In-line Inspection Tool Design and Assessment of Hydrogen Pipelines

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Abstract

Hydrogen is the smallest, lightest, most abundant element in the universe. It is 14 times lighter than air, colorless, odorless, tasteless and naturally exists as a gas that becomes a liquid at -252°C (-423° F). It is mostly used in refining gasoline, but is also used in manufacturing fertilizer, and in food processing transportation. Hydrogen gas is also extremely flammable with a lower explosive limit of 4% concentration and an upper explosive limit of 75% concentration.

Hydrogen gas, liquid hydrogen, and slush hydrogen can be transported by pipeline [1]. Hydrogen transportation is not a new idea, it was being transported around Germany as early as 1938 via a dedicated pipeline system. Today there are over 1,600 km (994 mi) of active pure hydrogen pipelines in Europe and by 2040 there are plans for expansion of 22,900 km (14,229 mi). There is also a plan for injection of hydrogen into existing natural gas (methane) pipelines to provide a co-transportation approach negating the installation of a new transportation network.

Around the world, hydrogen is used to remove Sulphur during petrol and diesel refining. It is also used in the manufacture of fertilizer. There is a growing network of hydrogen pipelines owned by merchant hydrogen producers operating in the United States: 1,600 miles (2,575 km) are already in place and one marketer of industrial chemicals and gases has already announced plans to add about 100 miles (161 km) of hydrogen pipelines in the next few years. Throughout their lifecycle, hydrogen gas pipeline assets need to be inspected periodically for safety and integrity of supply.

Magnetic flux leakage (MFL) has been used for decades as an in-line inspection (ILI) technology. MFL is very useful for detecting and sizing both internal and external metal loss in gas and liquid pipelines. Because MFL tools must be durable and robust, their design has relied on well-established materials such as high strength alloy steels and rare earth permanent magnets. These materials are especially susceptible to hydrogen embrittlement, which occurs when a material is mechanically stressed while being exposed to hydrogen. This reduces material tensile strength and ductility, affecting the performance of traditional tools.

Successfully inspecting hydrogen-carrying pipelines while reducing the risk of hydrogen embrittlement requires the use of alternate materials and methods to develop a capable ILI tool.

This white paper will discuss challenges of this unique inspection environment, which were resolved through innovative ILI tool design, and present the inspection results achieved with this ILI tool design.

INTRODUCTION

Hydrogen is extremely flammable, with a lower explosive limit (LEL) of 4 percent and an upper explosive limit (UEL) of 75 percent. Hydrogen is also potentially very useful as the smallest, lightest, most abundant element in the universe. Around the world, hydrogen is used to remove Sulphur during petrol and diesel refining. It is also used in the manufacture of fertilizer.

Since the 1970s, hydrogen has been promoted as a green alternative to fossil fuels in Europe. Currently, Europe has about 1,600 km (994 mi) of small-scale, dedicated hydrogen networks [2] and there is significant interest in developing a hydrogen economy. As part of the European Union (EU) Green Deal, Europe is changing the framework of their infrastructure to drive toward a hydrogen market that will include production, transportation, storage, distribution and consumption. One European industry blueprint estimates short term investment of €430 billion by 2030 to build a new hydrogen economy.

Initially, hydrogen will be blended into natural gas pipeline networks. The plans for the injection of hydrogen into existing natural gas (methane) pipelines provide a co-transportation approach, which will eliminate the need for a new transportation network. Pipeline operators have set a target capacity for integrating blended hydrogen into the networks of 10% hydrogen volume by 2030 which will increase to 20% after 2030. These rates are achievable with limited changes to the infrastructures.

While the United States hasn't announced any major effort of a similar scale, there are efforts being made in initiating a hydrogen economy in the future. There are many business sectors which can benefit from hydrogen. There are dedicated, government funded, initiatives which focus on emerging technologies and infrastructure development. The U.S. Department of Energy's (DOE's) Hydrogen and Fuel Cell Technologies Office, within the Office of Energy Efficiency and Renewable Energy (EERE), launched the H2@Scale initiative in 2016 to explore the potential for hydrogen to enable affordable, reliable, clean and secure energy across sectors [3].

In the United States there is a large hydrogen gas transmission pipeline operating along the Gulf Coast. This pipeline runs 295 km (183 mi) between Plaquemine, Louisiana, and Port Neches, Texas uniting 22 hydrogen plants and creating a network of 966 km (600 mi) of pipe. [4] The pipeline was developed using heavy wall thickness pipe for all above ground sections to protect against damage from vehicle impacts. In the United States hydrogen transportation falls under CFR 49, DOT 192 regulations which require verification of pipeline integrity. This can be accomplished through a number of methods such as pressure test, in-line inspection (ILI) and direct assessment. ILI was chosen as the integrity assessment method by a large hydrogen gas transmission pipeline operator because of the challenges associated with the other integrity assessment methods. The operator considered running the ILI tool in several different mediums, including water, air, nitrogen or the pipeline product 100% hydrogen. Hydrogen was selected because of the logistics, cost and timing associated with the pipeline operational requirements.

Project and Partnership

The operator had never attempted running a smart pig in hydrogen service before and initial concerns were around ILI to hydrogen material compatibility. The pipeline operator had limited experience with pigging operations and no existing business relationship with pigging or ILI companies.

T.D. Williamson (TDW) is known for hot tapping and is also a pioneer in the smart pig industry. They have in-house engineering with R&D capabilities for ILI tool development. The pipeline operator chose to partner with TDW in an R&D design contract as well as an ILI contract. The key to this partnership working was open communication between TDW and the hydrogen pipeline operator.

Magnetic flux leakage (MFL) technology was selected as the inspection method because it is very useful for detecting and sizing internal and external metal loss in liquid and gas hydrocarbon pipelines [5]. The pipeline operator also wanted high resolution mapping data for precise feature location which can be added to the MFL tool.

Evaluations and Testing

Existing ILI MFL tools were evaluated for their compatibility with hydrogen. The materials in MFL tools are largely rare earth permanent magnets and high strength alloy steels. Because these materials are susceptible to hydrogen embrittlement, using hydrogen as the pipeline inspection medium meant the potential for hydrogen embrittlement had to be addressed. Hydrogen embrittlement occurs when a material is mechanically stressed while being exposed to hydrogen which reduces the material tensile strength and ductility. This combination often leads to a catastrophic failure of the material. During evaluation of the tool magnets and high strength steel materials, there were several failure modes discovered most notably, the rare earth permanent magnets were found to disintegrate quickly in pure hydrogen. It was soon determined that the inspection would require designing a MFL magnetizer and associated support systems from the ground up.

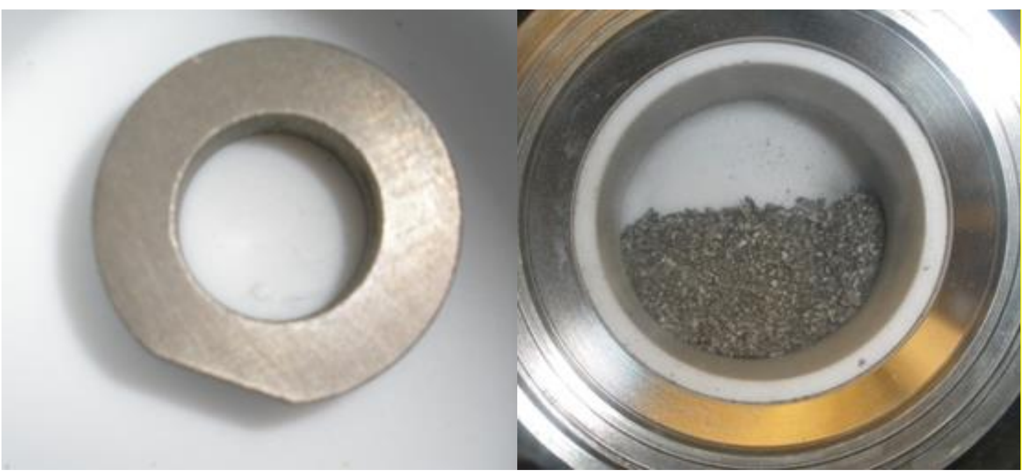

Figure 1- Test magnet (left) prior to testing and test magnet post testing (right)

All magnet and high strength steel items from the previous design had to be reengineered including the tool body-to-body coupling system. Following the design, all of the new systems and subsystems had to be tested for wear then validated in hydrogen.

Results

The first attempt to inspect the hydrogen pipeline ended with the tool getting lodged due to a failure in the drive assembly. Post inspection testing to determine the root cause were conducted. The results were mixed: The magnetizer section performed as expected, it was well supported throughout the inspection and the brushes experienced less than expected wear. The drive failure was determined to be caused by the body to body coupling mechanism. Design changes were implemented to correct this issue and tested to validate the new coupling mechanism. A follow up inspection was performed on a different section of the pipeline in 2017 and it was a complete success. The 2017 inspection results found the sensors had 100% MFL and IDOD coverage; the high resolution mapping data was also high quality and complete, tool brush wear was as expected, and the drive cup wear was better than expected due to drive design improvements. TDW and the pipeline operator concluded that it is possible to inspect hydrogen pipelines while they are in operation using MFL with mapping ILI technology.

Pipeline Operations

Throughout this effort many things were learned on how to successfully operate the pure hydrogen pipeline while running an ILI tool. The first lesson learned was when operating in pure hydrogen, ILI tool distance from the pipeline compressor can cause delayed reaction in tool response. Therefore, having fine flow control is very important. The second lesson learned, was that wall thickness changes caused issues for this tool due to the amount of force required for the tool to compress to a smaller diameter in heavy pipe wall thickness sections. Hydrogen is a very small molecule and bypassing of the drive cups easily happens. In addition, bends in the pipeline are a limiting factor to the maximum length of ILI tool runs. The tool successfully ran up to 98 km (61 mi) as long as the majority of the pipeline was straight [6]. Longer length pipelines with many bends and elevation changes resulted in poor tool speed profile due to a compressible product, increased tool drag in bends, and lack of drive caused by cup wear. Creating a system to have fine flow control, reducing pipe wall thickness changes and, where possible, having fewer pipeline directional changes are the major operational learnings from this project.

Conclusion

The case presented within this paper was a 100% hydrogen pipeline inspection while the line was in service. A key element of success in this challenging environment was the partnership between the ILI service provider and the pipeline operator. Through collaboration, TDW and the pipeline operator learned several important lessons about successfully running an ILI tool in a hydrogen pipeline while it remains in service.

Many of the same challenges exist when inspecting lower levels of hydrogen. Pipelines with as little as 10% hydrogen injected into methane will present some of the same challenges for ILI tools to overcome. TDW has found that as little as 500 parts per million (PPM) of hydrogen will permanently damage the magnets as well as the high strength steel used in typical ILI tools. It is recommended that operators with pure hydrogen and even if using injected hydrogen with more than 500 ppm consider using ILI tools specifically designed to inspect in these conditions.

Acknowledgements

The author would like to thank TDW's U.S. pipeline operations partner, as well as his colleagues at TDW who contributed information and expertise to this paper.

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