HySafe Research Priorities Workshop

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Passive ventilation of enclosures with one vent, the uniformity criterion, and validation of pressure peaking phenomenon (unignited releases)

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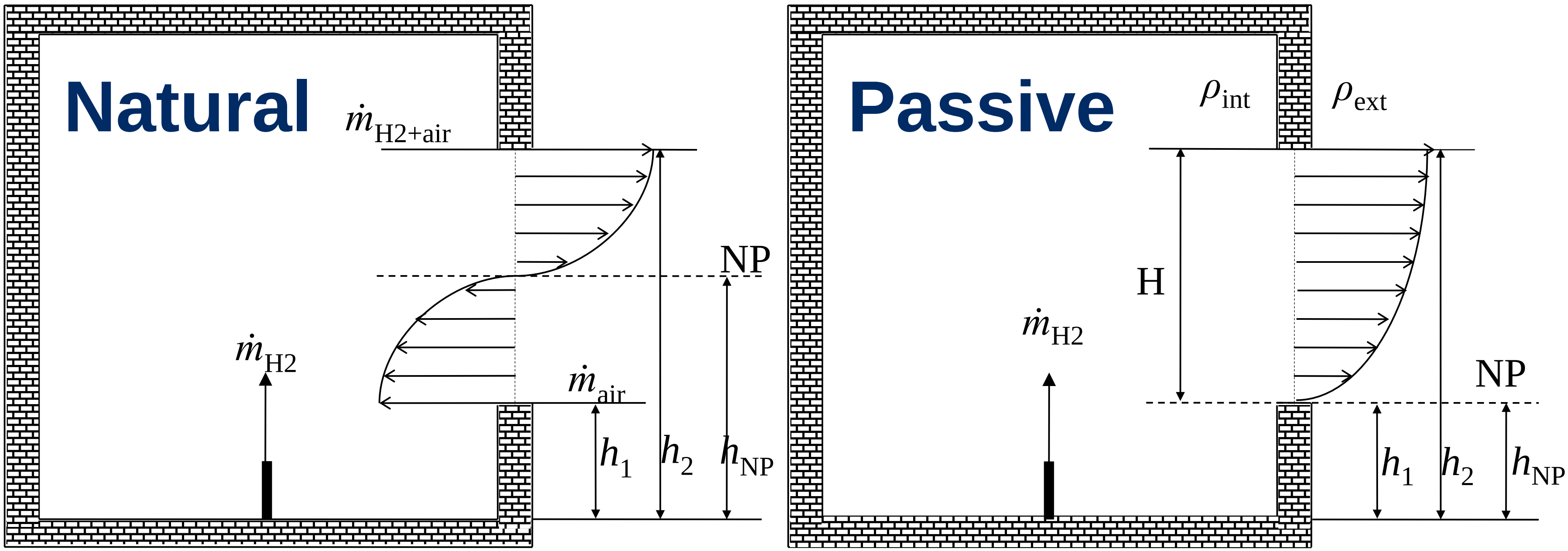
Outline

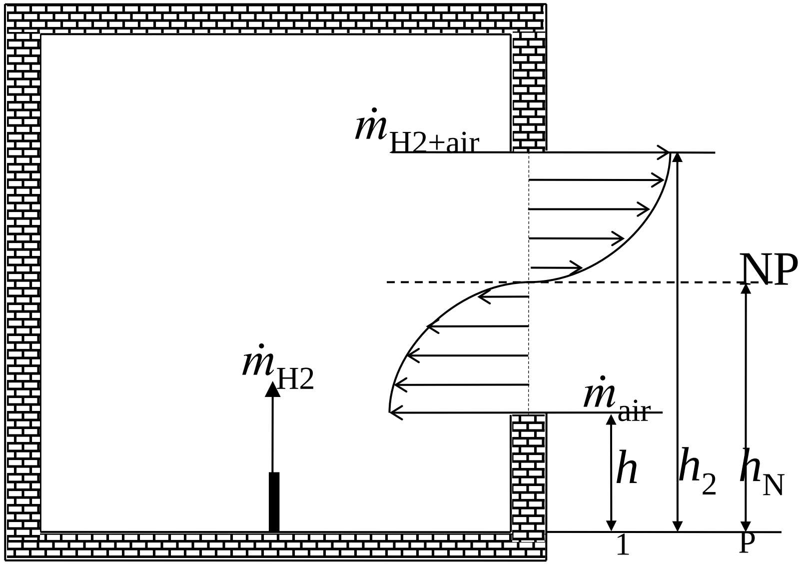
- Natural and passive ventilation
- The model and the nomogram for steady state hydrogen concentration in an enclosure with one vent (sustained leak)
- The criterion for mixture uniformity during leak in an enclosure with one vent
- The model and the nomogram for leak flow rate limit leading to 100% hydrogen accumulation in an enclosure with time
- Validation of pressure peaking phenomenon

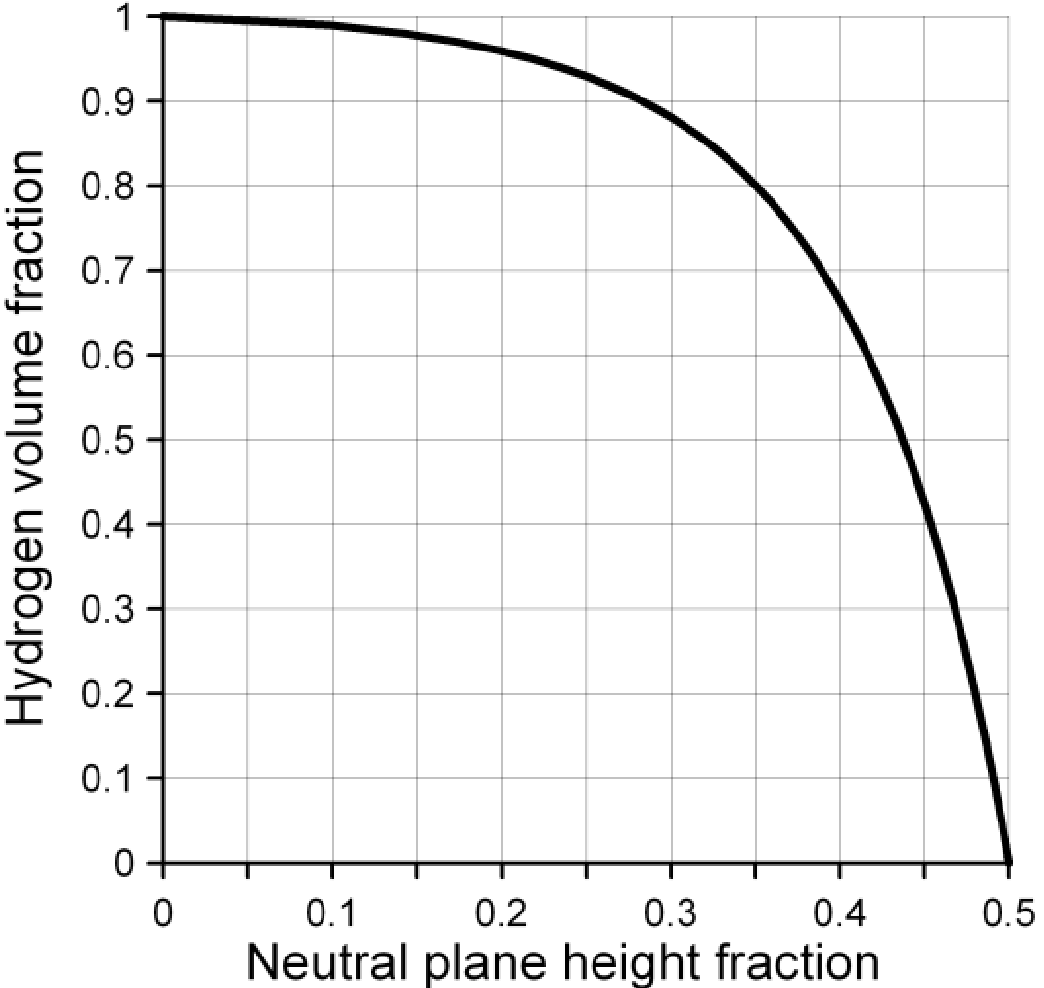
Ventilation



- **Natural ventilation** equations for air ventilation in buildings are derived in the assumption of equality of flow in and out of the enclosure (neutral plane is at the half of a vent height).
- **Passive ventilation**: neutral plane for lighter than air gases can be anywhere below the half of a vent height.

Neutral plane location





Mole fraction *X*: natural vs passive

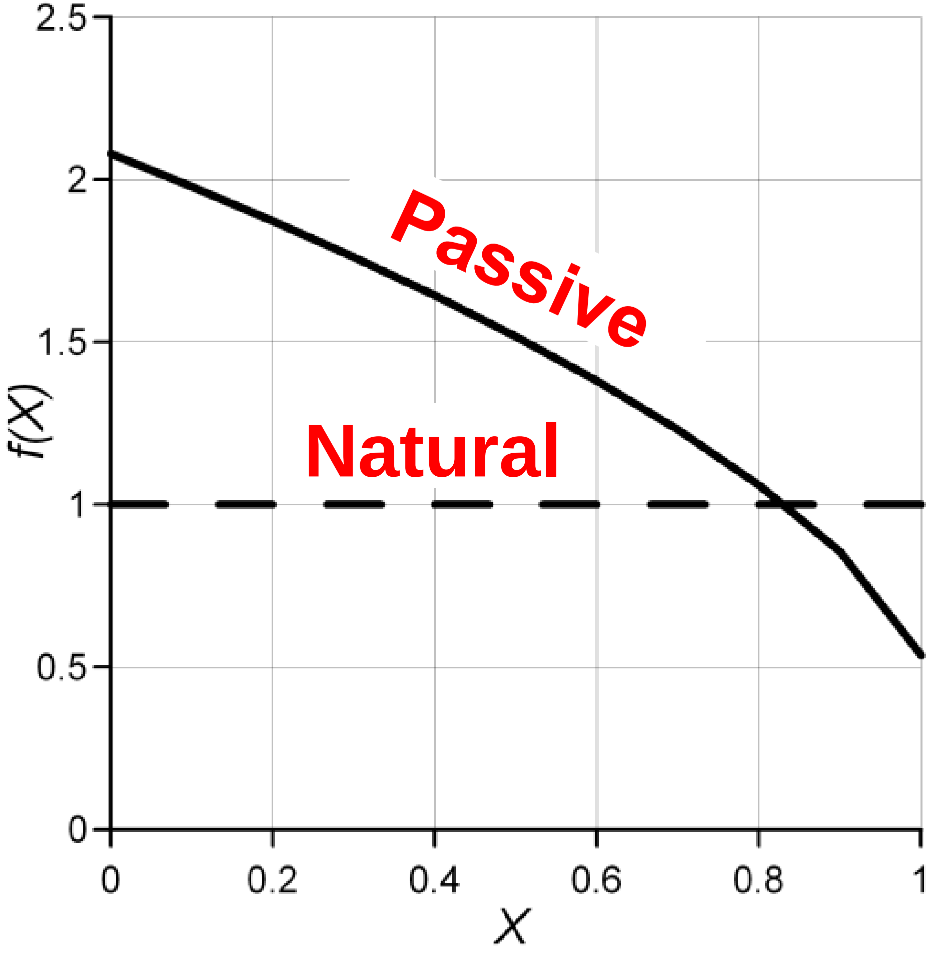
Natural ventilation: $$X = \left[\frac{Q_0}{C_D A (g' H)^{1/2}} \right]^{2/3}$$

Passive ventilation: $$X = f(X) \cdot \left[\frac{Q_0}{C_D A (g' H)^{1/2}} \right]^{2/3}$$

Difference: $$f(X) = \left(\frac{9}{8} \right)^{1/3} \cdot \left\{ \left[1 - X \left(1 - \frac{\rho_{H_2}}{\rho_{air}} \right) \right]^{1/3} + (1 - X)^{2/3} \right\}$$

Safety design: natural or passive?

Difference: $$f(X)=\left(\frac{9}{8}\right)^{1/3}\cdot\left\{\left[1-X\left(1-\frac{\rho_{H_2}}{\rho_{air}}\right)\right]^{1/3}+(1-X)^{2/3}\right\}$$



Natural ventilation equation (compared to passive):

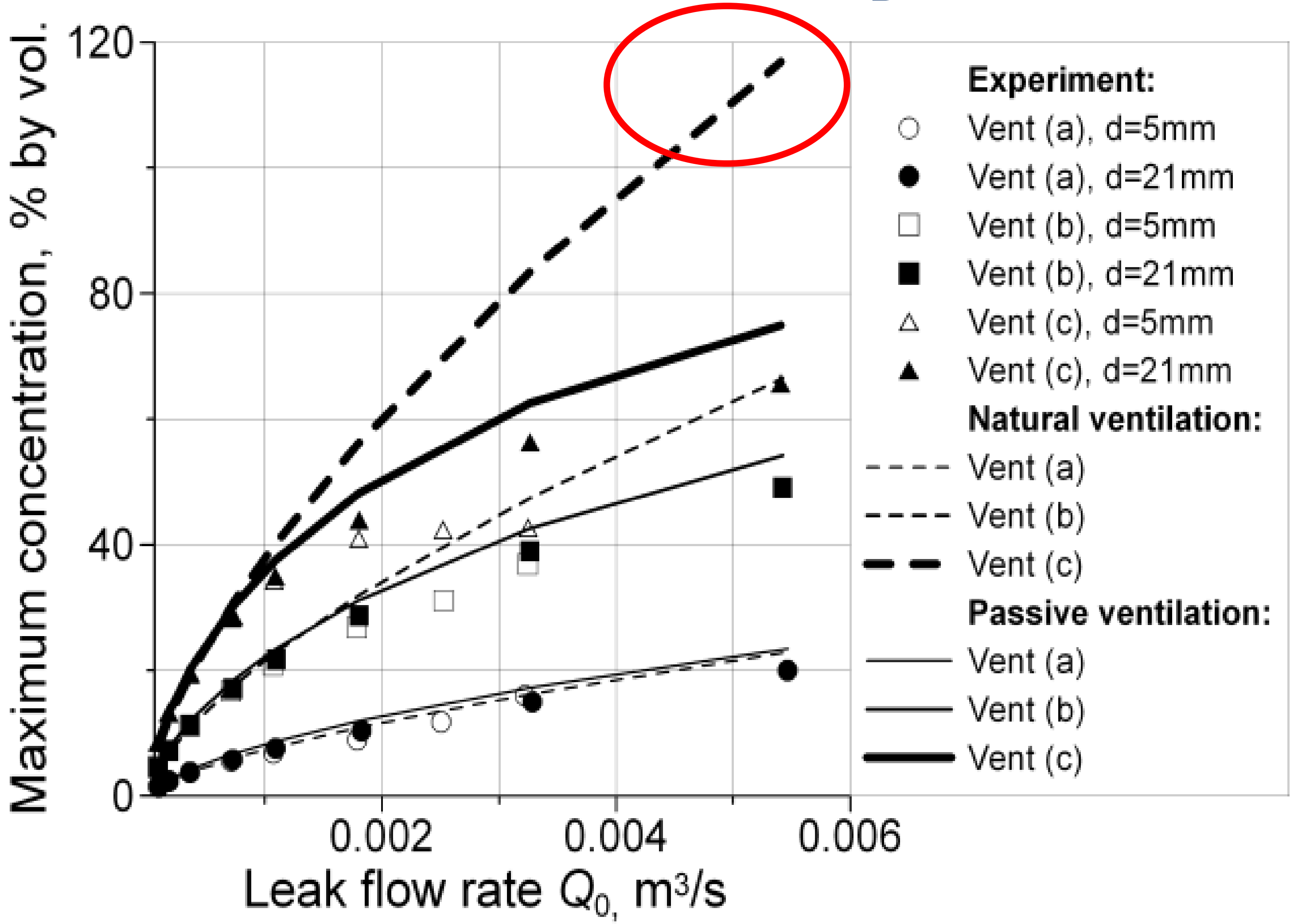
- ❖ Underestimate **x2 (lean)**
- ❖ Overestimate **x2 (rich)**

Validation tests with helium (CEA)

- Experiments were carried out by CEA (France) in the enclosure with sizes *HxWxD*=1.26x0.93x0.93 m.
- One vent located on a wall near the ceiling.
- Three different vent sizes were studied:
  - Vent (a) WxH=90x18 cm,
  - Vent (b) 18x18 cm,
  - Vent (c) 90x3.5 cm.
- Release of helium was directed upward from a tube located centrally 21 cm above the floor with internal diameter either 5 mm or 21 mm.
- Release rates ranges 5÷300 Nl/min.

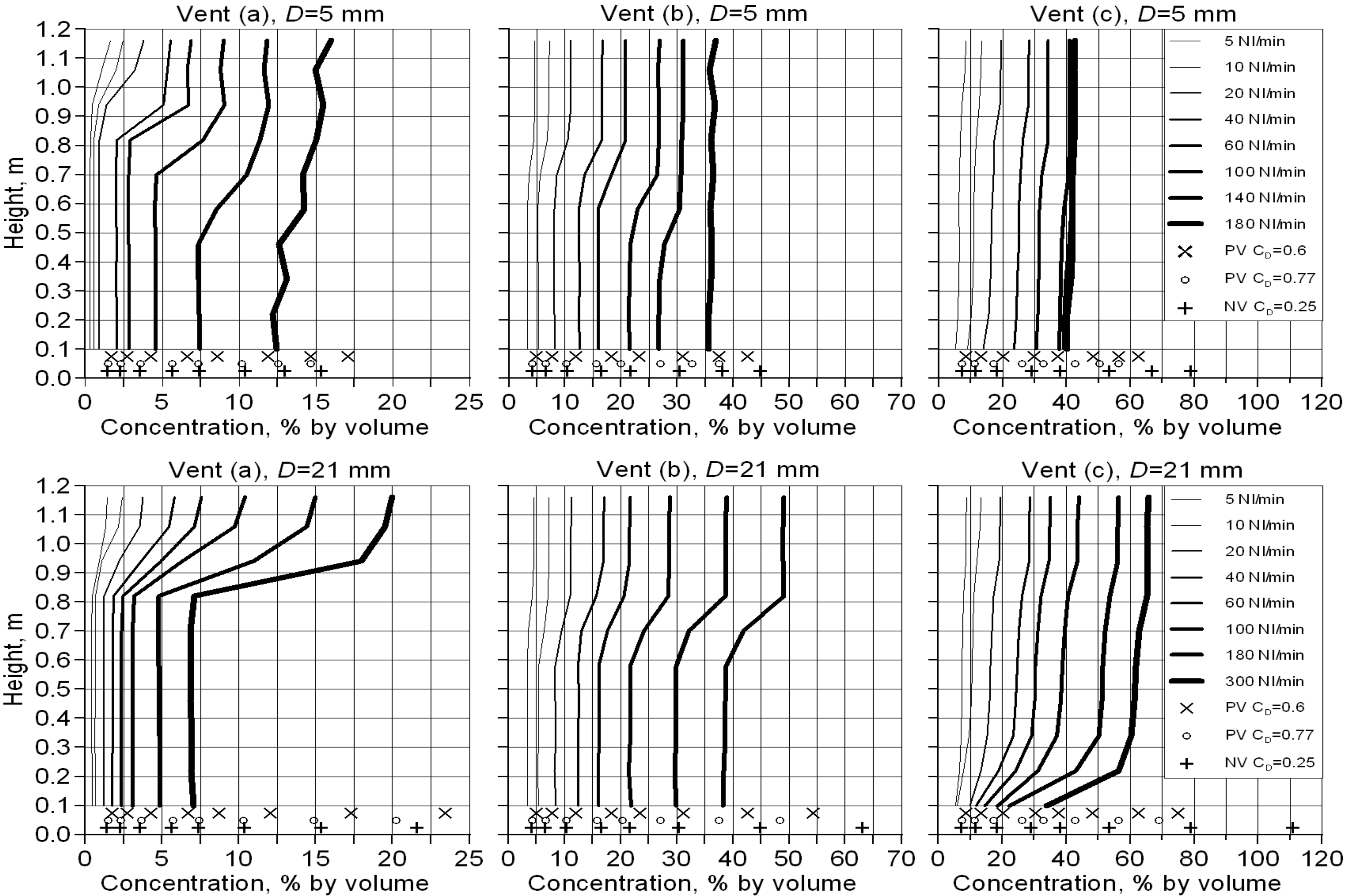
Predictions vs experiment C_{max}

Natural ventilation with "tuned" C_D**=0.25** - dashed lines.
Passive ventilation equation with C_D**=0.60** solid lines.



Experiments

Vent (a): *HxW*=18x90 cm; Vent (b):18x18 cm; Vent (c): 3.5x90 cm;

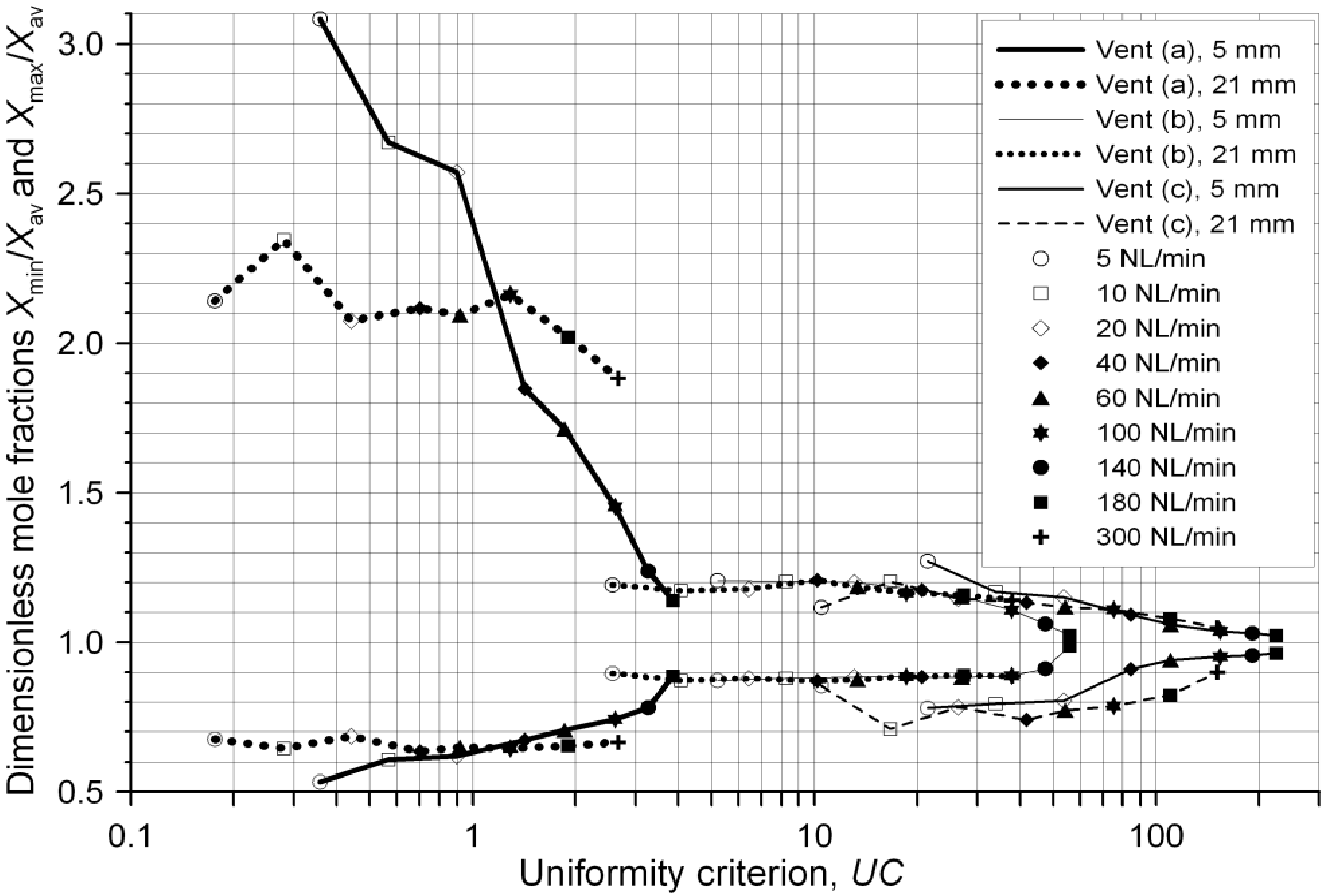


The criterion of uniformity

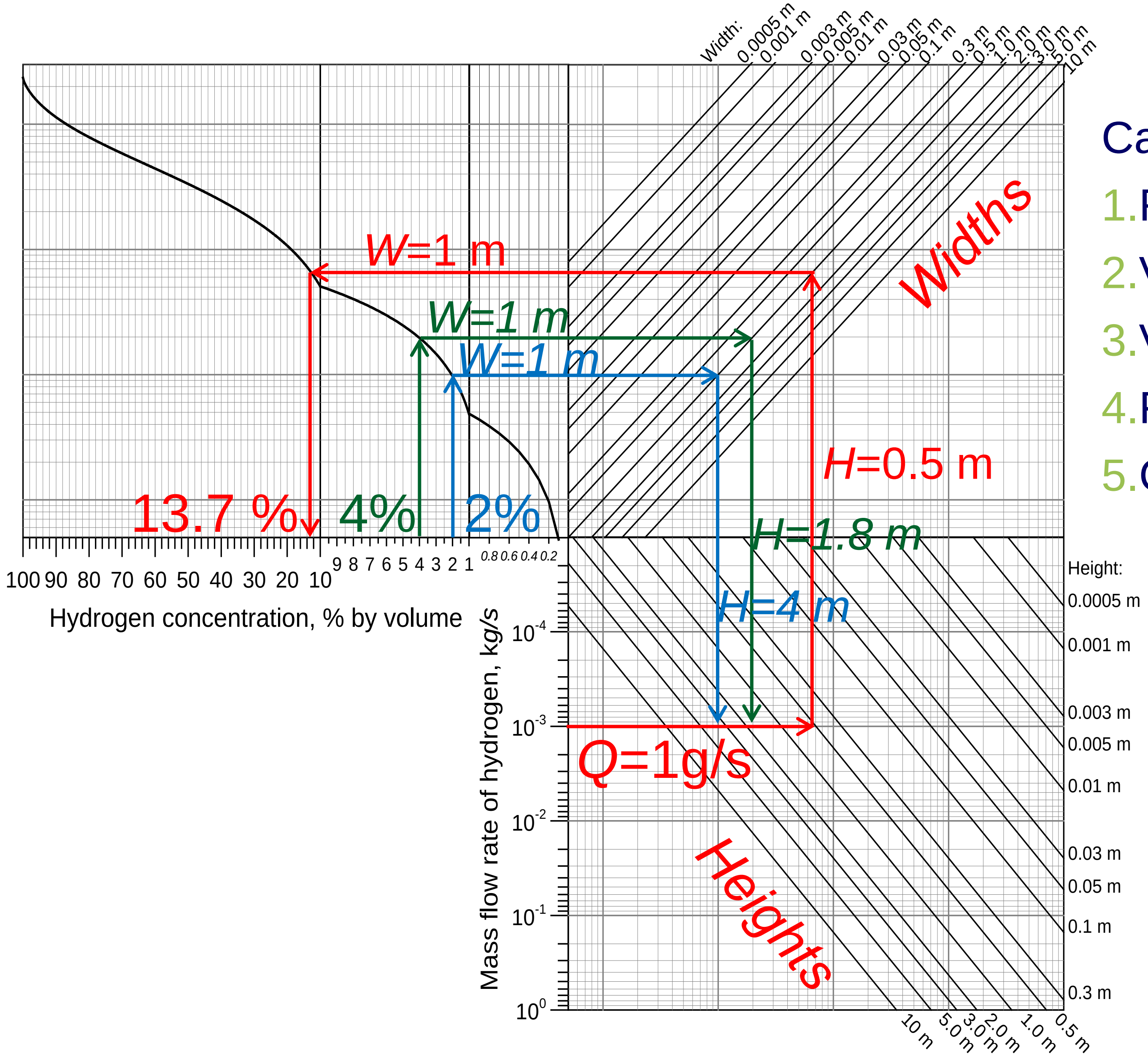
$$UC = \frac{V^{2/3}\sqrt{D}}{A\sqrt{H}} \frac{\dot{m}_{ent}(x)}{\dot{m}_{mix}}$$

$$\dot{m}_{ent}(x) = K_1 M_0^{1/2} \rho_{mix}^{1/2} x$$

$$\dot{m}_{mix} = \dot{m}_{H2} + \dot{m}_{air}$$



Nomogram (concentration C_{max})

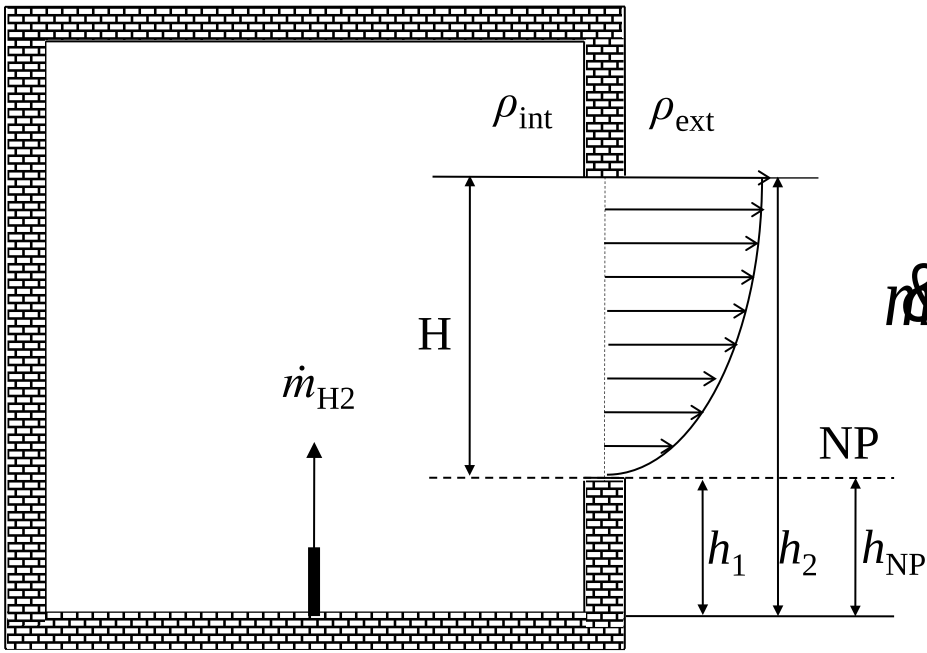


Calculation example:

1. Release rate (1 g/s)
2. Vent Height (0.5 m)
3. Vent width (1 m)
4. Function curve
5. Concentration (13.7%)

Release limit (100% H2 accumulation)

Depending on the release rate and vent size there can be 100% of hydrogen accumulation in the enclosure.



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

Equation gives the lower limit of release flow rate that leads to 100% of hydrogen accumulation in enclosure.

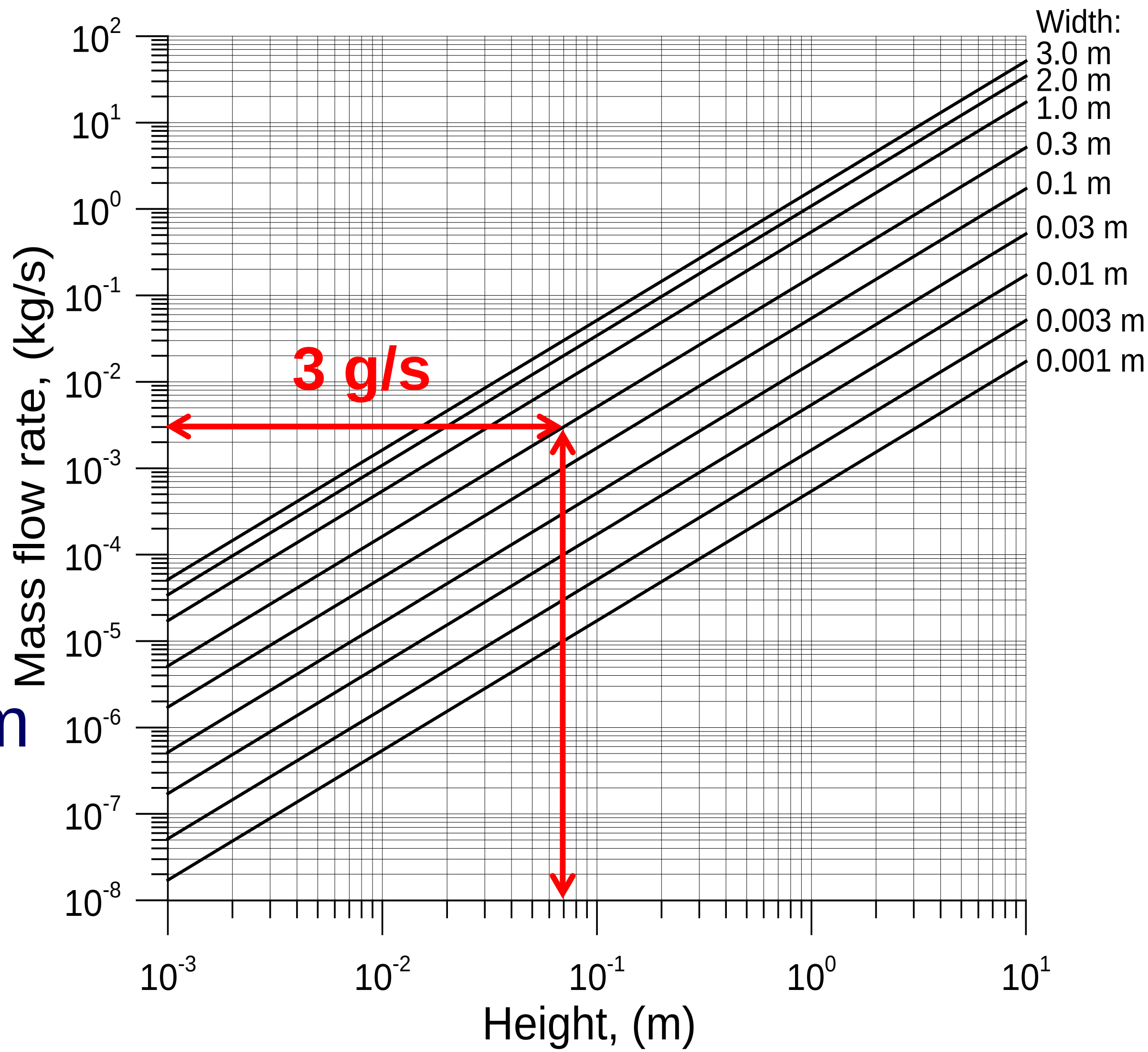
(This limit has to be exceeded to have the pressure peaking phenomenon – see in following slides)

Nomogram: 100% accumulation

Example of use: 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 accumulation time will depend).

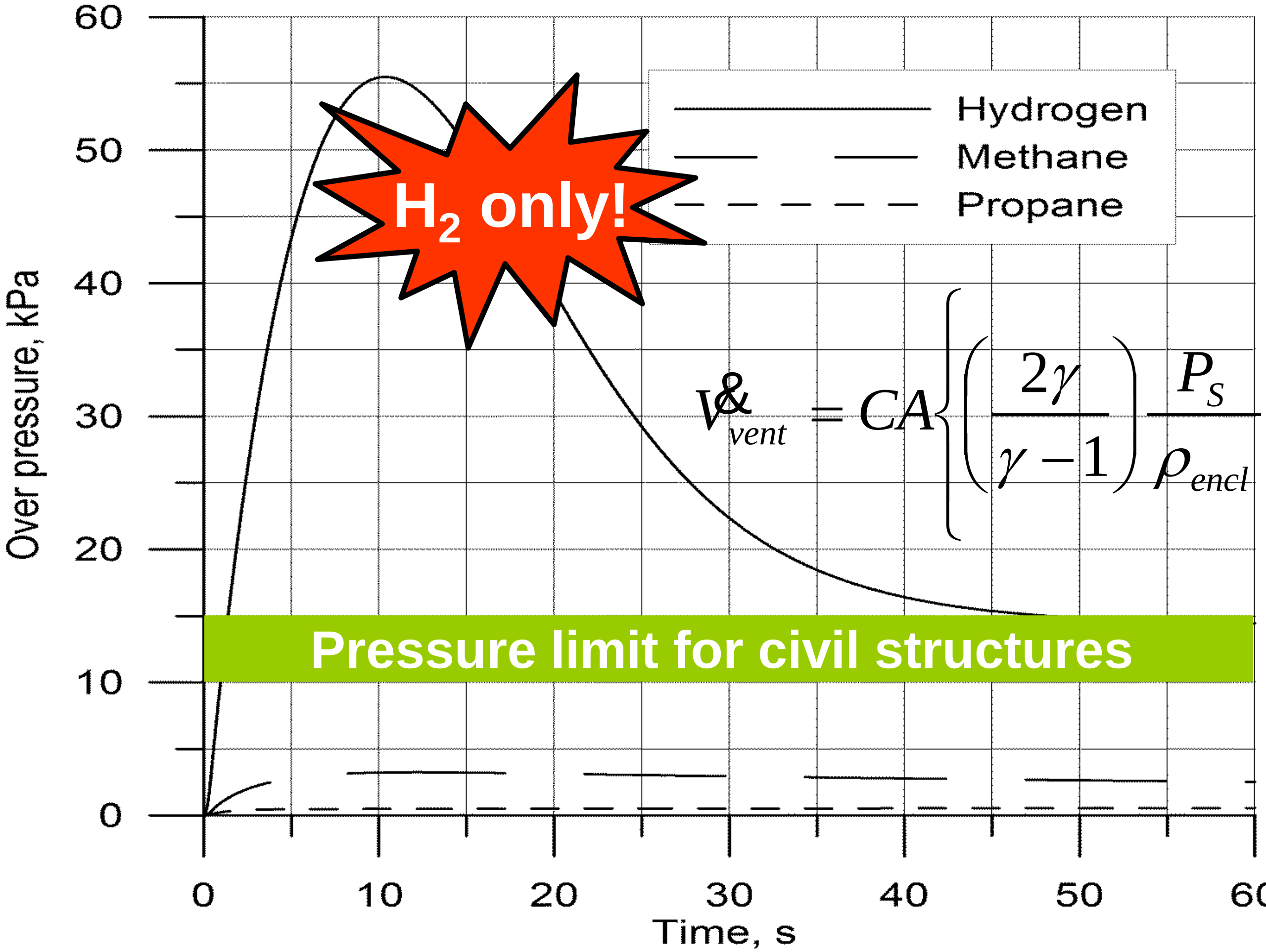
Reproduces previous nomogram at C_{max}=100%



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).



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

Solution: decrease PRD orifice size (and at the same time increase fire resistance of onboard storage)

Pressure peaking phenomena

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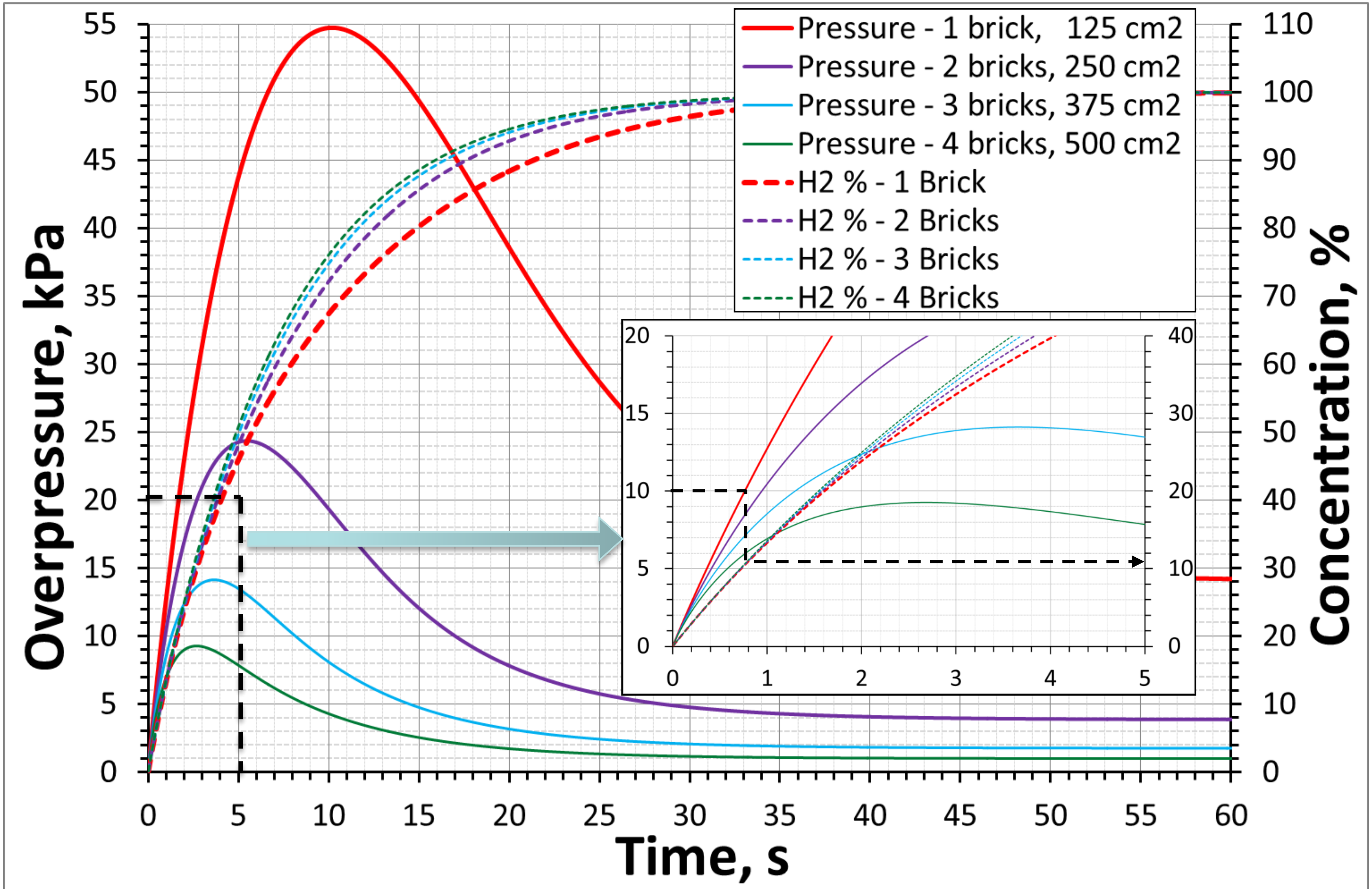
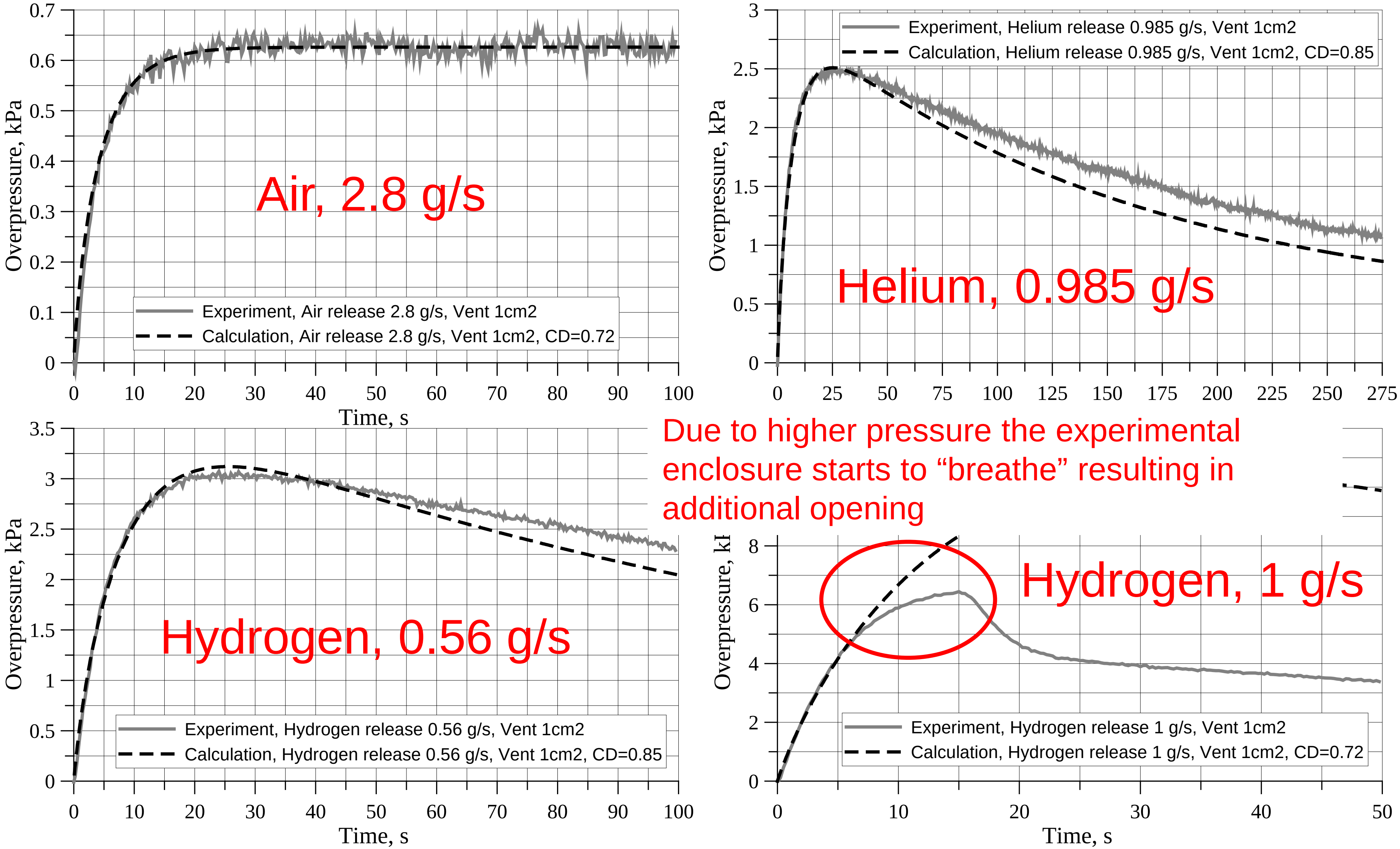


Pressure peaking: validation

Formula for the pressure peaking calculation had been validated against experimental result obtained by KIT for the steady state release.



Conclusions

- The analytical model for uniform concentration in an enclosure with one passive vent for sustained leak is developed, validated, and used to build engineering nomograms.
- The criterion for mixture uniformity in a vented enclosure is suggested.
- The nomogram to calculate the mass flow rate limit leading to 100% gas concentration in the enclosure as a function of the vent width and height is developed (flow rate should be above this limit to apply the pressure peaking phenomenon calculations).
- 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=0.6 is accepted for HSE as a conservative one.

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THANK YOU

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- FCH JU HyIndoor project (http://www.hyindoor.eu/)

H2FC SUPERGEN
THE HYDROGEN AND FUEL CELL RESEARCH HUB

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MSc in Hydrogen Safety Engineering (distance learning course):
http://www.ulster.ac.uk/elearning/programmes/view/course/10139

Fundamentals of Hydrogen Safety Engineering
(free download eBook, www.bookboon.com, 2012)