The European Network of Excellence for Hydrogen Safety

On the use of hydrogen in confined spaces: Results from the internal project InsHyde

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3rd International Conference on Hydrogen Safety
Ajaccio, Corsica (FR), 16-18 Sept. 2009
Use of hydrogen in confined spaces

Spaces containing parts where hydrogen can accumulate

garage

Electrolyser

Underground storage

Refuelling station
InsHyde IP

Internal project within HySafe NoE

- [http://www.hysafe.net/InsHyde](http://www.hysafe.net/InsHyde)

Scope

- To investigate realistic small-medium indoor leaks and provide recommendations for the safe use/storage of indoor hydrogen systems
- To pull together work packages proposals and existing research projects toward a common goal and a useful contribution to the society for the safe implementation of hydrogen technologies.

Participation/Duration

- Nearly all HySafe participants
- 3 years
InsHyde structure

Work packages (wp-leaders):

1. Review (DNV)
2. Hydrogen Detection experiments (JRC)
3. Study of permeation (VOLVO)
4. Dispersion experiments (CEA)
5. Explosion experiments (FZK)
6. Ignition (HSL)
7. CFD modelling (GEXCON)
8. Scaling methodology (FZK)
9. Recommendations (NCSRD, INERIS)
10. Dissemination (NCSRD, INERIS)
Hydrogen detection experiments

- **Scope**
  - Assessment of the performance of commercially available hydrogen detectors (JRC and INERIS)
  - Inter-laboratory comparison on calibration-type tests on selected sensor types (JRC and BAM)

- **Methodology**
  - Test program based on IEC 61779-1 & 4
  - 9 detectors were tested from different manufacturers (electrochemical and catalytic)
  - Acquisition of calibration curves, measuring the response and recovery time during an instantaneous variation of the hydrogen concentrations
  - Response to variation in environmental temperature, humidity and pressure
  - Cross-sensitivity in the case of CO
Hydrogen detection experiments

- **Some Results**
  - Tests have shown that the electrochemical technology allows to detect hydrogen concentration lower than in the case of catalytic technology, whose detection threshold is around 500 ppm (~1.25 % of hydrogen LFL)
  - A new “continuous calibration” concept has been tested. The results compare well with those obtained by the standardised technique.
  - The response time (t90) of catalytic detectors, with a gas test concentration of 50 % of hydrogen LFL, was less than 10 seconds. Response time was moderately influenced by temperature.
  - Humidity had a greater impact on response time. Increased humidity leads to higher response time value.
  - CO sensitivity was high for catalytic combustion sensors (approximately 1/3 of that to hydrogen).
  - In comparison to the humidity and cross-sensitivity effects, temperature and pressure variation induce a more limited signal deviation.
Study of permeation

• Scope:
  – Examine whether existing allowable permeation rates could relaxed
  – Examine whether permeation type releases lead to stratification or to homogeneous distribution

• Methodology
  – Review of previous pre-normative work and results (VOLVO)
  – Review of garage sizes/natural ventilation rates (VOLVO, BRE)
  – CFD simulations (NCSRD, UU)
  – Helium dispersion Experiments (CEA)
  – Theoretical considerations (VOLVO and all)
Study of permeation

• Previous allowable permeation values:
  – 1.0 NmL/hr/L water capacity @ SoL and AT (ECE draft)
  – 2.0 NmL/hr/L water capacity @ 350MPa, SoL and AT (ISO draft)
  – 2.8 NmL/hr/L water capacity @ 700MPa, SoL and AT (ISO draft)
  – 75 NmL/min (SAE draft)

• HySafe proposal:
  – 6.0 NmL/hr/L water capacity @ SoL and 15 °C or
  – 8.0 NmL/hr/L water capacity @ SoL and 20 °C
  – Proposed figures are not applicable for permeation into vehicle compartments
Dispersion tests

- **Scope**
  - Study of hydrogen accumulation in garage
  - Effect of source strength, source momentum, ventilation
  - Generation of new data sets for CFD validation

- **Experimental program**
  - INERIS tests, using H2
  - CEA tests, using He
H2 dispersion test INERIS-6C

Enclosure size: 7.2 x 3.78 x 2.88 m

- Plastic sheet
- Release chamber

<table>
<thead>
<tr>
<th>Sensor</th>
<th>X (cm)</th>
<th>Y (cm)</th>
<th>Z (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>283</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>0</td>
<td>283</td>
</tr>
<tr>
<td>6</td>
<td>140</td>
<td>0</td>
<td>283</td>
</tr>
<tr>
<td>7</td>
<td>1.84</td>
<td>0</td>
<td>283</td>
</tr>
<tr>
<td>8</td>
<td>140</td>
<td>0</td>
<td>268</td>
</tr>
<tr>
<td>9</td>
<td>140</td>
<td>0</td>
<td>238</td>
</tr>
<tr>
<td>10</td>
<td>140</td>
<td>0</td>
<td>188</td>
</tr>
<tr>
<td>11</td>
<td>140</td>
<td>0</td>
<td>138</td>
</tr>
<tr>
<td>12</td>
<td>140</td>
<td>0</td>
<td>88</td>
</tr>
<tr>
<td>13</td>
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<td>0</td>
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<td>14</td>
<td>0</td>
<td>0</td>
<td>238</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>0</td>
<td>138</td>
</tr>
</tbody>
</table>

- H2 mass flow rate: 1 g/s
- Nozzle diameter: 20 mm
- Release duration: 240 s
- Test duration: 5400 s
- Ambient temperature: 10 °C
- Target concentration: 3.53%

Lacome et al., Large scale hydrogen release in an isothermal confined area, ICHS-2, 2007
H2 dispersion test INERIS-6C

<table>
<thead>
<tr>
<th>Filling temperature</th>
<th>Flow rate (g/s)</th>
<th>Release diameter (mm)</th>
<th>Release direction</th>
<th>Exit velocity (m/s)</th>
<th>Release duration (s)</th>
<th>Opening status (open/closed)</th>
<th>Observation Time (s)</th>
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<tbody>
<tr>
<td>15 °C</td>
<td>0.7</td>
<td>20</td>
<td>Vertical upwind</td>
<td>38</td>
<td>240</td>
<td>closed</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>20</td>
<td></td>
<td>38</td>
<td>240</td>
<td>open</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td></td>
<td>53</td>
<td>240</td>
<td>closed</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td></td>
<td>210</td>
<td>240</td>
<td>closed</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>20</td>
<td></td>
<td>11</td>
<td>240</td>
<td>closed</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>5</td>
<td></td>
<td>170</td>
<td>240</td>
<td>closed</td>
<td>7200</td>
</tr>
</tbody>
</table>

![Graph showing height from release point vs. concentration %vol for different flow rates and release diameters.](image-url)
He dispersion tests by CEA

Garage facility at CEA

✓ Stainless steel skeleton
✓ Replaceable wall modules
✓ Commercial tilting door in the front side (not completely sealed)
✓ Technical access door in the back (sealed)
✓ Laser based measurements possible

Gupta et al. Hydrogen related risks within a private garage: Concentration measurements in a realistic full scale experimental facility, ICHS-2, 2007
## He dispersion tests by CEA

### Test matrix (free volume - no ventilation)

<table>
<thead>
<tr>
<th>Volumetric flow rate – STP (NL.min⁻¹)</th>
<th>GAR_FV nV-TEST1</th>
<th>GAR_FV nV-TEST2</th>
<th>GAR_FV nV-TEST3</th>
<th>GAR_FV nV-TEST4</th>
<th>GAR_FV nV-TEST5</th>
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</thead>
<tbody>
<tr>
<td>668</td>
<td>668.8</td>
<td>668</td>
<td>18</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Helium mass flow rate (g.s⁻¹)</th>
<th>1.99</th>
<th>0.2</th>
<th>1.99</th>
<th>0.05</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release diameter (mm)</td>
<td>20.7</td>
<td>20.7</td>
<td>20.7</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Release duration (s)</td>
<td>121</td>
<td>300</td>
<td>500</td>
<td>3740</td>
<td>3740</td>
</tr>
<tr>
<td>Release Direction</td>
<td>Upward</td>
<td>Upward</td>
<td>Upward</td>
<td>Upward</td>
<td>Upward</td>
</tr>
<tr>
<td>Release Type</td>
<td>Continue</td>
<td>Continue</td>
<td>Continue</td>
<td>Continue</td>
<td>Continue</td>
</tr>
<tr>
<td>Release period – if pulsed</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>x release (m)</td>
<td>2.88</td>
<td>2.88</td>
<td>2.88</td>
<td>2.88</td>
<td>2.88</td>
</tr>
<tr>
<td>y release (m)</td>
<td>1.48</td>
<td>1.48</td>
<td>1.48</td>
<td>1.48</td>
<td>1.48</td>
</tr>
<tr>
<td>z release (m)</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Garage temperature T️ₘₐₚ (°C)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Released volume – STP (Nm³)</td>
<td>1.35</td>
<td>0.33</td>
<td>5.57</td>
<td>1.12</td>
<td>1.12</td>
</tr>
<tr>
<td>Released volume - T️ₘₐₚ (m³)</td>
<td>1.45</td>
<td>0.36</td>
<td>5.97</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Released mass (g)</td>
<td>240</td>
<td>60</td>
<td>994</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Concentration T️ₘₚ (%)</td>
<td>3.5</td>
<td>0.9</td>
<td>14.5</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Exit velocity - 20°C (m.s⁻¹)</td>
<td>35.50</td>
<td>3.55</td>
<td>35.50</td>
<td>16.40</td>
<td>0.46</td>
</tr>
<tr>
<td>Rₑₚ - 20°C</td>
<td>6150</td>
<td>615</td>
<td>6150</td>
<td>686</td>
<td>114</td>
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<tr>
<td>Rₑₖ - 20°C</td>
<td>9.9E-04</td>
<td>9.9E-02</td>
<td>9.9E-04</td>
<td>1.1E-03</td>
<td>8.7E+00</td>
</tr>
</tbody>
</table>

- turbulent jet
- laminar jet-plume transition
- turbulent jet
- laminar jet
- Laminar plume

Gupta et al. Hydrogen related risks within a private garage: Concentration measurements in a realistic full scale experimental facility, ICHS-2, 2007
He dispersion tests by CEA

**Test 1**

Helium concentration profiles 100 s after start of release

- Test 1: 2 g/s - 20.7 mm
- Test 2: 0.2 g/s - 20.7 mm
- Test 4: 0.05 g/s - 5 mm
- Test 5: 0.05 g/s - 30 mm

ICH5-3, Ajaccio, Corsica (FR), 16-18 Sept. 2009
Hydrogen explosion tests

• Scope
  – What is the maximum amount of hydrogen that can be released and “safely” exploded?
  – Effects of obstacles (blockage)
  – Generation of new data sets for CFD validation

• Experimental program
  – FZK tests (up to 10gr)
  – KI tests (0.1 to 1 kg)
H2 explosion tests by FZK

Explosion tests facility at FZK

Confinement

Sound speed measurements:
- Concentration
- Gas velocity

Injection

BOS visualization. Test w/o ignition.
Flat enclosure. No obstruction.

Friedrich et al. Experimental study of jet-formed hydrogen-air mixtures and pressure loads from their deflagrations in low confined surroundings, ICHS-2, 2007

ICH3-3, Ajaccio, Corsica (FR), 16-18 Sept. 2009
**H2 explosion tests by FZK**

### Explosion tests matrix

**Release duration (s) for H, Inventory: 1g**

<table>
<thead>
<tr>
<th>Exit velocity; m/s</th>
<th>Nozzle d= 100mm</th>
<th>Nozzle d= 21mm</th>
<th>Nozzle d= 4mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>7.13 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.43 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.29 s</td>
<td>6.47 s</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.32 s</td>
<td>7.00 s</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>0.16 s</td>
<td>3.50 s</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
<td>1.75 s</td>
<td></td>
</tr>
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</table>

**Release duration (s) for H, Inventory: 3g**

<table>
<thead>
<tr>
<th>Exit velocity; m/s</th>
<th>Nozzle d= 100mm</th>
<th>Nozzle d= 21mm</th>
<th>Nozzle d= 4mm</th>
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</thead>
<tbody>
<tr>
<td>0.2</td>
<td>21.39 s</td>
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</tr>
<tr>
<td>1</td>
<td>4.28 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.86 s</td>
<td>19.40 s</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.97 s</td>
<td>21.00 s</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>0.49 s</td>
<td>10.50 s</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
<td>5.25 s</td>
<td></td>
</tr>
</tbody>
</table>

**Release duration (s) for H, Inventory: 10g**

<table>
<thead>
<tr>
<th>Exit velocity; m/s</th>
<th>Nozzle d= 100mm</th>
<th>Nozzle d= 21mm</th>
<th>Nozzle d= 4mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>71.30 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14.26 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.85 s</td>
<td>64.67 s</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>3.23 s</td>
<td>70.00 s</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1.62 s</td>
<td>35.00 s</td>
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</tr>
<tr>
<td>400</td>
<td></td>
<td>17.50 s</td>
<td></td>
</tr>
</tbody>
</table>

Friedrich et al. Experimental study of jet-formed hydrogen-air mixtures and pressure loads from their deflagrations in low confined surroundings, ICHS-2, 2007
H2 explosion tests by KI

ICH S-3, Ajaccio, Corsica (FR), 16-18 Sept. 2009
H2 explosion tests

Some results:

- FZK tests
  - *Undisturbed free jet* a maximum overpressure of 11.1 mbar at distance 0.403 m from the ignition source
  - *Hydrogen accumulation in a hood* a maximum overpressure of 53.2 mbar at the highest position inside the hood at a distance of 0.78 m from the ignition
  - *Grid net layer structures for flame acceleration* a maximum overpressure of 9176 mbar and 410 mbar at distance 0.345 and 1.945 m from the ignition

- KI tests
  - *For congested area (BR= 0.3 and 0.54)* slow combustion took place with maximum overpressure lower than 60 mbar. With additional congestion maximum overpressure reaches 400 mbar.
  - *Special geometry* was found that results in fast deflagration with overpressure more than 10 atm.
CFD modelling

- **Scope**
  - Support of experimental activities by performing pre-test calculations
  - CFD validation against existing and newly obtained experimental data
  - CFD applications
Venetsanos et al., An Inter-Comparison Exercise On the Capabilities of CFD Models to Predict the Short and Long Term Distribution and Mixing of Hydrogen in a Garage, IJHE, 2009

ICHS-3, Ajaccio, Corsica (FR), 16-18 Sept. 2009
Post CFD modelling of INERIS-6C

Venetsanos et al., An Inter-Comparison Exercise On the Capabilities of CFD Models to Predict the Short and Long Term Distribution and Mixing of Hydrogen in a Garage, IJHE, 2009
Recommendations

Deliverable D113
- Initial guidance for using hydrogen in confined spaces - Results from InsHyde (90 pp.)

Scope
- To provide general guidance on the use of hydrogen in confined spaces
- To summarize results obtained during InsHyde

Concerned public
- Research, industry and general public

Contributions
- Coordination: NCSRD and INERIS
- Authors (alphabetically): BMW, BRE, FH-ICT, FZJ, FZK, GEXCON, HSL, INASMET, INERIS JRC, KI, NCSRD, STATOIL/HYDRO, UNIPI, UU
- Reviewers: VOLVO, AVT, SH
Recommendations

Deliverable 113 structure

1. Introduction
2. Risk control measures when using hydrogen indoors
3. Hydrogen behaviour in accidental situations
4. Risk assessment recommendations
5. Experiences from HYSAFE members
Dissemination

- Scientific papers
  - Conferences: ICHS-2 and ICHS-3
  - Journals: IJHE

- InsHyde Website ([http://www.hysafe.net/InsHyde](http://www.hysafe.net/InsHyde))
  - Public deliverables
    - D113 (Guidance)
    - D54 (detectors)
    - D74 (permeation)

- Direct contacts
  - Presentation of Guidance document (D113) to the members of the HySafe database of hydrogen safety related organizations
  - Presentations of HySafe permeation proposal (D74) to EC, ISO, SAE and other regulatory/standardization organizations
Future work

- Further pre-normative work is needed:
  - To formulate the requirements for permitting the use of hydrogen systems (vehicles, hydrogen storage and delivery systems, fuel cells) in confined spaces both from the perspective of the hydrogen systems and of the buildings
  - To increase our understanding on hydrogen behaviour in confined spaces
  - To be jointly undertaken by research + industry + regulatory bodies

Thank you!!