Guidance for using hydrogen in confined spaces

Results from InsHyde
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InsHyde coordination
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Workshop on New Energy Carriers in tunnels and underground installations,
Frankfurt Airport, 20 Nov 2008
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

Scope
  - To investigate realistic small-medium indoor leaks and provide recommendations for the safe use/storage of indoor hydrogen systems

Participation/Duration
  - Nearly all HYSAFE participants
  - 3 years
InsHyde structure

Work packages:

1. Review
2. Gas Detection experiments (public D54, see website)
3. Theoretical study of permeation
4. Dispersion experiments (see refs 1-3, ICHS-2)
5. Explosion experiments (see refs 4-5, ICHS-2)
6. Ignition
7. CFD modelling (see refs 2,6, ICHS-2)
8. Scaling methodology
9. Recommendations (D113 public by Dec 2008)
10. Dissemination (ICHS-2, ICHS-3, …)
H2 dispersion test INERIS-6C (ref 1)

Enclosure size: 7.2 x 3.78 x 2.88 m

Sensor locations:

1 0 0 283
4 40 0 283
6 140 0 283
7 1.84 0 283
8 140 0 268
9 140 0 238
10 140 0 188
11 140 0 138
12 140 0 88
13 0 0 268
14 0 0 238
16 0 0 138

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%

Plastic sheet
Enclosure size: 7.2 x 3.78 x 2.88 m

Release chamber

Height: 265 mm
Diameter: 120 mm
Blind CFD modelling of INERIS-6C (ref 2)

Risk assessment parameters

- Too much mixing. Transition to homogeneous conditions. Group of LVEL_NCSRD, ML_CEA, KE_UPM, RNG_AVT, SST_GRS, VLES_UU
- Stratification. Group of LVEL_AVT, KE_FZK, KE_NCSRD, KE_GXC, KE_DNV_a, KE_FZJ, SST_HSL

Workshop on New Energy Carriers in tunnels and underground installations, Frankfurt Airport, 20 Nov 2008
Post CFD modelling of INERIS-6C (ref 2)
He dispersion tests by CEA (ref 3)

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

\[ x_i = 5.76 \text{m} \]
\[ y_i = 2.96 \text{m} \]
\[ z_i = 2.42 \text{m} \]
\[ V_i = 40.92 \text{m}^3 \]
### He dispersion tests by CEA (ref 3)

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

<table>
<thead>
<tr>
<th>Volmetric 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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>668</td>
<td>66.8</td>
<td>668</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Helium mass flow rate (g.s⁻¹)</td>
<td>1.99</td>
<td>0.2</td>
<td>1.99</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<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 Tₘoy (°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 - Tₘoy (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 Tₘoy (%)</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>Re₉ - 20°C</td>
<td>6150</td>
<td>615</td>
<td>6150</td>
<td>686</td>
<td>114</td>
</tr>
<tr>
<td>R₁₉ - 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
H2 explosion tests by FZK (refs 4,5)

Explosion tests facility at FZK

Confinement

Sound speed measurements:
- Concentration
- Gas velocity

Injection

BOS visualization. Test w/o ignition. Flat enclosure. No obstruction.
## H2 explosion tests by FZK (refs 4,5)

### 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>6.47 s</td>
<td>0.29 s</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>3.50 s</td>
<td>0.16 s</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1.75 s</td>
<td>1.75 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>64.67 s</td>
<td>2.85 s</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>70.00 s</td>
<td>3.23 s</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>35.00 s</td>
<td>1.62 s</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>17.50 s</td>
<td>5.25 s</td>
<td></td>
</tr>
</tbody>
</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>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>21.39 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.28 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>19.40 s</td>
<td>0.86 s</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>21.00 s</td>
<td>0.97 s</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>10.50 s</td>
<td>0.49 s</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>5.25 s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
H2 explosion tests by FZK (refs 4,5)

Some results:

- 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 at distance 0.345 m from the ignition
  - a maximum overpressure of 410 mbar at distance 1.945 m from the ignition
InsHyde/ Document D113

Title:
- Guidance for using hydrogen in confined spaces - Results from InsHyde (90 pp.)

Scope
- To provide general guidance on the use of h2 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
Document 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
InsHyde/ D113 structure

1. Introduction
   - Scope
   - Hydrogen basic properties
   - Confined spaces and hydrogen systems
   - Reference documentation

2. Risk control measures when using hydrogen indoors
   - Fuel supply and storage arrangement
   - Detection
   - Ventilation and exhaust
   - Fire and explosion safety
   - Commissioning, inspections, training and worker protection
   - Reference documentation
3. Hydrogen behaviour in accidental situations
   - Hydrogen release and dispersion
   - Hydrogen ignition
   - Hydrogen explosion
   - Hydrogen fire
   - Reference documentation

4. Risk assessment recommendations
   - Risk assessment methodology
   - Consequence assessment
   - Reference documentation
5. Experiences from HYSAFE members

- Schematic for the assessment and prevention of explosive risks
- Safety assessment for hydrogen laboratory at Forschungszentrum Juelich, Germany
- Safety assessment for Statoil/Hydro 15 bar electrolyser
- BMW (H2 research centre – 250 bar CGH2 and LH2)
- Safety assessment of the PEMFC test laboratory at INASMET-Tecnalia, Spain
- Safety assessment for explosion risks at Fraunhofer Solid Oxide Fuel Cell Laboratory
- Safety assessment for hydrogen facilities at University of Pisa, Italy
- Safety assessment for the Safety Vessel A1 on the hydrogen test site HYKA at Forschungszentrum Karlsruhe, Germany
- Safety assessment for dispersion and explosion testing at INERIS, France
- Safety assessment for the “Globus” facility at Russian Research Center Kurchatov Institute Moscow, Russia
- HSL Risk assessment
Future work

Further pre-normative work is needed:

- To be funded by JTI + …
- To be jointly undertaken by research + industry + regulatory bodies
- To increase our understanding on hydrogen behaviour in confined spaces
- In order to formulate the requirements (at EC and global level) for permitting the use of hydrogen vehicles (cars and commercial vehicles) in confined spaces
References


