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

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I. Context
Context of the study

**H₂ 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**

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

**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
ONE OPENING NATURAL VENTILATION MODEL

Linden 1999 mixed regime model

\[ h (m) \]

\[ S (m^2) \]

In transient:

\[ \frac{dX^*}{dt^*} = 1 - X^{*\frac{3}{2}} \]

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

Buoyancy Conservation

Steady State

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

Characteristic filling time

\[ \tau = \frac{V}{C_D S (X_f g_0 h')^{\frac{1}{2}}} \]

In transient:

\[ X^* = \frac{X}{X_f}, t^* = \frac{t}{\tau} \]
Comparison with Cariteau et al. (2011)

- CEA garage installation
  - 2.96 x 5.76 x 2.42 m → 41 m³
  - \( Av = 38.5 \text{ cm}^2 \) (circular vents)
- \( C_D \) adjusted to 0.254
  - In good agreement with Brown and Salvason (1962)

- Bias # 8% and absolute average deviation # 15%
Comparison with Pitts et al. (2009)

- ¼ scale two-car rectangular garage
- 1.5 x 1.5 x 0.75 m → 1.69 m³
- 3.74 L/min during 4 hours (transient calculations)

3.74 L/min – 5.8 cm²

3.74 L/min – 9.9 cm²

He and the environment
III. Two vents configuration
TWO-OPENINGS NATURAL VENTILATION MODEL

Linden (1999) displacement model

\[ X = \frac{1}{C} \left( \frac{Q_0^2 h_i^{-5}}{g'_0} \right)^{\frac{1}{3}} \]

With

\[ S' = \frac{C_D S_t S_b}{\left( \frac{C^2}{c} S_t^2 + S_b^2 \right)^{\frac{1}{2}}} \]
\[ \xi = \frac{h_i}{H} \]

Steady state: independent of V but H dependant

Limitations:
- No wind / no grids / no obstacles / near cubic box
- Leak on the floor / \( X(H_2) < 10\% \)
- \( \alpha = 0.1 \) (average value) \( \Rightarrow \) 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 m³
  - Av = 38.5 cm² (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 m³
- $A_v = 787 \text{ cm}^2$

<table>
<thead>
<tr>
<th>Case</th>
<th>Ys (m)</th>
<th>$Q_0$ (Nl.min⁻¹)</th>
<th>% (He) exp.</th>
<th>% (He) calc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.61</td>
<td>9.0</td>
<td>1.2</td>
<td>0.9</td>
</tr>
<tr>
<td>P2</td>
<td>0.61</td>
<td>20.2</td>
<td>2.0</td>
<td>1.5</td>
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<tr>
<td>P3</td>
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<td>37.1</td>
<td>2.9</td>
<td>2.3</td>
</tr>
<tr>
<td>P4</td>
<td>0.91</td>
<td>11.3</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>P5</td>
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<td>22.6</td>
<td>2.6</td>
<td>1.6</td>
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<tr>
<td>P6</td>
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<td>17.0</td>
<td>2.7</td>
<td>1.3</td>
</tr>
<tr>
<td>L1</td>
<td>1.22</td>
<td>20.3</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>L2</td>
<td>0.61</td>
<td>37.3</td>
<td>2.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

AAD is about 17%
Other validations

- **Swain et al. (1999)**
  - 2.99 x 0.74 x 1.22m → 2.7 m³
  - \(Av = 232 \text{ cm}^2\)
  - 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 m³
  - \(Av\) (top) = \(Av\) (bottom) = 0.11 m²

<table>
<thead>
<tr>
<th>NL/min</th>
<th>Exp (H_2) %</th>
<th>Calc (H_2) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1720</td>
<td>22.8</td>
<td>24.9</td>
</tr>
<tr>
<td>164</td>
<td>5.8</td>
<td>5.2</td>
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</tbody>
</table>
Conclusions and perspectives

Validation of the engineering models proposed by Linden to evaluate the \( \text{H}_2\% \) in an enclosure naturally ventilated in case of leak:
- For enclosure with a one or two openings
- With leak on the floor and \( \text{H}_2\% < 10\% \)
- 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 \( \text{H}_2\% \) 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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