Composite Technology for Hydrogen Pipelines

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Overview

Timeline

- Start: Jan 2005
- Finish: Project continuation & direction determined annually by DOE

Budget

- Total project funding
  - DOE: $1.65M
- Funding received in FY 08
  - $600k
- Funding for FY 09
  - $0k

Barriers

- D. High Capital Cost and Hydrogen Embrittlement of pipelines
- Technical Targets on next slide

Partners & Collaborators

- Fiberspar, PolyFlow
- Arkema, Ticona, Fluoro-Seal
- SRNL
- Pipeline Working Group
## Overview

### Technical Targets

<table>
<thead>
<tr>
<th>Category</th>
<th>2005 Status</th>
<th>2012</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pipelines: Transmission</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Capital Investment</td>
<td>$720k</td>
<td>$600k</td>
<td>$490k</td>
</tr>
<tr>
<td>(16-in pipeline, $/mile)</td>
<td></td>
<td></td>
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<tr>
<td><strong>Pipelines: Distribution</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Capital Investment</td>
<td>$320k</td>
<td>$270k</td>
<td>$190k</td>
</tr>
<tr>
<td>(2-inch pipeline, $/mile)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pipelines: Transmission and Distribution</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability/Integrity</td>
<td>Acceptable for current service</td>
<td></td>
<td>Acceptable for H₂ as a major energy carrier</td>
</tr>
<tr>
<td>(including 3rd-party damage issues)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ Leakage *</td>
<td>Undefined</td>
<td>TBD</td>
<td>&lt; 0.5%</td>
</tr>
</tbody>
</table>

* Leakage targets are being reviewed by the Delivery Tech Team
# Project Milestones

<table>
<thead>
<tr>
<th>Month-Year</th>
<th>Milestone or Go/No-Go Decision</th>
</tr>
</thead>
</table>
| Sep 2008   | **Milestone**: Survey of existing modifications and treatments available for reducing permeability in liner materials completed and reported (completed)  
**Milestone**: Recommendations for sensor integration, manufacturing and joining technologies completed and reported (50% complete) |
| May 2009   | **Milestone**: Hydrogen compatibility evaluations of composite pipeline materials and construction completed (60% complete). |
Technical Accomplishments-Initial Compatibility Testing Completed

- Pipeline materials compatibility testing
  - Hydrogen compatibility testing following eight-month accelerated-aging protocol showed no quantifiable materials degradation
  - Hydrogen leakage measurements in Fiberspar pipeline yielded smaller than predicted leak rates (<0.02% per day); Leakage measurements on PolyFlow FRP pipeline are in progress
  - Fiberspar FRP pipeline specimen passed blowdown testing with hydrogen
Technical Accomplishments-Evaluation of Joining Technologies is Progressing

- Joining and sensor technologies
  - Hydrogen leakage through Fiberspar LinePipe™ connectors is very low, $<3 \times 10^{-6}$ mol/s
  - Collaborative effort underway with SRNL to assess joint loading, pipeline flexure, and pressure/temperature cycling on hydrogen leakage for both Fiberspar and PolyFlow connectors

FiberSpar connector with compressive o-ring seals

PolyFlow swaged connector
Completed \( \text{H}_2 \) compatibility screening of Fiberspar pipeline and materials

- Accelerated aging procedure used to screen for long-term effects of hydrogen exposure on composite pipeline under normal-usage conditions

- Completed post-treatment tests of Fiberspar pipeline and constituent materials
  - Immersion in 1000 psi \( \text{H}_2 \)
  - Accelerated aging at 60°C for 8 months (equivalent to 5+ years at RT)
  - No deleterious effects due to \( \text{H}_2 \) noted in qualification testing of pipelines or tensile and DMA testing of polymer and composite matrix resin specimens
Hydrogen blowdown testing of composite pipeline

- Guidance: API 15S - Qualification of Spoolable Reinforced Plastic Line Pipe, Appendix D
  - Specimen filled with hydrogen* to pressure rating, specimen heated to temperature rating, these conditions held until pipeline structure is saturated with gas
  - Following hold period, specimen depressurize at a rate greater than 1000 psi/min
  - Following blowdown, specimen liner was examined and no visual evidences of liner blistering or collapse

*API 15S specifies the use of supercritical CO₂ for blowdown testing
Blowdown de-pressurization rate was 3X specified minimum rate

HYDROGEN BLOWDOWN TEST IN FIBERSPAR LP 4-1/2 1,500(E)
3-FT PIPELINE SPECIMEN
DE-PRESSURIZATION PROFILE

De-pressurization completed in 27 seconds
\( \Delta p/\Delta t \sim 3300 \text{ psi/min} \)
Post-blowdown leakage rate was identical to pre-blowdown rate.
Actual \( \text{H}_2 \) leakage rate is nearly 50X below predicted rate
## Summary of H₂ leakage rate measurements for Fiberspar LinePipe™

<table>
<thead>
<tr>
<th>Start Date</th>
<th>Specimen</th>
<th>Nominal Pressure</th>
<th>Leakage Rate (mol/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/15/08</td>
<td>3-ft pre-blowdown</td>
<td>1500 psi</td>
<td>-4.4x10⁻⁴</td>
</tr>
<tr>
<td>5/22/08</td>
<td>3-ft post-blowdown</td>
<td>1500</td>
<td>-4.4x10⁻⁴</td>
</tr>
<tr>
<td>6/3/08</td>
<td>3-ft post-blowdown</td>
<td>500</td>
<td>(+7.6x10⁻⁵)</td>
</tr>
<tr>
<td>3/26/08</td>
<td>6-ft</td>
<td>1500</td>
<td>-5.5x10⁻⁴</td>
</tr>
<tr>
<td>4/7/08</td>
<td>6-ft</td>
<td>500</td>
<td>(+3x10⁻⁴)</td>
</tr>
<tr>
<td>8/25/08</td>
<td>9-ft</td>
<td>1500</td>
<td>-5.5x10⁻⁴</td>
</tr>
</tbody>
</table>
### Summary of H₂ leakage rate measurements to date

<table>
<thead>
<tr>
<th>Specimen Length</th>
<th>Nominal Pressure (psig)</th>
<th>Measured Leakage Rate (mol/h)</th>
<th>Predicted Leakage Rate (mol/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-ft</td>
<td>1500</td>
<td>-4.4x10⁻⁴</td>
<td>-8.2x10⁻³</td>
</tr>
<tr>
<td>6-ft</td>
<td>1500</td>
<td>-5.5x10⁻⁴</td>
<td>-1.6x10⁻²</td>
</tr>
<tr>
<td>9-ft</td>
<td>1500</td>
<td>-5.5x10⁻⁴</td>
<td>-2.5x10⁻²</td>
</tr>
</tbody>
</table>

In most extensive test to-date, hydrogen lost due to permeation and leakage through end cap seals was less than 0.02% per day. The rate is 45 times below the predicted value for HDPE (PE-3408) liner.
Summary of H₂ leakage rate measurements to date

- Loss due to leakage is much lower than expected (and might be good enough to meet leakage target)
- Reinforcement layer might be providing some gas barrier benefit but probably can’t account for full extent of discrepancy between predicted and measured values
- Rapid decompression of pipeline is probably not going to be a failure mechanism for liner
- Joints with elastomeric seals have worked well (so far)
Future directions for H$_2$ leakage rate measurements in Fiberspar FRP pipeline

- Subject specimens to 4-pt bend testing to reveal the extent of how microcracking increases permeation and leakage
- Measure pressure as a function of depth in wall or within composite layers
Hoop strain in Fiberspar FRP pipeline during leakage measurements

FIBERSPAR PIPELINE LEAKAGE MEASUREMENT
Nominal 1500 psi Pressurization
9-ft Pipeline Specimen

ELAPSED TIME (h)

HOOP STRAIN (µε)

PRESSURE (psia)

- SG at 1/4-length
- SG at 1/2-length
- SG at 3/4-length
- Hydrogen Pressure
Axial strain in Fiberspar FRP pipeline during leakage measurements

FIBERSPAR PIPELINE LEAKAGE MEASUREMENT
Nominal 1500 psi Pressurization
9-ft Pipeline Specimen

<table>
<thead>
<tr>
<th>Curve</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>SG at 1/4-length</td>
</tr>
<tr>
<td>Orange</td>
<td>SG at 1/2-length</td>
</tr>
<tr>
<td>Green</td>
<td>SG at 3/4-length</td>
</tr>
<tr>
<td>Red</td>
<td>Hydrogen Pressure</td>
</tr>
</tbody>
</table>

ELAPSED TIME (h) vs. AXIAL STRAIN (ue) vs. PRESSURE (psia)
H₂ leakage rate measurements in PolyFlow Thermoflex® Reinforced Pipe

- Liner: Coextruded PPS and PA-6
- Reinforcement: aramid fiber rovings braided on liner, laid over four longitudinal rovings
- Burst strength determined by braid angle, not by number of plies
- PP jacket with damage indicating colorant
- Couplings with swaged metal seals
- Leakage rate measurements in progress
**Future Work**

- **FY 2009**
  - Report test results from 8-month accelerated aging and hydrogen exposure of pipeline and material specimens
  - Continue measurements of liner materials, including measurements of surface fluorination samples, using new diffusion and permeation measurement apparatus for polymers with additional capabilities
  - Begin assessment of possible hydrogen-induced cracking in the reinforcement layers during cyclical strain, perform long-term stress rupture tests, perform high-pressure cyclical fatigue tests, assess joint sealing under cyclic loading
  - Collaborate on development of codes & standards for hydrogen-service FRP pipelines

- **FY 2010**
  - Coordinate initial field test of FRP pipeline for hydrogen service, providing springboard for commercially viable demonstration project
Project Summary

Relevance: Need viable alternative to metallic pipelines to achieve cost and performance targets for hydrogen transmission and distribution

Approach: Investigate applicability of commercially available FRP polymer pipelines and develop path forward for hydrogen delivery

Progress: Cost scenario shows composite pipelines can meet DOE 2012 goals and are close to 2017 goals; hydrogen compatibility of pipeline materials is acceptable; pipeline leakage rates are lower than predicted

Collaborations: Pipeline and polymer industries, National Lab

Future: Codes & standards; prototype FRP pipeline system for H₂ delivery; demonstration project