Evaluation of Natural Gas Pipeline Materials and Infrastructure for Hydrogen/Mixed Gas Service

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This presentation does not contain any proprietary or confidential information.

Overview

Timeline

- Start Date: November, 2004
- Initiation of 4-year program in FY05

Barriers

- Retrofitting Existing NG Pipelines fro Hydrogen/Hythane Service
- New Pipeline Installation and ROW Lower Capital Cost
- Hydrogen Effects on Materials
- Leakage/Seals
- Compressor/Valves/Inspection

Budget

- Total funding (to date) - $50 K
- FY05 Funding - $50 K—Program De-scoped from $150K
- FY06:Proposed $150K

Collaborators

- South Carolina Electric and Gas
- University of South Carolina
- Praxair
- Hydrogen Pipeline Working Group
  - SRNL, ORNL, GTI, SECAT, U of Ill, CTC, ANL, ASME
  - H2 Materials, H2 Testing, H2/NG Materials and Testing, H2 Permeability

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Objectives

- To assist DOE-EE in evaluating the feasibility of using the existing natural gas transmission and distribution piping network for hydrogen/mixed gas delivery
  - Develop and Perform the Requisite Hydrogen/Hythane Testing Methods and Data Regression to Provide the Technical Basis for Qualification of Existing NG Pipelines for Hydrogen/Mixed Gas Service
  - Develop and Apply Advanced Fracture and Failure Methodologies to Allow for Data Transference from Laboratory Testing to Real-World System and Components
  - Identify Key Technical Challenges and Risks to Successfully Using the Existing NG Pipeline Network for Hydrogen/Mixed Gas and Develop Mitigating Strategies for These Risks

Technical Approach

- Establish A Testing Protocols for Assessing Materials and Components for Hydrogen/Mixed Gas Service
  - Baseline Testing Methodologies by Evaluating Existing NG Transmission and Distribution Pipeline Materials
  - Apply Advanced Fracture Methodologies to Allow for Laboratory data to be Transferred to Real-World Systems and Components
- Test Existing NG Transmission and Distribution Pipeline Materials and Components in Hydrogen/Mixed Gas Environments
  - Focused Data Generation Coupled to Advanced Fracture Modeling
  - Testing Focused on Data Generation to provide Technical Basis for Qualification via National Consensus Codes and Standards
  - Characterize Materials and Components Performance, Materials Integrity, and Effects of Operating Conditions (Temperature and Pressure)

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SRNL Hydrogen Pipeline Delivery Focus

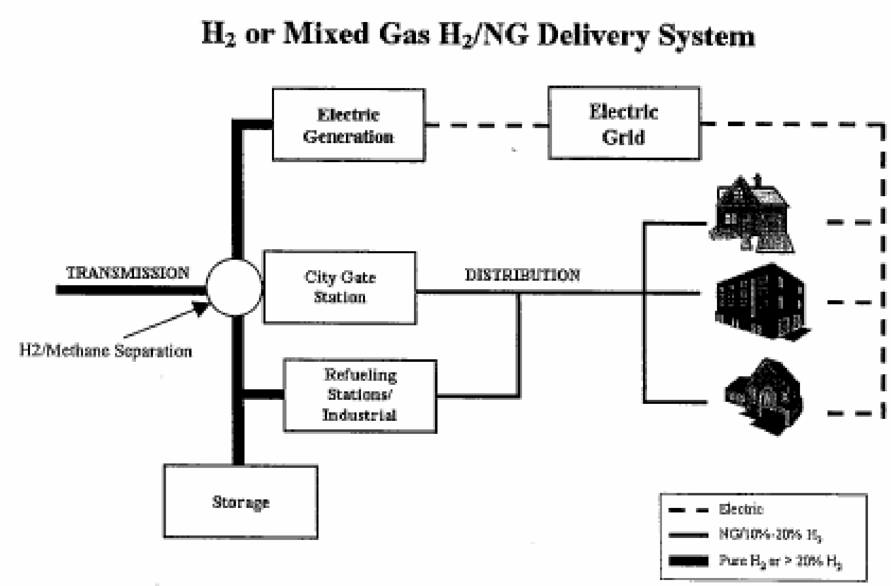
<u>Use Existing NG Pipeline System for H2 or Mixed Gas Transport</u>

"Develop hydrogen fuel delivery technologies that enable the introduction and long long-term viability of hydrogen as an energy carrier for transportation and stationary power"

-*DOE Hydrogen Delivery Goal*

- NG Transmission Pressure Range 500-1200 psig
- Few 100's Miles of Transmission Pipeline

- NG Distribution Pressure Range <100 psig
- Few Million Miles of Distribution Piping



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H2/NG Distribution Systems Materials Challenges

Performance Criteria for Materials in Hydrogen Service

The following should be considered when choosing piping material for hydrogen systems:

- Hydrogen state (slush, liquid, or gas)
- Temperature, and/or temperature range
- Pressure
- Other secondary loading conditions
- Compatibility with operating environment (also include effects due to corrosion)
- Ease of fabrication and assembly
- Potential to minimize damage due to hydrogen fires.
- Cost

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SRNL H2 Pipeline Delivery Program

SRNL Program is Focused on Developing the Necessary Materials Data for Demonstrating the Use of Existing NG Pipeline Network for Hydrogen Service

- **Mechanical Property Studies on Archival NG Pipe—FY05**
- Fracture Mechanics Testing and Approaches for NG Pipeline Materials
- Component Fatigue Testing
- Burst Prediction and Modeling

The Initial Focus of this Program is Centered on Metallic Transmission NG Pipeline Materials; However, the approach and methodology developed under this program could be adapted to evaluating distribution piping materials which include both metallic and polymeric materials

SRNL is working to leverage its experience at developing and operating hydrogen production, storage, and delivery Technologies to develop the necessary technical data for qualification of the existing NG pipeline network for hydrogen service

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Accomplishments

- Established Suite of High Pressure Hydrogen Testing Capabilities
  - Mechanical Testing
    - Charging Station Capability: 10,000psi/350°C
    - In-Situ Testing: 3000psi/350°C
  - Fracture Testing-- C-shaped Fracture Specimens
    - Charging Station Capability: 10,000psi/350°C
    - In-Situ Testing: 3000psi/350°C
  - Fracture Energy—Small Sample Punch Test
    - In-Situ Testing: 3000psi/350°C
- Additional Testing Capabilities
  - Pressure Cycle Fatigue
    - Cycling Capability:0-2000psi/RT
    - Sample Size up to 2" Diameter
  - Disc Rupture/ Burst Test
    - Pressures up to 3000psi in Hydrogen
    - Hydraulic Burst of Hydrogen Charged Components: 30,000psi
- Testing Completed
  - Small Sample Punch Tests
    - X42—Baseline and H2 Charged
  - Tensile/Fracture Tests
    - X-42—Baseline and H2 Charged
    - K_{th} C-ring samples Initiated
  - Initiated Burst Prediction Modeling
    - X42 and ASTM 106 Grade B

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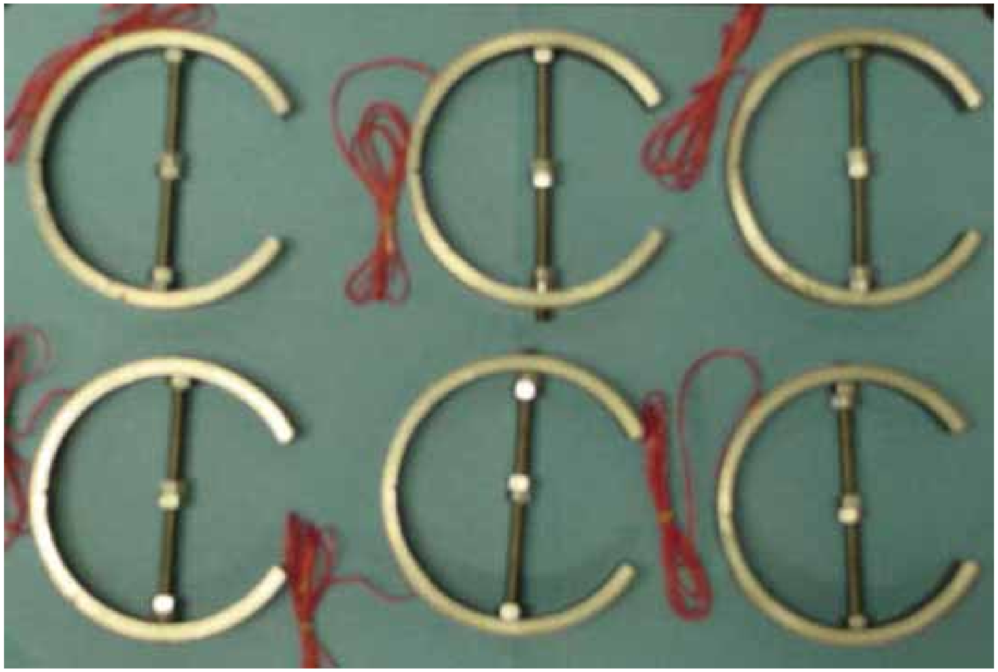
Accomplishments

K_{Th}– Threshold Stress Intensity

- C-ring Samples Harvested from Archival API-5L X42 Pipe
- 4" Pipe with 0.188 wall thickness
- Static Loaded Specimens
- 6.9MPa (1000psi) H_2
- Check Interval 250hrs
- SMYS=42Ksi
- K-Net Section Stress Intensity
    - K_1=23.5 ksi $in^{1/2}$
    - K_2= 38.4 ksi $in^{1/2}$
    - K_3= 45.7 ksi $in^{1/2}$
    - K_4= 52.2 ksi $in^{1/2}$
    - K_5=58.2 ksi $in^{1/2}$
    - K_6= 64.3 ksi $in^{1/2}$



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Accomplishments

Mechanical Properties-- Tensile

- 1/2” Gauge Length 1.25” Sub-Miniature Specimens
- Samples Harvested from Archival API-5L X42 Pipe
- 4” Pipe with 0.188 wall thickness
- Crosshead Speed=0.02 in/min
- Baseline Sample w/ No H2 Charge
- H2 Exposed Sample
    - 4250 psi H2/14 days
    - ≅ 65wppm

Sample	YS (ksi)	UTS (ksi)	%EL
X-42 Base	68	78	19
X-42 H2 4250psi (65wppm)	47	53	3

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Accomplishments

Mechanical Properties– Fracture Energy

- Small Sample Punch Testing
- Samples Harvested from Archival API-5L X42 Pipe
- 4” Pipe with 0.188 wall thickness
- D=0.118in , thickness=0.010in
- Crosshead Speed=0.20 mm/min
- 1mm WC Ball
- Baseline Sample w/ No H2 Charge
- H2 Exposed Sample
    - 4250 psi H2/14 days
- Report Specific Fracture Energy
- Equivalent Failure Strain

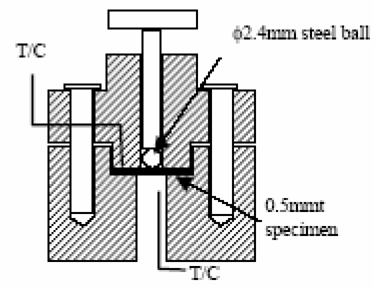
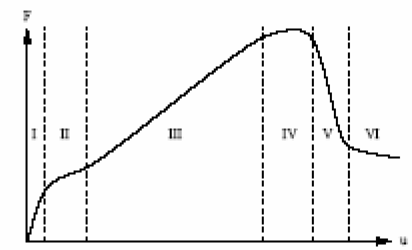
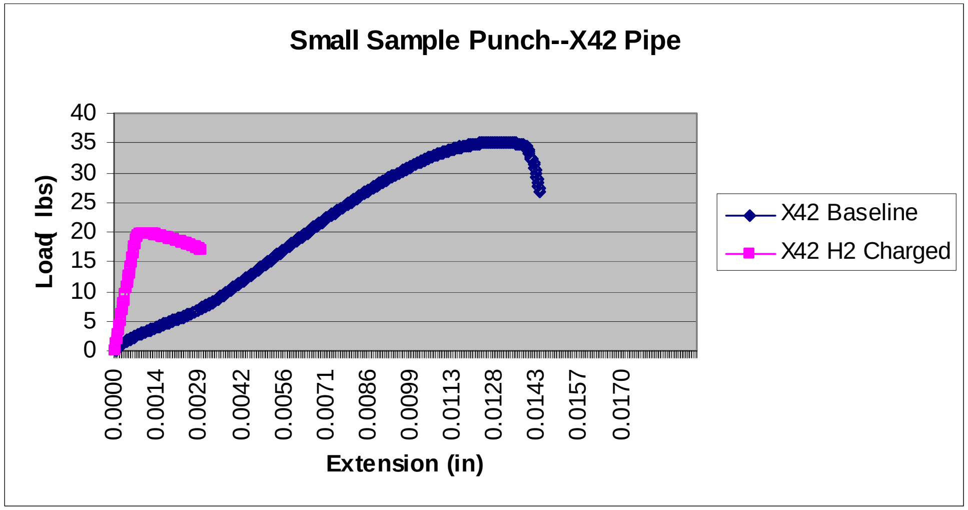


Fig. 1. The schematic illustration of the small punch test jig.





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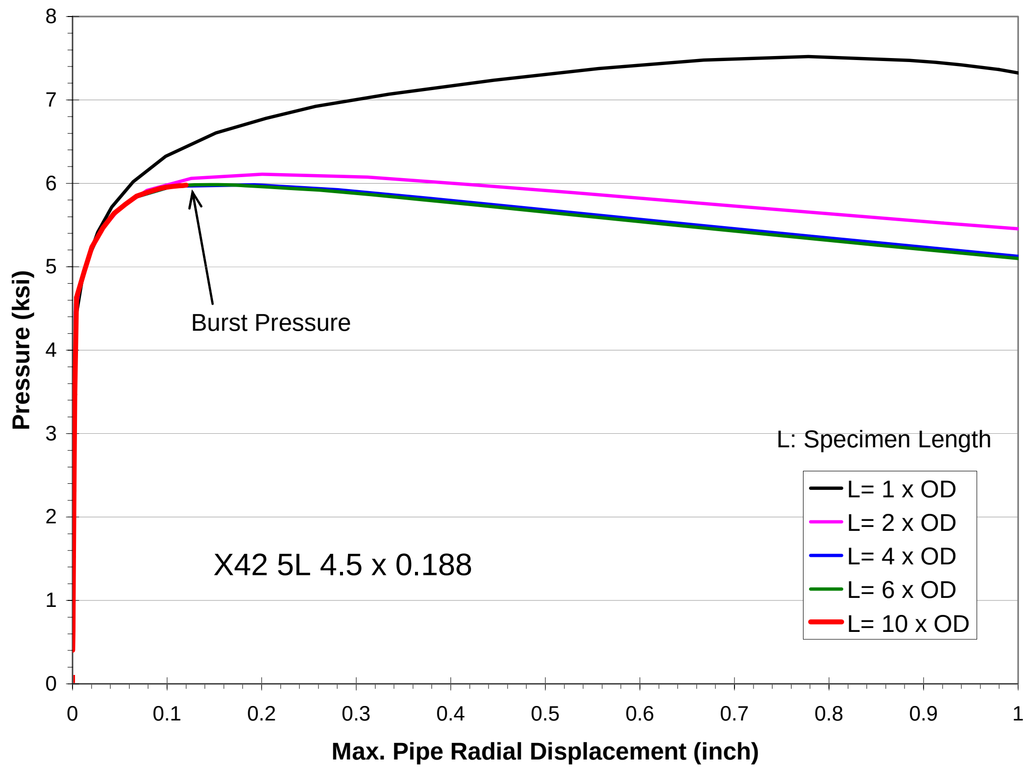
Accomplishments

Initiation of Burst Prediction Modeling



Finite Element Analysis of Burst Pressure

- For defected, repaired, or welded pipelines with geometry and material discontinuities
- For degraded pipelines with local material property variation due to previous NG service or hydrogen exposure
- For actual material tensile property input (full stress-strain curves up to failure)

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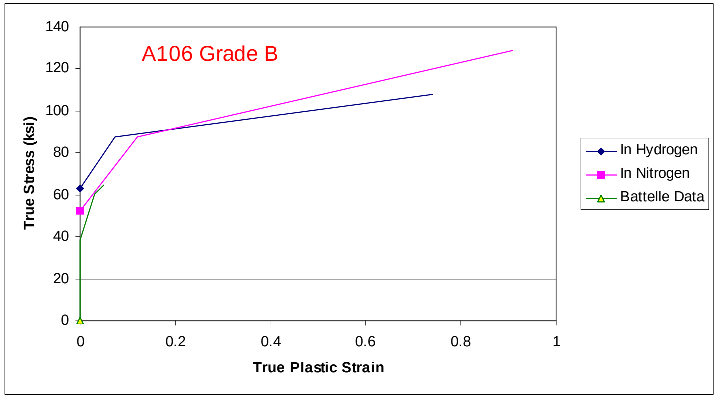
Accomplishments

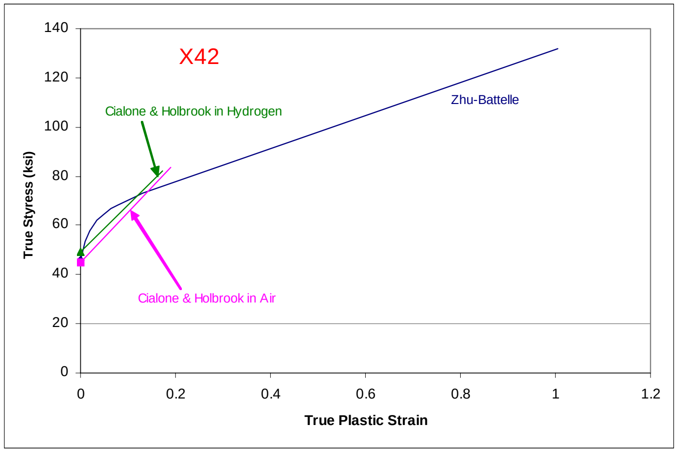
ASTM A106-Grade B

Size	Gas	Burst Pressure((ksi)	DV/Vo (%)
2-3/8	H2	15.14	18.25
	N2	13.87	27.84
4	H2	8.571	13.34
	N2	7.883	31.14
4-1/2	H2	7.700	15.03
	N2	6.962	22.90
6-5/8	H2	5.165	14.67
	N2	4.671	22.38
8-5/8	H2	3.869	12.65
	N2	3.560	29.49



API 5L-X42

Size	Gas	Burst Pressure((ksi)	DV/Vo (%)
2-3/8	H2	11.84	43.0
	Air	11.72	43.0
4	H2	6.742	31.1
	Air	6.634	48.2
4-1/2	H2	6.036	35.2
	Air	5.873	35.2
6-5/8	H2	4.044	34.3
	Air	3.935	34.3
8-5/8	H2	3.044	29.5
	Air	2.997	45.7



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H2/NG Distribution Systems Materials Challenges

Materials Data Needs for Hydrogen Service

- Minimum Specified Yield Strength
- Minimum Specified Tensile Strength
- Yield Strength to tensile Strength Ratio
- Steel Chemistry
- Weld-ability
- Minimum Design Temperature
- Fracture Initiation Toughness
- Burst/Rupture Strength
- Permeability
- Corrosion resistance, and corrosion prevention
- Failure prevention program including periodic inspection
- Resistance to environmentally caused degradation

"Coordinated research efforts is necessary to understand how line pipe steels are affected when exposed to hydrogen (particularly at high pressures), how to prevent or minimize the failure probability of a system, and finally to gather critical data that is essential for the development of codes and standards and government regulations"

•*Mohitpour,* Tempsys Pipeline Solution Inc, CANADA, 2004

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Technical Issues and Concerns

- Potential for Degradation of Material Properties from NG Service
- Acceptance of Possibility for “De-Rating” NG Piping for Hydrogen/Mixed Gas Service
- Better Understanding of Potential User-End Energy Density requirements and Subsequent Operating Pressure Requirements
- Better definition of Operating Service Conditions
- Definition of “Data Needs” for Qualification of Pipeline Materials for Hydrogen/Hythane Service
- Upper-Bound for Hythane Mixture Concentrations
- Definition of Options to Reduce/Retard Hydrogen/Mixed Gas Interaction with Pipeline Materials and Potential Materials Issues with Proposed Approaches
- Definition of Potential “First” Use Strategies—Local/Regional Distribution or Cross-Country Distribution as They Impact Materials Issues

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Future Plans

- FY06 Proposed
  - Finalize Mechanical Property Testing
  - Fracture Testing and Advanced Fracture Modeling
  - Constraint Modified J-R Curve Fracture Testing and Transference of Laboratory Data to Real-World Systems and Components
  - Optimize Burst Model and Transference from Disk Rupture Testing

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