V.A.4 Evaluation of Natural Gas Pipeline Materials for Hydrogen/Mixed Hydrogen-Natural Gas Service

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Projected End Date: Project continuation and direction determined annually by DOE

Objectives

The objective of this project is to evaluate the feasibility of using the existing natural gas transmission and distribution piping network for hydrogen/mixed hydrogen-natural gas delivery.

- Develop and perform the requisite hydrogen/mixed hydrogen-natural gas testing methods and data regression to provide the technical basis for qualification of existing NG pipelines for hydrogen/mixed hydrogen-natural 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 use the existing NG pipeline network for hydrogen/mixed hydrogen-natural gas distribution and develop mitigating strategies for these risks

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- D. High Capital Cost and Hydrogen Embrittlement of Pipelines
- I. Hydrogen Leakage

Technical Targets

This project is conducting comprehensive characterization of steel materials, with and without prior natural gas service, to evaluate their behavior in hydrogen/mixed hydrogen-natural gas operating environments. Insights gained will support qualifications of these materials for hydrogen service including the DOE 2010 delivery targets:

- Pipeline Transmission and Distribution Cost: $1M/mile
- Pipeline Transmission and Distribution Reliability: Understood
- Hydrogen Leakage: <2%

Approach

- Establish testing protocols for assessing materials and components for hydrogen/mixed hydrogen-natural gas service

  - Establish 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 hydrogen-natural gas environments
  - Generate data for advanced fracture modeling
  - Generate data to provide technical basis for understanding hydrogen embrittlement and materials reliability

Accomplishments

- Performed extensive literature review of hydrogen embrittlement, fracture, and fatigue for pipeline steel materials
- Re-established high pressure hydrogen test facilities and completed safety documentation
- Initiated sub-critical hydrogen cracking (K_{th}) tests of C-ring specimens harvested from archival natural gas piping materials

Future Directions

- Perform mechanical testing of hydrogen charged archival NG piping samples
- Perform K_{th} testing of self-loaded C-ring piping specimens
- Perform advanced fracture modeling to allow for data transference and prediction of actual system from lab scale data
- Development of environment modified/controlled failure assessment diagrams
- Evaluate and test fatigue in typical pipeline materials
- Perform burst prediction modeling and testing: understanding the effects of hydrogen on pipe burst properties

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Introduction

The use of the natural gas pipeline network to deliver pure hydrogen or mixed (natural gas/ hydrogen gas) gas, without significant modification, could provide major cost/schedule benefits in the transition to a hydrogen energy economy. Natural gas is presently transported long distances at high-pressure (generally between 500 and 1200 psig) and distributed at lower pressure (below 100 psig) to end-users. Similar practices are likely to emerge for hydrogen. High-pressure natural gas (and hydrogen pipelines) today use steel alloys, while natural gas "distribution" pipes can be made of a variety of materials such as cast iron, copper, steel or plastic (PVC or PE). The process of transitioning to hydrogen delivery via the existing network is complicated by the diversity of materials used in natural gas piping systems and of operating strategies adopted by utility operators. Steel and plastic are the primary materials, but even these materials will have subsets that may be more or less acceptable for hydrogen service. The aging effects of natural gas service, coupled with the new environment of hydrogen service, need to be quantified to assure safe service conditions. For example, carbon steels are susceptible to hydrogen embrittlement and cracking. Plastic materials may also experience a loss in ductility or reduction in other mechanical properties either through aging or through exposure to some gas concentrations under some operating temperature and pressure conditions. The development of the technical basis for qualifying the use of existing natural gas pipeline materials (steels and plastics) for hydrogen service is proposed. The work will focus on the effects of hydrogen service on physical and mechanical properties such as tensile strength, fracture resistance, etc, and on their impacts on pipeline burst pressure and flaw tolerance.

Hydrogen embrittlement can include surface cracking, slow crack growth, loss of ductility, and decreases in fracture stress. This deterioration can lead to premature failure, possibly with little warning. Safety is paramount to all aspects of natural gas operations so before hydrogen gas can be introduced into the pipeline, operators must be assured that embrittlement risks have been minimized. For steel pipes, there is considerable debate whether or not hydrogen gas would have a significant effect on operating performance. The reliability of the hydrogen pipeline system is of the utmost concern for the DOE, DOT, other regulators, and stakeholders, whether using the existing natural gas delivery system or installing new dedicated hydrogen delivery systems. To this end, it is critical that a complete understanding of the effects of hydrogen embrittlement/degradation processes in these pipeline materials is developed to support the basis for qualification of the materials and existing system for hydrogen service.

Approach

In the past, hydrogen-induced losses in mechanical properties have been attributed to three primary factors:

- the development of a critical, absorbed, localized hydrogen concentration;
- the existence of a critical stress intensity (crack length and applied or residual stress); and
- the existence of a susceptible path for hydrogen damage

Full characterization of the mechanical behavior of natural gas pipeline alloys which have experienced extensive field service when exposed to gaseous hydrogen comprises the central focus of the proposed research. The investigation of the ability of existing distribution pipeline steels to transport either nominally pure gaseous hydrogen (GH2) or mixed hydrogen–natural gas (i.e., hythane—20%H_2-80% natural gas) will consist of four tasks. Task I will investigate the mechanical properties of typical pipeline steels exposed to the expected hydrogen/ mixed hydrogen-natural gas environments and will evaluate the overall susceptibility of these materials to hydrogen embrittlement using advanced fracture mechanics measurement techniques and analysis. Task II will focus on the development of environment controlled/modified failure assessment diagrams used to predict flaw tolerance and stability in pipeline systems. Task III will evaluate fatigue behavior of pipes in distribution service environments. Task IV will consist of finite element modeling using properties developed in the previous phases to predict burst failure.

Results

This research was initiated in fall of 2004 with limited funding. Since that time, an extensive literature review was performed on hydrogen and mixed hydrogen-natural gas (hythane) effects (embrittlement, sub-critical cracking, fracture toughness) on typical API pipeline steels. This review has suggested that a clear consensus with regard to the microalloyed API-type pipeline steels with respect to extent or occurrence of hydrogen embrittlement is lacking. Additionally, there is much evidence that the hydrogen purity plays a critical role in either increasing or decreasing the susceptibility of these materials to hydrogen embrittlement (see Figure 1).

Preliminary testing of samples harvested from API-5L X42 archival natural gas piping provided by South Carolina Electric and Gas has begun. Sub-critical cracking samples comprised of notched C-ring specimens harvested from the nominal 4”

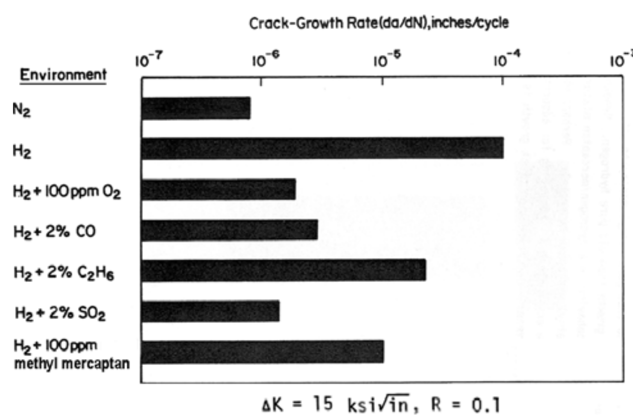

Figure 1. Impact of Hydrogen Gas Purity on Fatigue Crack Growth Rates (J.H. Holbrook, Battelle Labs, 1988)

diameter archival pipe are being tested. These self-loaded (bolt loaded) specimens are currently being tested for up to 1000 hours under various loads in an initial attempt to establish the hydrogen threshold concentration for the given test condition and sample configuration.

Preliminary mechanical (tensile property) testing in hydrogen of both hydrogen-charged and unexposed samples harvested from the same archival piping materials is planned for later this fiscal year.

FY 2005 Publications/Presentations

1. T.M. Adams, "Evaluation of Natural Gas Pipeline Materials for Hydrogen Service", DOE-EE Hydrogen Pipeline Delivery, Pipeline Delivery Workshop, Oak Ridge, TN January5-6, 2005.
2. T.M. Adams, "Evaluation of Natural Gas Pipeline Materials for Hydrogen Service", DOE-EE Hydrogen Program Review Meeting, Arlington, VA, May 23-26, 2005.