DIMITRHY

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Application of "natural "ventilation" models to hydrogen build-up in confined zones

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Content

I. Context

Context of the study

H_2 Energy applications

- **Design the system** even in accidental conditions
- Define **safety barriers** (detection, calibrated orifice, EFV, low pressure alarms...)
- Define the **safety distances** and **recommendations** for internal and external (customers, fire brigades, ...)
- Obtain **permits from authorities**

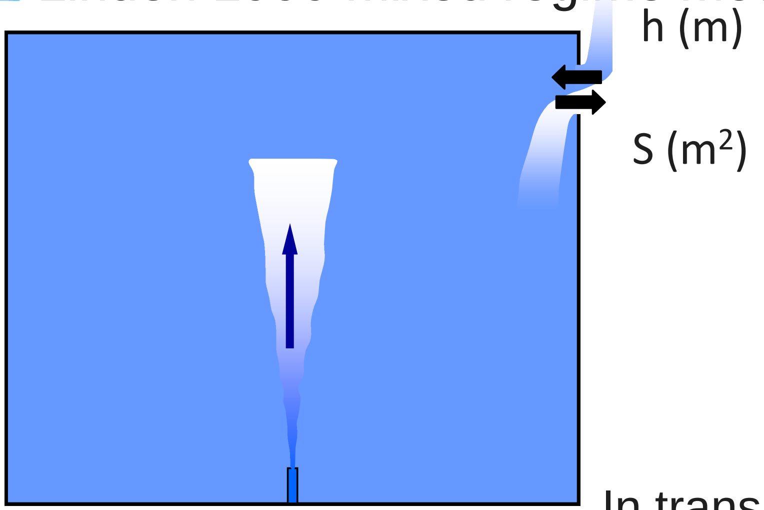
- ➔ <u>Need to dispose to accurate, simple, **rapid and validated** calculation tools for H2 build -up in confined areas</u>

Objective of the study

- Validation of the Linden et al models (air based models) against numerous experimental data with hydrogen and helium releases in various configurations (volume, vents shape and area, ...).

II. One vent configuration

- Linden 1999 mixed regime model



Buoyancy Conservation

Steady State

$$X_f = \left(\frac{Q_0}{C_D S (g_0' h)^{1/2}} \right)^{2/3}$$

Characteristic filling time

$$\tau = \frac{V}{C_D S \left(X_f g_0' h \right)^{1/2}}$$

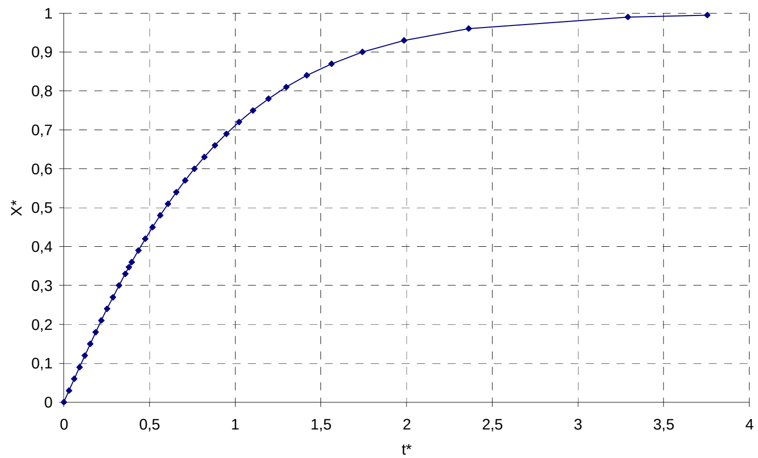
In transient :

$$\frac{dX^*}{dt^*} = 1 - X^{*3/2}$$

with

$$X^* = \frac{X}{X_f}, t^* = \frac{t}{\tau}$$

- Steady state : independent of volume
- Limitations :
  - Leak on the floor / Near cubic box
  - No wind / no grids / no obstacles
  - $X(H_2) < 10$ % ➔ OK for safety studies



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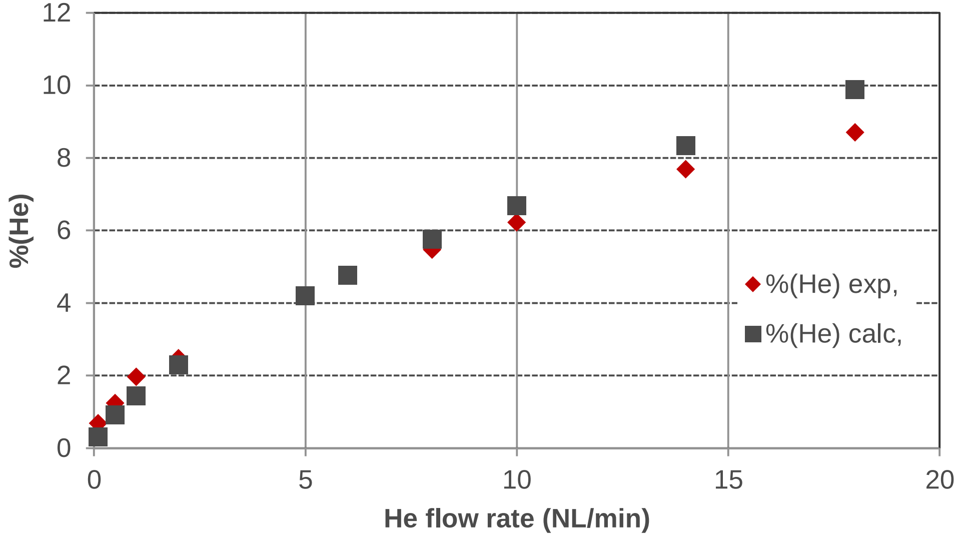
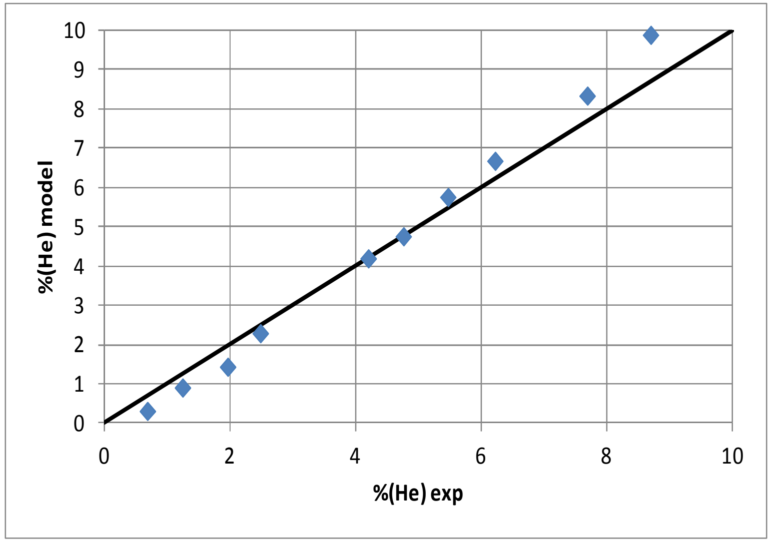
Comparison with Cariteau et al. (2011)

- CEA garage installation
  - 2.96 x 5.76 x 2.42 m → 41 m^3
  - Av = 38.5 cm^2 (circular vents)
- C_D adjusted to 0.254
  - In good agreement with Brown and Salvason (1962)





- Bias # 8% and absolute average deviation # 15%

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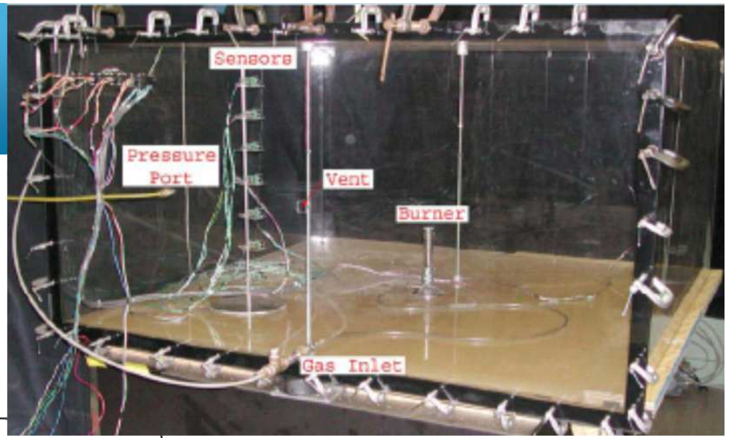
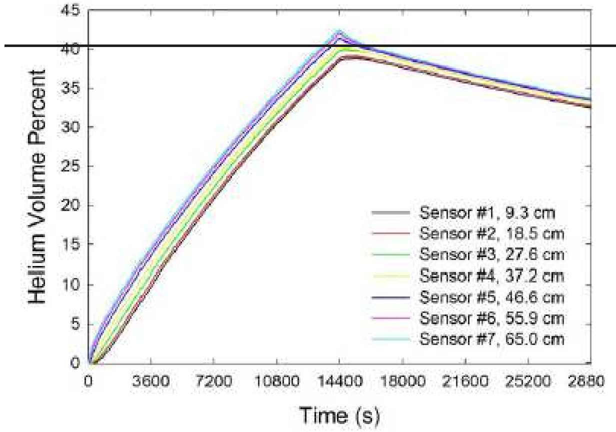
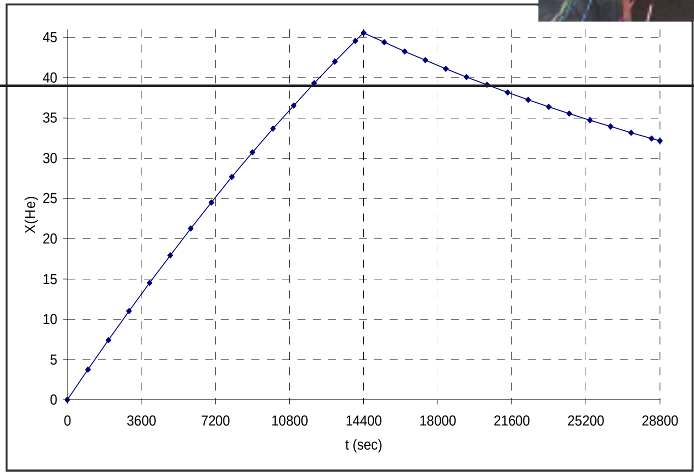
Comparison with Pitts et al. (2009)



- ¼ scale two-car rectangular garage
  - 1.5 x 1.5 x 0.75 m → 1.69 m^3
  - 3.74 L/min during 4 hours (transient calculations)

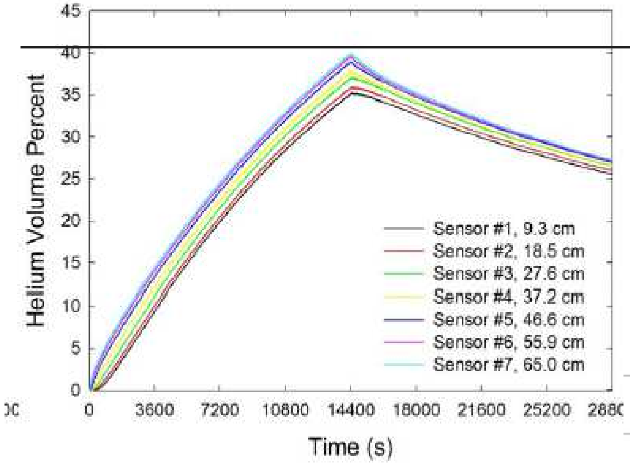
3.74 L/min – 5.8 cm^2

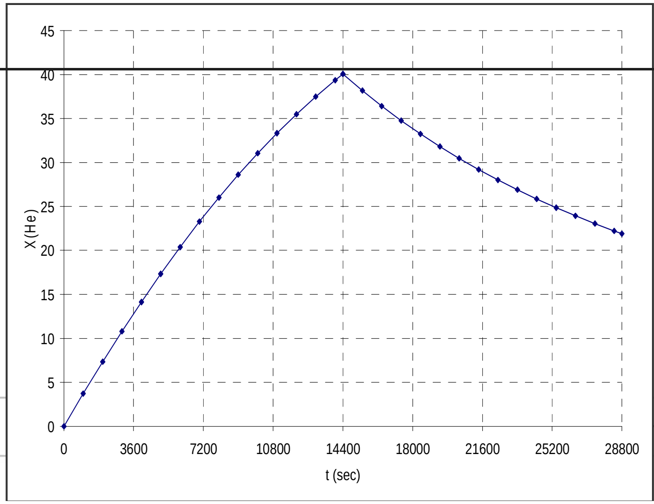




40%

3.74 L/min – 9.9 cm^2



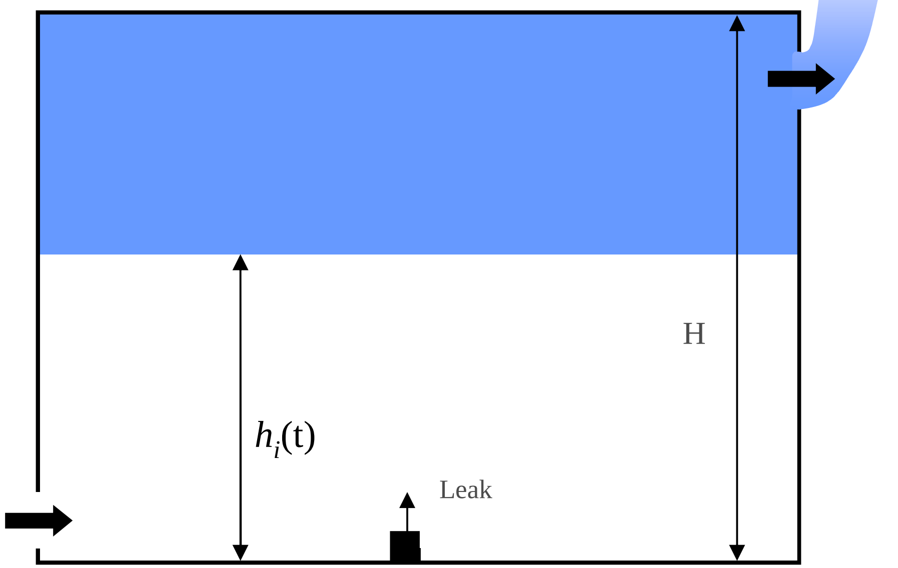


40%

III. Two vents configuration

TWO-OPENINGS NATURAL VENTILATION MODEL

- Linden (1999) displacement model



$$X = \frac{1}{C}\left(\frac{Q_0^2 h_i^{-5}}{g_0'}\right)^{1/3}$$

With $$\frac{S'}{H^2} = C^{3/2}\left(\frac{\xi^5}{1-\xi}\right)^{1/2}$$

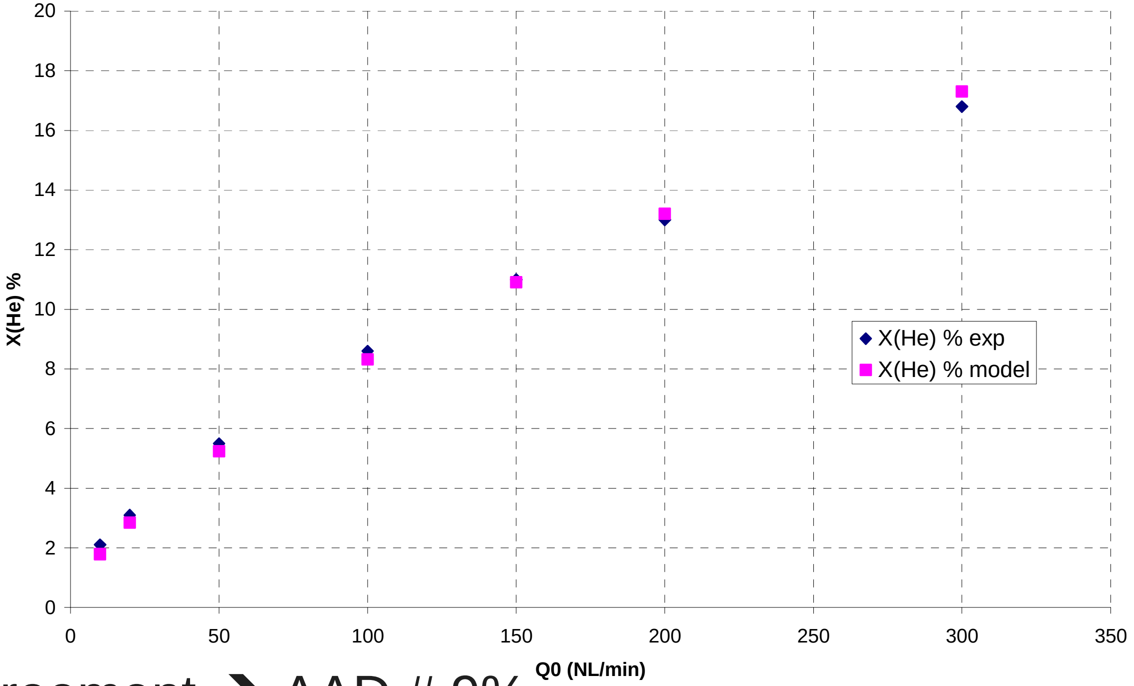
$$S' = \frac{C_D S_t S_b}{\left(\frac{1}{2}\left(\frac{C_D^2}{c} S_t^2 + S_b^2\right)\right)^{1/2}} \qquad \xi = \frac{h_i}{H}$$

- Steady state : independent of V but H dependant
- Limitations :
  - No wind / no grids / no obstacles / near cubic box
  - Leak on the floor / $X(H_2) < 10$ %
  - α = 0,1 (average value) ➔ not adapted to jets in principle

$$C = \frac{6}{5}\alpha\left(\frac{9}{10}\alpha\right)^{\frac{1}{3}}.\Pi^{\frac{2}{3}}$$

CEA GARAGE exp (un-published)

- CEA garage installation
  - 2.96 x 5.76 x 2.42 m → 41.26 m^3
  - Av = 38.5 cm^2 (circular vent)
- C_t & C_b # 0.5



- Good agreement → AAD # 9%

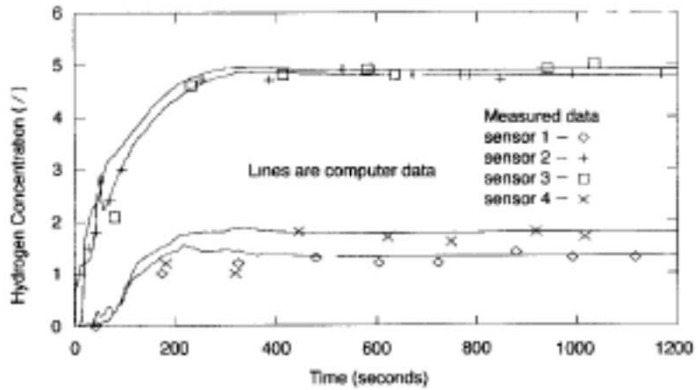
Barley and Gawlick (2009)

- NREL Garage
  - 7.02 x 4.29 x 2.74 m → 82.52 m^3
  - Av = 787 cm^2

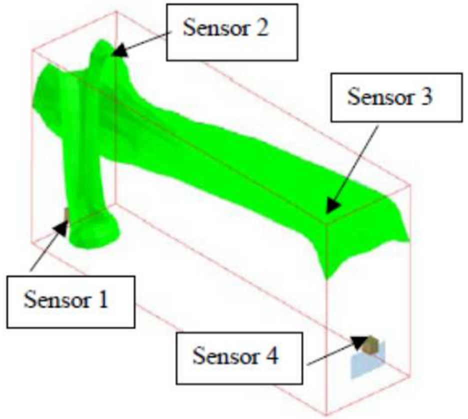
Case	Ys (m)	Q_0 ($Nl.min^{-1}$)	%(He) exp.	%(He) calc.
P1	0.61	9.0	1.2	0.9
P2	0.61	20.2	2.0	1.5
P3	0.61	37.1	2.9	2.3
P4	0.91	11.3	1.5	1.0
P5	0.91	22.6	2.6	1.6
P6	0.91	17.0	2.7	1.3
L1	1.22	20.3	1.7	1.5
L2	0.61	37.3	2.4	2.3

- AAD is about 17%

Other validations



- **Swain et al. (1999)**
  - 2.99 x 0.74 x 1.22m ➔ 2,7 m^3
  - Av = 232 cm^2
  - Calculated : 6.00 and 6.16% for H_2 and He
  - Experimental : 5% for H_2 and He



- **Merilo et al. (2010)**
  - 2,72 x 3,63 x 6,10m ➔ 60 m^3
  - Av (top) = Av (bottom) = 0,11 m^2

NL/min	Exp H_2 %	Calc H_2 %
1720	22.8	24.9
164	5.8	5.2

Conclusions and perspectives

- **Validation of the engineering models proposed by Linden to evaluate the H_2% in an enclosure naturally ventilated in case of leak :**
  - **For enclosure with a one or two openings**
  - **With leak on the floor and H2% < 10 %**
  - **without wind effects, grids on openings, obstacles and for a near cubic box**

- **With only one ventilation opening**
  - **Well-mixed configuration with a homogenous gas concentration in the enclosure**
  - **A good agreement is obtained between calculations performed with Linden method and recently published experiments**
  - **Improvement for high H_2% could be achieved using the modified Molkov et al. method (see paper 152)**

- **With two openings**
  - **Displacement regime with formation of a homogenous upper layer**
  - **A good agreement is also obtained between Linden based calculation method and recent experiments.**

- **Modifications of the models to take into account wind effects, leak location effects (see paper 161) and jet momentum effects could improve the prediction**

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Thanks for your attention

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