Hydrogen Pipeline Experience

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Hydrogen Pipeline – Scope of Presentation

- Only those systems that are regulated by DOT in the US, DOT delegated state agency, or other federal regulatory authority.
- Cross property of third party and/or public properties for delivery to customers.
- Does not include in-plant or in-house hydrogen piping.
- Does not include piping (aboveground or underground) that delivers to a customer if all property is owned and controlled by Air Products and the customer.
Pipeline Photos

Concrete coated pipeline with floats in Taft, Louisiana
Pipeline Photos

Hydrogen pipeline - Mississippi River Crossing
Pipeline Photos

Multiple pipeline trench - Baytown, TX
Pipeline Photos

Horizontal bore of railroad
Pipeline Photos
Overview of North American Air Products Hydrogen P/L Systems

- Approximately 350 miles of Hydrogen Pipelines in North America
- Major systems located in Texas, Louisiana, and California.
- These major networks account for 340 miles of the above total.
- Operating and maintaining portions of these systems since 1970.
- Currently developing two systems in Canada; one in Alberta and one in Ontario.
Air Products H₂ P/L System – West Gulf Coast

- System has numerous production facilities serving many customers in the PetroChemical and Refining Industry.
- System extends from Laporte, TX to near Lake Charles, LA.
- This system has approximately 228 miles of DOT regulated H₂ pipeline.
- Portions of this system operating since early 1970.
- Pipeline size is principally 8” and 10”.
Air Products H2 P/L System – Louisiana

- System is made up of two separate segments; one near New Orleans and the second extending from Plaquemine, LA to Taft, LA
- System has numerous production facilities serving many customers in the PetroChemical and Refining Industry.
- This system has approximately 100 miles of DOT regulated H2 pipeline.
- Portions of this system operating since early 1983.
- Pipeline size is principally 6”, 8”, and 12”.
Air Products H2 P/L System – California

- System has two production facilities serving numerous customers in the Refining Industry.
- System is located in the Los Angeles Basin and a portion is located in DOT Class 4 location.
- This system has approximately 12 miles of DOT regulated pipeline.
- Transportation agreement for additional 4 miles.
- Air Products has been operating portions of this system since 1995. A part of this system was acquired from others who operated it in hydrogen service since 1982.
- Pipeline size is principally 6”, 8”, and 10”. 
Overview of Worldwide Air Products Hydrogen P/L Systems

- Additional existing networks in multiple worldwide locations.
  - Rotterdam
  - Brazil
  - Thailand
  - Indonesia
  - South Africa

- These networks total approximately 100 miles in length and in some cases multiple systems are contained within a network.
Pipeline Standards and Regulations

- CFR 49 Part 192 and as amended by delegated state agency.
- Air Products standards employ minimum design to Class 3 location except for very remote unpopulated areas and typically exceed the requirements of Part 192.
- Environmental Impact Studies designate additional design considerations.
- Local jurisdictions (City, Township, Parish, County, etc.) have imposed additional requirements beyond basic regulatory requirements.
Typical Designs for Air Products Hydrogen Pipeline Systems

- Pipe sizes 4 to 12 inch diameter.
- Minimum depth of Pipeline is 3 feet (In most cases 4 feet).
- Operating pressures between 350 and 1900 Pounds per Square Inch (PSI).
- All current systems constructed using steel pipe.
- Majority of pipelines have operating stresses limited to 30% of SMYS (Specified Minimum Yield Strength).
- Routing of hydrogen pipelines carefully considered and include proprietary Risk and Consequence Analysis.
- Extensive use of automated EFV’s (Excess Flow Valves). In excess of 30 EFV’s in operation today.
Excess Flow Valve (EFV)
Pipeline Materials of Construction

- Hydrogen pipelines constructed by Air Products have utilized carbon steel pipe with corrosion protective coatings.
  - Mild strength steels – API 5L X42 or X52
  - Weld procedures developed to API 1104 - Typically SMAW with low hydrogen weld rods
    - 100% radiography of all welds
    - Limit the hardness in the heat affected zone
    - Normally, PWHT is not needed to achieve acceptable weld hardness
  - Line pipe primarily coated with FBE although other coatings have been utilized for abrasion resistance.
  - These materials have been utilized by Air Products for hydrogen pipelines since 1970.
Basis of Material Selection

- Hydrogen gas can cause hydrogen embrittlement (HE) of steels.
- Best known, most studied HE service is wet H$_2$S (sour service) in the petroleum and petrochemical industries.
- NACE developed a standard (MR 0175) on the selection of metals in H$_2$S service in 1970’s and this standard is recognized worldwide.
- MR 0175 allows use of carbon steel in wet H$_2$S service as long as the hardness is no more than 22 HRC.
- Applying the relationship between hardness and tensile strength this indicates a maximum tensile strength of 115 ksi.
Based on MR 0175, as long as the hardness is less than 22 HRC or the tensile strength is less than 115 ksi, the steel will not suffer wet H₂S cracking or HE.

Air Products believes that MR 0175 describes a much more severe HE environment than any of Air Products H₂ pipeline systems.

Air Products material selection is based on the interpretation that if we adhere to MR 0175 hardness/strength criteria we will not be subject to HE.

The use of the lower strength steels has not been a cost hindrance since Air Products employs a conservative approach with wall thickness because of concern of third party damage.
Pipeline Operating Parameters

- The pressure in Air Products hydrogen pipelines remains basically constant with minor fluctuations based on customer demand.

- Pipe size, compression equipment, valves stations, and custody metering stations determine flow capacity in the pipeline systems.

- Pipelines are monitored from central control location for each major system. Operators view live data from custody metering stations, production units, and EFV stations.

- Remote shutoff capability from these central control locations.
Pipeline Maintenance

- All preventive maintenance is performed in accordance with DOT 192 requirements.
- Air Products has not to date performed internal inspection of any of the H2 pipeline systems.
- Our systems are complex and were not designed to incorporate pigging at regular intervals.
- Since the H2 product in the pipelines is pure and dry there is little risk of internal corrosion.
- Air Products is basing its integrity management program on direct assessment techniques that are recognized in DOT 192 and ANSI B31.8S.
Pipeline Conversion Experience

- Air Products has converted a liquid products pipeline (DOT 195) that was built in the 1940’s into H2 service.

- After extensive studies on the metallurgy of the pipeline Air Products decided to proceed with a project to convert the pipeline.

- Metallurgy experts had concerns over the composition of the 1940’s carbon steel pipe material and the pipe manufacturing process.

- Extensive research was completed to understand the history of the pipeline and any previous replacement work. This included removal of pipeline segments for laboratory analysis.
Air Products developed a plan to replace pipe in sensitive areas and perform additional hydro testing of the existing pipeline.

The plan included extensive legal review of the existing ROW documents.

The key to successful implementation of the conversion plan was to follow all the recommendations of our proprietary Risk and Consequence Study.

Numerous EFV’s were installed in the pipeline system to limit exposure to 3rd parties.
A reduction in the allowable pressure was required and therefore a pressure reduction station and additional pipeline safety valves were installed.

Air Products has converted two segments of this pipeline and has operated the first converted segment for more than 10 years.

Air Products has no direct experience of converting Natural Gas pipelines into H2 service.
Pipeline Cost Data

- Cost of H2 pipeline installation is very dependent on the location (State, rural, street, etc.).
- Air Products cost data base is limited to construction of what is considered short lengths in the pipeline industry.
- ROW costs are variable and can add significant costs to a project.
- All Air Products H2 pipelines are private carrier status.
- Environmental permitting is having the biggest impact on pipeline cost at this time.
Conclusion

- Air Products has operated H2 pipelines since 1970 without a single pipeline incident that has caused injury to our employees or the general public.
- Air Products testified before US Congress in 2002 regarding its philosophy of systematically analyzing the risks and consequences and employing design and operating standards that exceed federal regulations.
- The Industrial Gas Community in association with the CGA and EIGA recently developed and published a document (CGA G-5.6) that complies the collective safe experiences and practices for Hydrogen Pipeline Systems.
- Thank you for this opportunity to present this information regarding Air Products experience with H2 pipelines.