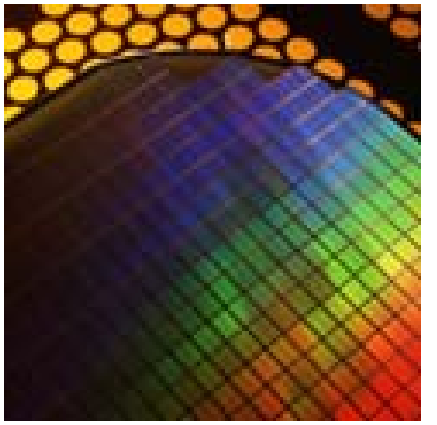
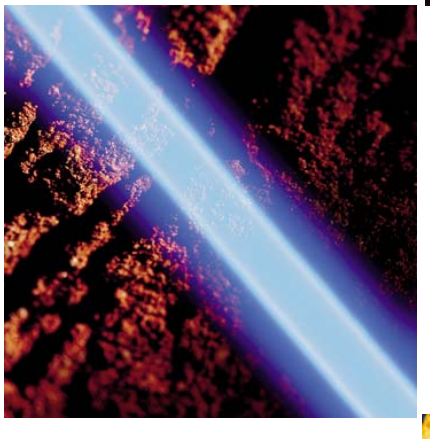
Hydrogen Pipeline Discussion





BY

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TONAWANDA, NEW YORK

DOE Hydrogen Pipeline Workshop

Augusta, GA

August 2005

Introduction

- Regulatory and technical groups that impact hydrogen and hydrogen systems
- ASME, DOE, DOT etc, Compressed Gas Association activities
- ASTM TG G1.06.08
- Hydrogen pipelines and CGA-5.6
- Selected experience and guidance
- Summary and recommendations

CGA Publications Pertinent to Hydrogen

- √ G-5: Hydrogen
- √ G-5.3: Commodity Specification for Hydrogen
- √ G-5.4: Standard for Hydrogen Piping at Consumer Locations
- G-5.5: Hydrogen Vent Systems
- √ G-5.6: Hydrogen Pipeline Systems (IGC Doc 121/04/E)
- √ G-5.7: Carbon Monoxide and Syngas Pipeline Systems (IGC Doc 120/04/E)
- H-1: Service Conditions for Portable, Reversible Metal Hydride Systems
- H-2: Guidelines for the Classification and Labeling of Hydrogen Storage Systems with Hydrogen Absorbed in Reversible Metal Hydrides
- H-3: Cryogenic Hydrogen Storage (in progress)
- H-4: Terminology Associated with Hydrogen Fuel Technologies (in progress)
- H-X: Installation of Cryogenic Hydrogen Supply Systems (in progress)
- √ P-28: Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Systems
- PS-17: Underground Installation of Liquid Hydrogen Storage Tanks
- PS-20: Direct Burial of Hydrogen Gas Storage Tanks (in progress)
- PS-21: Adjacent Storage of Compressed Hydrogen and other Flammable Gases (in progress)

ASTM T.G. G1.06.08 Goals and Workshop, May 17, 2005

- Formed on November 11, 2004.
- Identify major laboratory facilities and capabilities.
- Understand major directions and interests of key standards organizations, maintain liaison activity.
- Assess potential new hydrogen applications and adequacy of hydrogen test standards and data.
- Monitor existing hydrogen test standards; worldwide basis; develop new ones, as required.
- Provide workshops, sponsor symposia and help publish critical data to support standards.
- First workshop on May 17, 2005, next in November, 2005

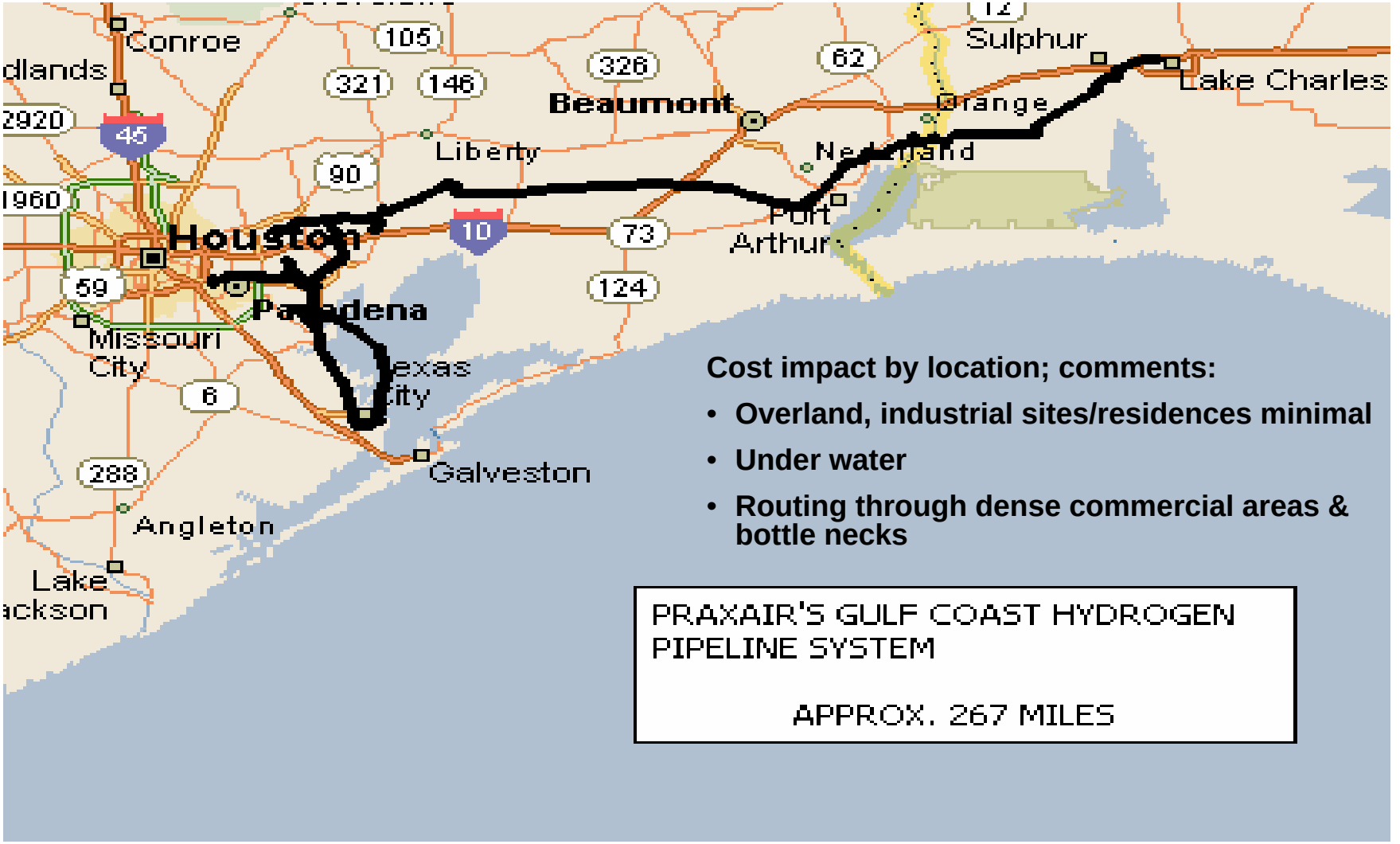
ASTM G1.06.08 Workshop Papers

1. The Goals of ASTM T.G. G01.06.08
2. Development of ASME Code Rules for 15,000 PSI Hydrogen Vessels
3. Materials Selection and Performance Criteria for Hydrogen Pipeline Transmission
4. Compressed Gas Association Bulletin G-5.6: Hydrogen Pipeline Systems
5. Hydrogen Fuel Production, Transportation, Storage and Dispensing
6. Sandia National Laboratories Perspective on Hydrogen Assisted Fracture: Materials Testing and Variables Governing Fracture
7. Properties of Linepipe Steels in High Pressure Hydrogen
8. Testing Methods for the Investigation of Hydrogen Gas Embrittlement of Metallic Materials
9. Results of Investigations on Hydrogen Embrittlement of Steels
10. SRNL Research on Hydrogen Effects on Materials; Past, Present and Future
11. Unusual Failures in Hydrogen Production
12. Selecting Metals for High Pressure Hydrogen Service
13. Measurement and Prediction of Materials Performance Subject to Hydrogen Exposure
14. The Inclusion of Hydrogen Embrittlement Data in NASA Standards and Hazard Analysis

Pipelines

- **Hydrogen pipelines have operated safely over scores of years.**
- **Hydrogen pipelines will be increasingly important.**
- **Guidance on hydrogen pipelines from authoritative sources is scarce.**
- **The “Hydrogen Economy” is drawing a lot of interest to pipelines.**
- **A need existed for the industrial gas business to prepare a document for hydrogen pipelines similar to oxygen pipeline documents in existence; i.e. CGA-5.6**
- **A similar lack of guidance existed for carbon monoxide and syngas pipelines; i.e. CGA-5.7**

Praxair Gulf Coast Hydrogen Pipeline System



Composition Ranges For Hydrogen, Carbon Monoxide and Syngas per CGA Pipeline Documents G-5.6 and G-5.7

- **Hydrogen**
  - Hydrogen - 10% - 100%
  - Carbon Monoxide - < 200ppm
  - Balance - inerts and/or methane (natural gas)
- **Carbon monoxide**
  - Hydrogen - < 10%
  - Carbon Monoxide - > 200ppm
  - Balance- inerts and/or methane (natural gas)
- **Syngas**
  - Hydrogen - > 10%
  - Carbon Monoxide - > 200 ppm
  - Balance - inerts and/or methane (natural gas)
- **Toxicity of carbon monoxide has a significant impact on composition ranges.**

Contents of CGA G-5.6 “Hydrogen Pipeline Systems”

- 1. Introduction
- 2. Scope and Purpose
- 3. Definitions
- √ 4. Design Philosophy
- √ 5. Piping, Valves, and Equipment
- √ 6. Cleaning
- √ 7. Construction
- √ 8. Design and Construction of Stations
- √ 9. Operation and Monitoring
- 10. General Protective Measures
- Tables 1-6
  - Absorption Energies, Nonmetallics, Thermal Radiation, Cleaning
- Figures 1-4
  - Typical piping systems, Process control, Gas mixture definition, Risk criteria
- Appendices A-K

Comments on G-5.6 Contents

1. Introduction

- Document only applies to future hydrogen pipeline installations
- Recognizes excellent experience and comparable safety records though differences in design and operations exist.

2. Scope

- Hydrogen gas & mixtures per Appendix G
- Temperature- -40 °C to 175 °C
- Pressure- 150 psig to 3,000 psig
- Special guidance for UHP H2, Appendix I

3. Definitions

- Extensive listing of metallurgical definitions such as austenite stability, carbon equivalent, microalloyed steels, etc.

Comments on G-5.6 Contents Continued

- 4. Design Philosophy
  - 4.1 General Criteria
    - Risks, Hazards, Appendix K References
  - 4.2.2 Brittle Fracture Mechanisms
    - Hydrogen Gas Embrittlement (Appendix B)
    - Discusses degradation mechanisms pertinent and non pertinent.
  - 4.3 Metallic Materials
    - Strength and hardness limitations for pipeline steels
    - Selected higher strength steels (ASME SA-372 Gr. J, Cl. 70) for “buffer” vessels
    - Microstructure: fine grained, homogenous, inclusion free preferred.
    - Reduced stresses may be considered.
  - 4.3.2 Carbon Steels
    - Appendix C- Extensive Multinational Listing
    - Product Specification Levels (PSL) in API 5L
      - PSL 1 vs. PSL 2 (PSL 2 Preferred)
      - Heat Treatment
      - Chemistry: Tramp Elements, Carbon Equivalent
      - Toughness Requirements

Comments on G-5.6 Contents Continued

4.3.3 Microalloyed Steels

- Microalloyed steel is a steel in which small additions of alloying elements achieve properties improvements seemingly out of proportion to the amounts added.
- Strength, toughness, weldability and formability improvements
- Reactive metals, rare earths, boron and sulfide shape control agents are examples of microalloying agents. Vanadium, niobium and titanium most commonly used.
- Many users may not be aware that they are using microalloyed steels.
- Microalloying may be used in pipeline steels such as API 5L-X42 and X52. Full potential of microalloyed steels remains to be explored.

Comments on G-5.6 Contents Continued

- **4.3.4 Stainless Steels**
  - **Generally considered to be immune to HGE; but isolated cases of embrittlement have occurred.**
  - **Austenitic stainless steels with a positive austenitic stability factor are preferred for hydrogen service.**
  - **Transformation of metastable austenite to martensite, of concern.**
- **4.6 Hazard Analysis and Risk Assessment**
  - **Hazards**
  - **Event Scenario**
  - **Consequences**
  - **Criteria for thermal radiation**
- **5. Pipeline, Valves and Equipment**
- **6. Cleaning**

Comments on G-5.6 Contents Continued

- 7. Construction
  - General
  - Specification of line pipe materials
  - Pipe fabrication and welding
  - Assembly
  - Inspection
  - NDT
  - Documentation
- 8. Design and Construction of Stations
- 9. Operation and Monitoring
- 10. General Protective Measures

G-5.6 Appendices

Appendix	Subject
A	Typical Arrangements for Pipeline Systems
B	Embrittlement and Environmental Damage Mechanisms Involving Hydrogen; Applicable Test Methods
C	Table of Nominal Alloy Compositions
D	Metallurgical Factors Affecting Hydrogen Toughness and Brittle Fracture Mechanisms
E	Table of Typical Safety Distances
F	Example of Preventive Maintenance Program
G	Composition Criteria for Hydrogen and Mixtures
H	Requalification of Existing Pipelines
I	UHP Hydrogen Pipelines
J	Examples of Risk Criteria
K	References

G-5.6 Appendix H - Requalification of Existing Pipelines for Hydrogen Service

- Following are sequential steps for evaluating existing pipelines for hydrogen service:
- Review of technical documentation and history
  - Pipeline records
  - Fluid service
  - Leaks and repairs
  - Cathodic protection
  - Drawings
- Visual inspection
  - Above ground piping
  - Crossings
- Physical inspection
  - Location (depth & horizontal)
  - Depth of cover

G-5.6 Appendix H - Requalification of Existing Pipelines for Hydrogen Service

- Materials audit (unknown material properties)
  - Tensile tests (pm, welds, seam welds)
  - Impact tests (pm, welds, seam welds)
  - Microhardness tests
  - Metallographic inspection of selected areas
  - Chemical analysis
  - Radiographic inspection, other NDT
  - Analysis of internal pipeline residual
- Internal pipeline inspection
- Valve and flanges
- Cleaning
- Records
- Risk assessment

Comments on CGA G-5.7: CO and Syngas Pipeline Systems

- G-5.7 Developed in parallel with G-5.6
- Document organization similar to G-5.6
- Major differences:
  - Toxicity issues and mitigation
  - Water elimination critical
  - Potential for anodic stress corrosion mechanism
  - Carbonyl formation concern impacts alloy selection
  - No pipeline requalification section
  - Equipment impact
    - Avoid rupture discs
    - Nonmetallics usage should be minimized
    - Flanges should be minimized, use welded connections
    - Safety distances impacted by CO presence
    - Avoid/minimize storage vessels

Hydrogen as an Industrial Gas, Selected Experience

- Sources
  - Reforming of natural gas
  - Purification of hydrogen rich gases
    - Cryogenic (hydrogen upgrader)
    - Pressure Swing Absorption (PSA) and variants
  - Electrolytic
- Distribution
  - Pipelines
  - Cryogenic tankers and vessels
  - Cylinders
  - Hydrides (minimal usage as of 2005)
- Codes regulations (major: DOT, ASME)
- Materials (ferrous, aluminum, copper and nickel alloys)

Selected case studies will be covered by transparencies

Material Testing Techniques for Evaluating Pipeline Alloys

- **Basic evaluation methods**
  - Tensile tests
  - Charpy V notch impact
  - Hardness and Microhardness
  - Metallographic examination
- **Advanced tests in hydrogen gas to 5000 psig**
  - Tensile tests
  - Crack growth under sustained load (K1H)
  - Fracture toughness K1c or J1c
  - Fatigue crack growth da/dN
  - PM, welds and weld HAZ

Summary and Recommendations

- Technical societies such as ASME, ASTM, CGA etc. can have a significant impact on the increased use of hydrogen in the developing economy.
- DOE and various government laboratories are unique facilities and a critical reservoir of talent for the “hydrogen economy”.
- Continued interaction between key technical groups from industrial and government laboratories is required.
- Successful materials usage in hydrogen applications requires close attention to “details” and specifications; Further work required to extend pressure envelop for hydrogen pipelines