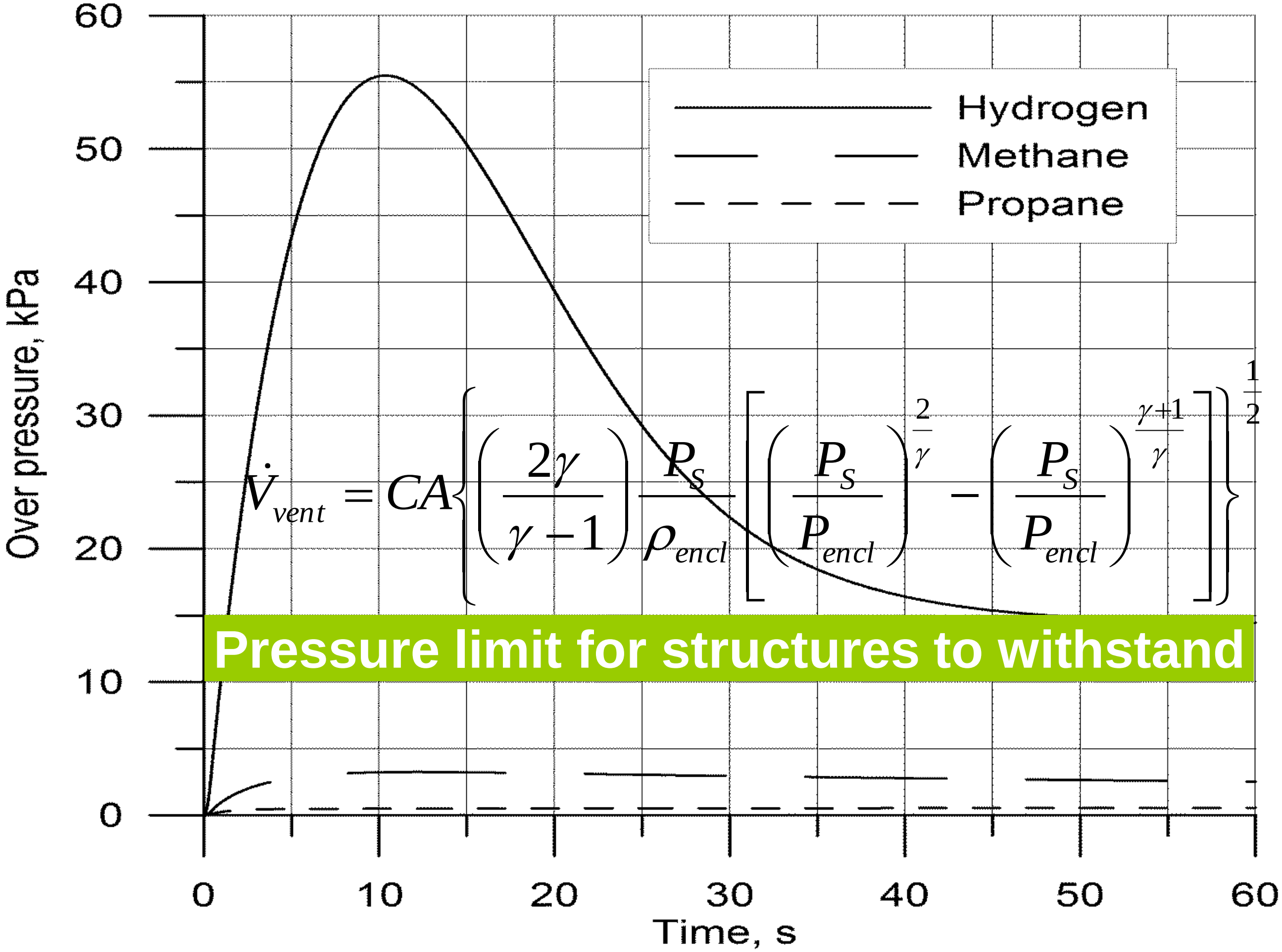
Engineering nomogram (example): sustained release of hydrogen 3 g/s in enclosure with a vent of W=0.3 m and H=0.07 m will lead to 100% accumulation.

No dependence on enclosure volume (only time will depend)



Pressure peaking phenomena

Small garage *LxWxH*=4.5x2.6x2.6 m (“brick” vent).
Mass flow rate 390 g/s (350 bar, 5.08 mm orifice).



$$\dot{V}_{vent} = CA\left\{\left(\frac{2\gamma}{\gamma-1}\right)\frac{P_S}{\rho_{encl}}\left[\left(\frac{P_S}{P_{encl}}\right)^{\frac{2}{\gamma}} - \left(\frac{P_S}{P_{encl}}\right)^{\frac{\gamma+1}{\gamma}}\right]\right\}^{\frac{1}{2}}$$

Overpressure levels reached inside the garage increase as the molecular mass of the gas injected into the garage decreases

Solution: decrease PRD orifice size and increase fire resistance of onboard storage

Nomogram for PPP

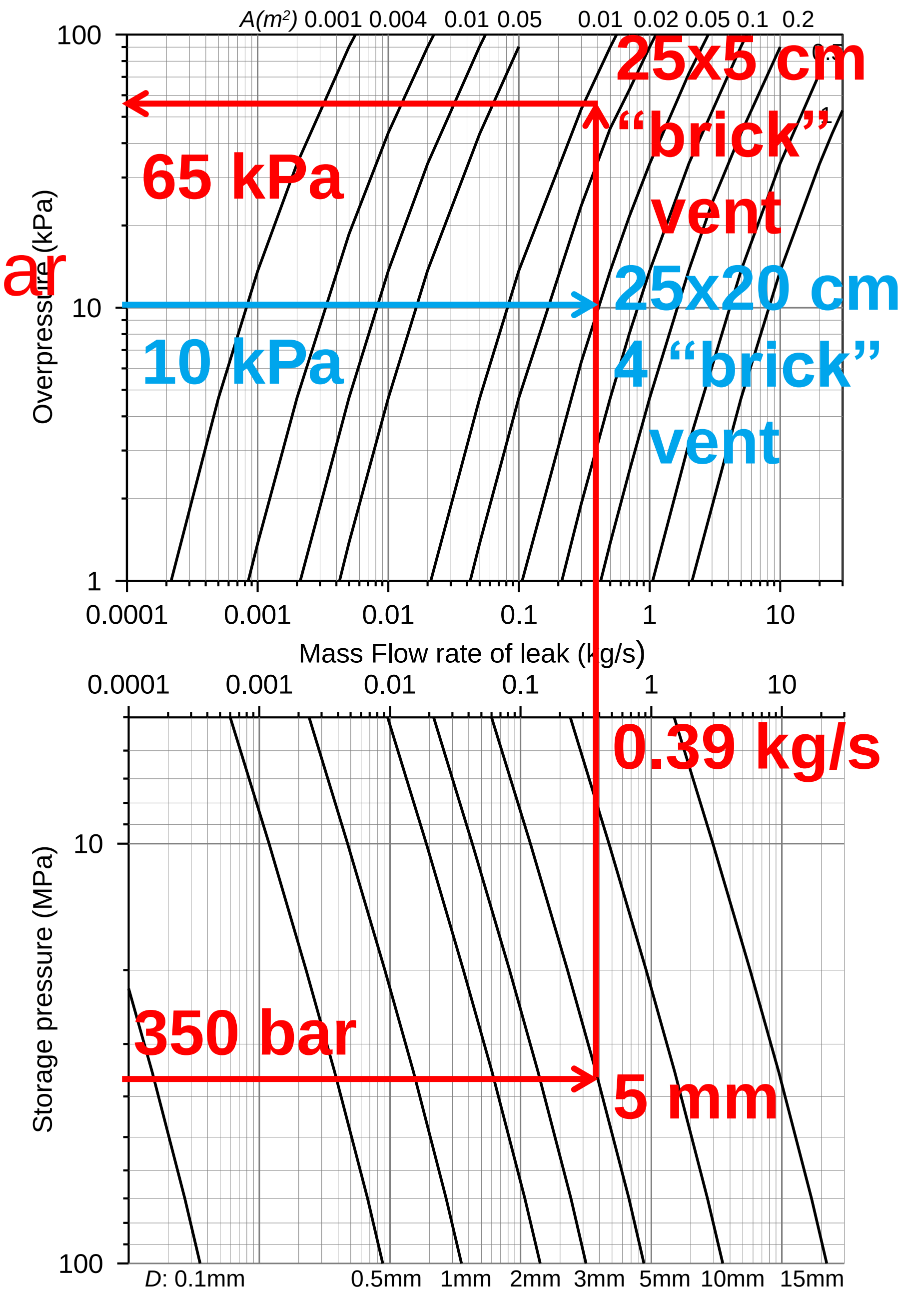
Use of nomogram (example) to calculate overpressure:

select storage pressure 350 bar
select leak diameter 5 mm
you will get mass flow rate
select vent area 0.0125 m^2
get overpressure 65 kPa

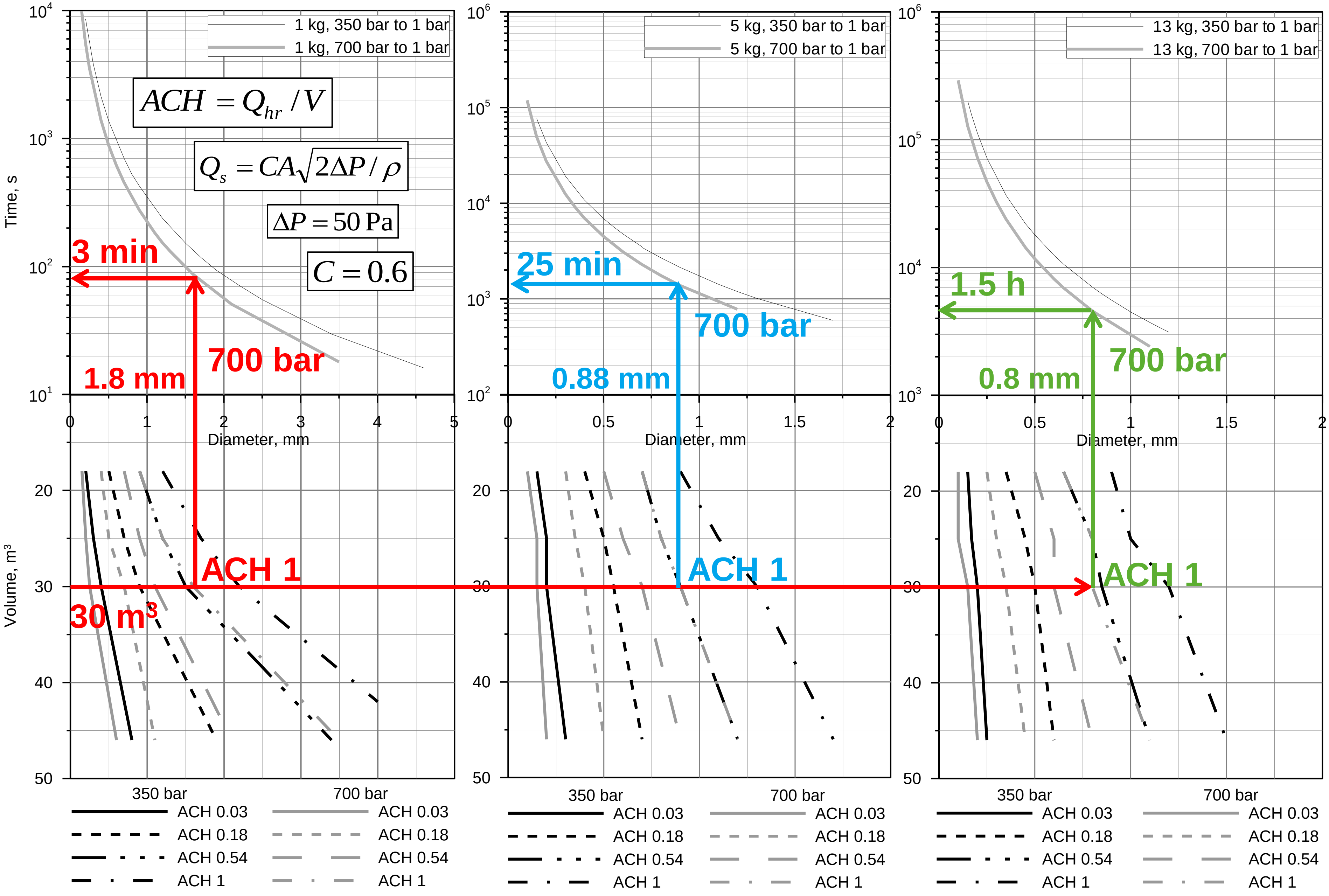
to calculate vent area:

select overpressure 10 kPa
Get vent area 0.05 m^2

No dependence on enclosure volume and time to rich the peak overpressure

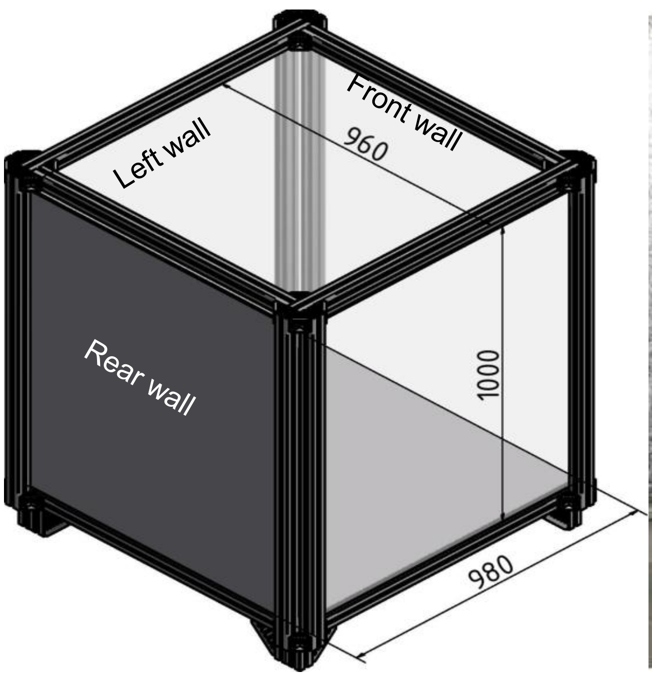


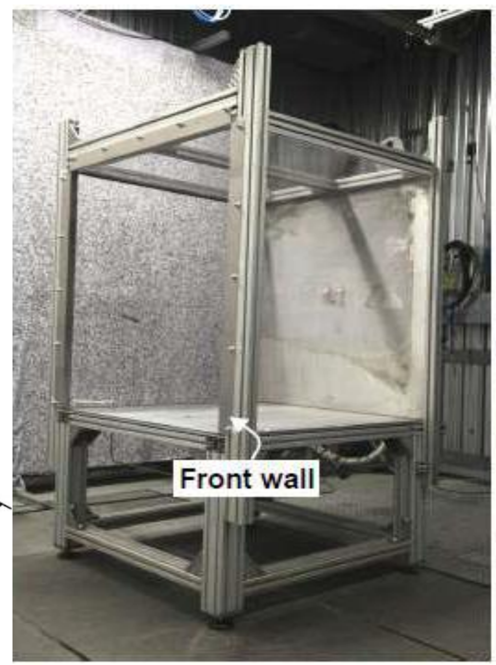
Nomograms for 'safe' blow-down (below 20kPa)

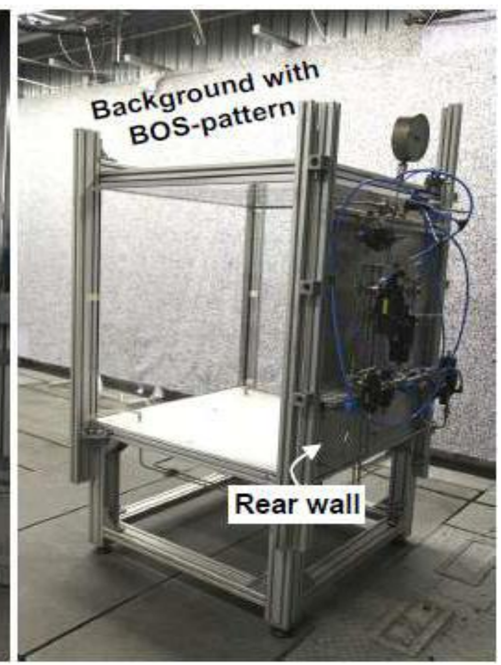


Installation and tests (KIT)

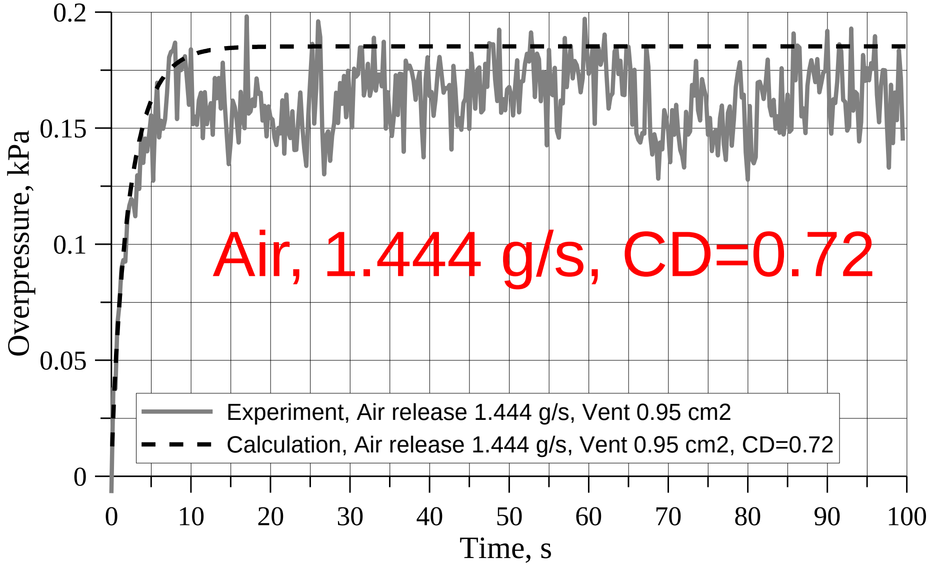
- 17 experiments on PPP were carried out by KIT (Germany) in the enclosure with sizes *HxWxL=1x0.98x0.96 m*.
- Round vent of diameter either 11 or 16.5 mm was located centrally at the top of the front panel or at the bottom.
- Three gases were tested: air, helium and hydrogen
- Internal diameter of the release nozzle is specified to 5 mm, located at the centre of enclosure 10 cm above the floor directed vertically.
- Release rates ranges 0.1 ~ 2.8 g/s.

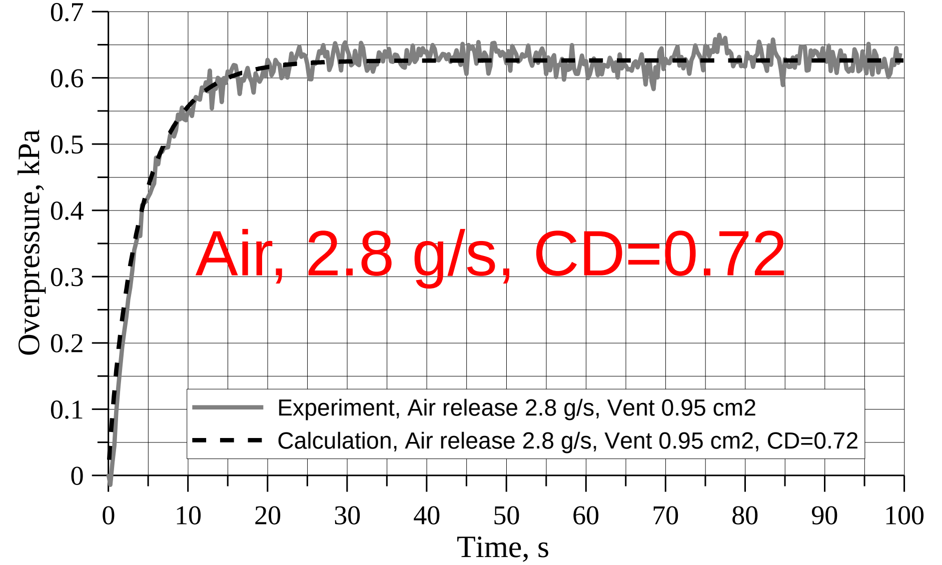


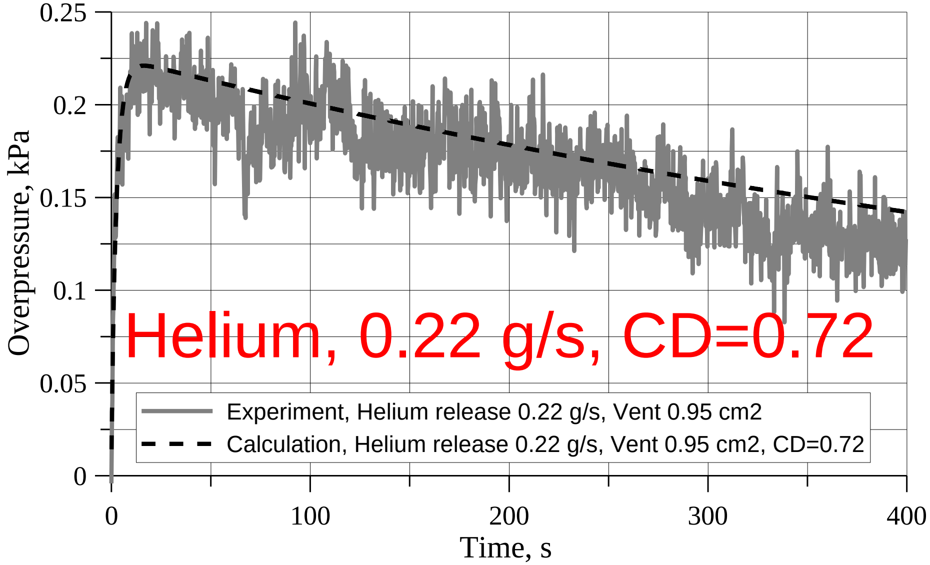


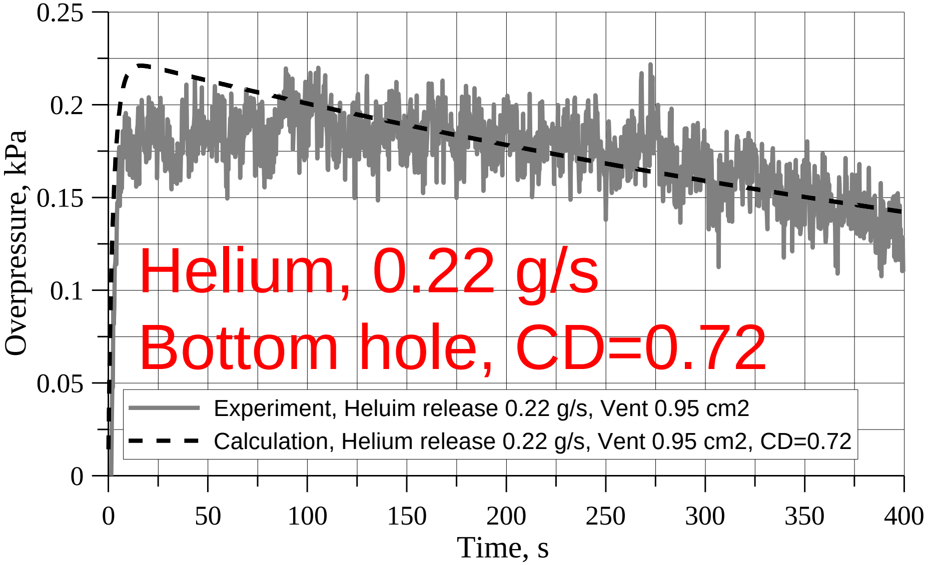


Pressure peaking validation 1/2



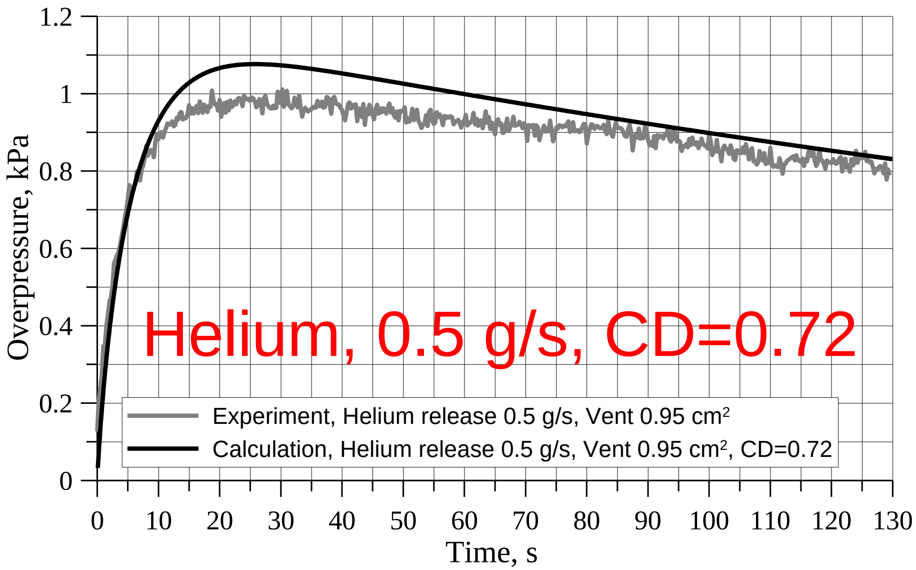


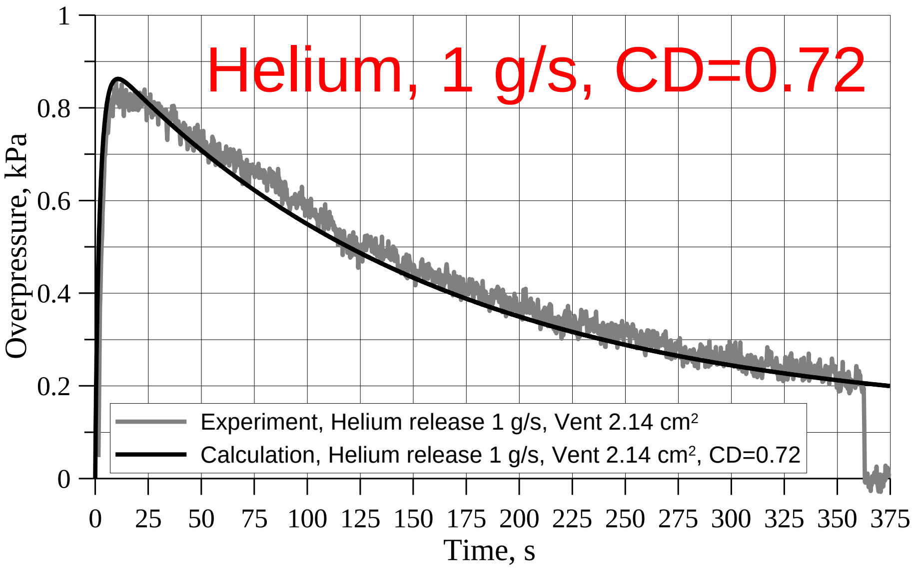




PPP is independent on vent location

Pressure peaking validation 2/2





Concluding remarks

- Experiments with release of air, helium and hydrogen performed by KIT proved the existence of pressure peaking phenomena (PPP).
- It can be concluded that the PPP is essential part of hydrogen safety engineering (HSE) for all indoor use of HFC systems.
- It is recommended that value CD=0.72 is accepted for HSE as a conservative one.
- **RCS recommendation.** Enclosure with high pressure hydrogen equipment: exclude Pressure Peaking Phenomenon (PPP) in enclosures with low ventilation level and high release flow rate

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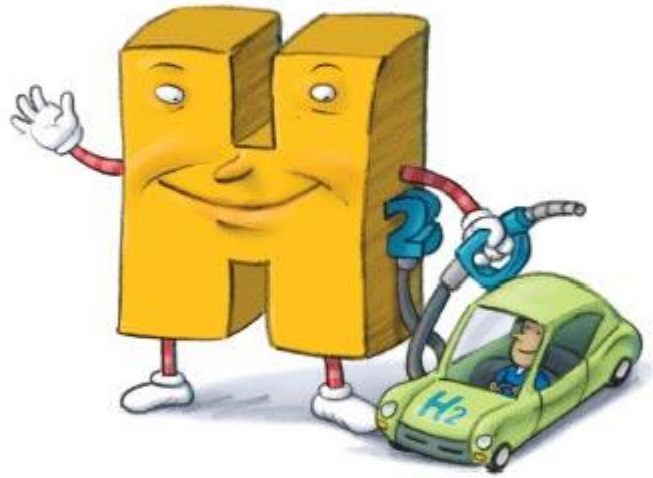
Thank you for your attention!



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