Questions and Issues on Hydrogen Pipelines

Pipeline Transmission of Hydrogen

Doe Hydrogen Pipeline Working Group Meeting ■ August 31, 2005
Breakdown by gases

Pipeline Inventory 2004

- N2: 2956 km
- O2: 3447 km
- H2: 1736 km
- CO/Syngas: 61 km

TOTAL 8200 km
Pipping of GH2 Pipeline

Background

- FG 64 built in 50ies
- KP added in 70ies
- active mining area over total length
- length approx. 25 km
- incl. 150 expansion joints (EJ) and 40 foundations
- all damaged caused by mining influence payed 55% by mining company
- EJ in end position considered as damage

Weltmarktführer für technische und medizinische Gase
3. Special structures

River Crossings (culvert): 6 (Rhein, Ruhr, Rhein-Herne-Kanal)
River crossing (on bridge): 1 (Rhein-Herne-Kanal)
Motorway Crossings: 26
Overground Pipelines: approx 21 km
5. Mining areas
France & Netherlands

Oxygen, nitrogen, hydrogen and carbon monoxide pipelines

NORTHERN EUROPE networks

FRANCE

BELGIUM

NETHERLANDS

Copyright: AIR LIQUIDE

Pipeline Transmission of Hydrogen --- 6
Air Liquide Oxygen, Nitrogen, Hydrogen Pipelines
<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>France, Belgium</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years H2 operation</td>
<td>&lt;49</td>
<td>&lt;22</td>
<td>&lt;17</td>
</tr>
<tr>
<td>miles</td>
<td>150</td>
<td>646</td>
<td>245</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>250 psig</td>
<td>1400 psig</td>
<td>700 psig</td>
</tr>
<tr>
<td>Steel grade</td>
<td>&lt;X42</td>
<td>&lt;X52</td>
<td>&lt;X60</td>
</tr>
<tr>
<td>Pipe manufacture</td>
<td>ERW</td>
<td>ERW</td>
<td>ERW</td>
</tr>
<tr>
<td>Welding</td>
<td>SMAW</td>
<td>SMAW</td>
<td>SMAW</td>
</tr>
<tr>
<td>Valve type</td>
<td>ball</td>
<td>ball</td>
<td>ball</td>
</tr>
<tr>
<td>Valve make</td>
<td>Audco</td>
<td>Argus</td>
<td>Cameron</td>
</tr>
</tbody>
</table>
Air Liquide Oxygen, Nitrogen, Hydrogen Pipelines
Corpus Christi 8” H2 Pipeline (1998)

- Originally built as crude oil gathering pipelines (1940-1950) – 140 miles of 8 inch pipe
- Purchased by AL in 1998
- Intelligent pig inspection, cleaned, hydrotest
- Used in H2 service at 700 psig for 6 months
- Rupture because of corrosion 1998
- Derated to 350 psig, 65 miles still in service
Freeport to Texas City 14” Pipeline

- Originally built as crude oil pipeline in 1979
- 34 miles, various grades and wall thickness
- Intelligent pig inspection, cleaned, hydrotest
- Original pipeline ball valves still in use for H2.
- Has been in service at 740 psig since 1996
- Successful repeat hydrotest in 2004
- No problems in service
## Steel Properties of Converted Pipelines

<table>
<thead>
<tr>
<th></th>
<th>New pipe Spec.</th>
<th>Freeport-Texas City</th>
<th>Corpus Pipelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>&lt;250 HB</td>
<td>225</td>
<td>178</td>
</tr>
<tr>
<td>Carbon Equivalent</td>
<td>&lt;0.43</td>
<td>0.63</td>
<td>0.325</td>
</tr>
<tr>
<td>Grade</td>
<td>&lt;X52</td>
<td>X60</td>
<td>Gr.B</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt;0.015%</td>
<td>0.015</td>
<td>0.036</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>&lt;0.015%</td>
<td>0.017</td>
<td>0.011</td>
</tr>
<tr>
<td>Charpy Impact</td>
<td>&gt;35J</td>
<td>&gt;27J</td>
<td>6J</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>Normalized</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Build VS. Buy

FOR

- **Cost** – new transmission line averages $694,000 per km.
- **Easements** – major issue in industrial/urban areas
- **Schedule** – months vs. years

AGAINST

- **Material** – will not match “ideal” H2 compatibility
- **Corrosion** – old pipelines, several fluids, corrosion?
Smart Pigs can be introduced into operating pipelines and propelled by the gases or liquids being delivered. Smart Pigs for pipelines from 10” and larger have been developed.

Different technologies are used to locate defects in the pipeline wall.

Magnetic Flux Leakage (MFL) measurements can detect corrosion on thinning walls.

Ultrasonic sensors can detect external coating disbondment, cracks, dents and gouges.

The pigs contain data acquisition and storage devices. After the pig is recovered from the pipeline, the data can be downloaded. Analysis of the data reveals exact location of defects detected.
Pipping of GH2 Pipeline

Express Analysis of scan data

- 6 sections identified to be replaced immediately (pinholes)

- section 4, 4380 m
  - Wall thickness: 0.5 mm
  - length: 20 mm
  - width: 10 mm
  - leak relevant

- section 4, 4415 m
  - Wall thickness: 0.7 mm
  - length: 8 mm
  - width: 8 mm
  - leak relevant

Weltmarktführer für technische und medizinische Gase
Freeport H2 Supply to GM Fuel Cells

- Purified using pressure swing adsorbers
- Crude H2 purchased from Dow Chemical
- Compressed to 740 psig (lubricated reciprocal)
- Multi-stage vane type filtration for lubeoil removal
- <1 ppm CO, -300F dewpoint
- Fuel cells supplied through 1 inch pipeline
Risk Analysis & Liability Concern

- Risk analysis is required for all H2 pipelines
- Commercial software available (PHAST, Canary)
- Evaluate full bore rupture and 1” puncture
- Assume that nearest valve is closed after 10 mins.
- Examine explosion and jet fire cases
- Quantitative analysis gives fatality risk
- Risk analysis may result in re-route or mitigation
Plume Study
Radiation vs. Distance
### Full bore rupture Horizontal 3F

<table>
<thead>
<tr>
<th>Effects</th>
<th>Distance m</th>
<th>Area m²</th>
<th>% fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersion 1.5m Height 5D</td>
<td>41</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Thermal radiation kW/m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.4</td>
<td>143</td>
<td>10593</td>
<td>1</td>
</tr>
<tr>
<td>18.2</td>
<td>137</td>
<td>8416</td>
<td>10</td>
</tr>
<tr>
<td>22.8</td>
<td>133</td>
<td>6999</td>
<td>30</td>
</tr>
<tr>
<td>26.6</td>
<td>130</td>
<td>6104</td>
<td>50</td>
</tr>
<tr>
<td>31</td>
<td>127</td>
<td>5175</td>
<td>70</td>
</tr>
<tr>
<td>38.7</td>
<td>124</td>
<td>4200</td>
<td>90</td>
</tr>
<tr>
<td>52.5</td>
<td>120</td>
<td>1590</td>
<td>99</td>
</tr>
<tr>
<td>Maximum</td>
<td>129</td>
<td>105</td>
<td>1182</td>
</tr>
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</table>
LIKELIHOOD and ACCEPTABLE RISK

Probability of Pipeline failure

<table>
<thead>
<tr>
<th>Probability of pipeline rupture year x km</th>
<th></th>
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<tbody>
<tr>
<td>Full bore rupture</td>
<td>6.50E-06</td>
</tr>
<tr>
<td>Large leak</td>
<td>1.00E-04</td>
</tr>
<tr>
<td>Small leak Out corridor</td>
<td>1.00E-04</td>
</tr>
<tr>
<td>Small leak In corridor</td>
<td>2.00E-05</td>
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Acceptable risk (Netherlands advisory)

<table>
<thead>
<tr>
<th>Nederland Advisory</th>
<th>Societal risk</th>
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<tbody>
<tr>
<td>Nbs of people</td>
<td>Likelihood</td>
</tr>
<tr>
<td>0.1</td>
<td>1.00E-01</td>
</tr>
<tr>
<td>1</td>
<td>1.00E-03</td>
</tr>
<tr>
<td>10</td>
<td>1.00E-05</td>
</tr>
<tr>
<td>100</td>
<td>1.00E-07</td>
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</table>
Design & Operation

--- Special Issues for H₂ Service

- H₂ pipeline ruptures always catch fire
- Need a flare at pipeline vents & reliefs
- Small leaks hard to detect
- Valves, gaskets, fittings no real problem
- Odorization will be a challenge
Conclusion

- Conventional pipeline materials have been successfully used for H2 up to 1400 psig
- Existing pipelines can be converted to H2 service with some limits on stress and pressure
- Current design of H2 compressors and H2 pipelines can supply fuel cells
- Little experience with urban “distribution” pipelines

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