Hyway to the Future

By Marion Erdelen-Peppler, Neil Gallon and Michael Tewes

The climate emergency is one of the biggest challenges humanity must face in the 21st century. At the same time, the advancing global energy transition faces many challenges when it comes to ensuring a sustainable, reliable and affordable energy supply. An emphasis on decarbonizing the existing gas infrastructure will lead to greater penetration of greener fuels, such as hydrogen, which will ultimately be produced from renewable energy. Many operators are currently in the initial stages of investigating possibilities to build dedicated hydrogen pipelines or convert natural gas pipelines to hydrogen.
While the transportation of hydrogen in pipelines has been safely managed for decades, there is a common understanding that future hydrogen lines in the context of the energy transition will need to be operated differently from their present-day equivalents (either hydrogen or natural gas), which could potentially lead to differing results when threats are being investigated. However, this extensive experience with hydrogen pipelines has provided valuable inputs to help understand the overall system and identify the gaps that do remain in certain areas, such as material property requirements and the applicability of established defect assessment approaches. The differences between natural gas and hydrogen pipelines that have been identified provide an opportunity for the development of dedicated technologies to help ensure the safe conversion and operation of hydrogen pipelines. This paper will summarize the role of different technologies in this context.

Introduction

There are currently more than 4,500 km of pipelines transporting hydrogen; almost 1,600 km of these are located in Europe, and most of them are dedicated hydrogen product lines designed and built to bring process gas hydrogen from gas producers to industrial users, such as chemical plants and refineries. The plans for the European hydrogen backbone have a different focus: they have been established around the vision of hydrogen as a source of energy. The quantities of hydrogen that are needed will be significantly larger than they are today; the network will eventually need to deliver the gas across the continent. This can be achieved by making use of the existing natural gas grid, adding dedicated new lines only where needed. However, because of the differences between hydrogen and natural gas, these plans for the future pose significantly different challenges to the system, mainly related to volume, pressure, and maintaining pipeline integrity and safety.
For both new and repurposed lines, it is necessary to assess the relevant threats and define an integrity management strategy. One key element is to understand the pipeline condition and assess it against the threats.
This understanding and assessment encompasses a robust knowledge of material properties, and any significant local variations in properties, to form the basis of a "fitness-for-hydrogen" assessment. While this does not represent a challenge for newly built lines, available records can be incomplete when it comes to vintage lines. In addition, preexisting anomalies must be known. Depending on the history of the repurposed line, it may be reasonable to collect additional, potentially relevant data, such as material-related or geometrical properties.

Assessment of Hydrogen-Related Threats

The development of a hydrogen integrity management plan is fundamentally the same as that of a natural gas pipeline integrity management plan. It includes data gathering to perform a threat analysis and selecting a system based on the results. If the pipeline is being repurposed, the inspection plays a significant role because it is important to capture crucial information related to the characteristics of the existing line. After the preliminary assessment, an integrity management plan can be refined. (***Figure 1***)

Pipeline Integrity Management codes (for example ASME B31.8S [1]) require that all integrity threats be identified, evaluated and mitigated adequately. Consequently, current conversion feasibility studies and initiatives are primarily focused on the left part of the framework, identifying threats, material compatibility, code compliance or code amendment, and operational compatibility. The two main categories of hydrogen-specific threats that have been identified are (i) cracks/damage related to hydrogen and (ii) degradation of material properties in response to exposure of the steel to hydrogen.
The assessment of the material-related threats is interesting because it combines several different aspects when it comes to repurposing existing lines. It is necessary to have detailed knowledge of the pipes and their properties as per manufacturing certificate. Depending on the age of the pipeline, this data might not be readily available. However, even if the documentation is complete, it will contain material properties in air that then need to be transferred to hydrogen-related properties, either by applying a knockdown factor that is specific to the material or by testing.
It is generally acknowledged that the interaction between hydrogen and steel can lead to a major degradation of steel ductility and fracture toughness as well as to an acceleration of fatigue crack growth. However, the quantification of such influences remains uncertain, and there is a large scatter in the data [2,3]. A key reason for this is that the magnitude of interaction of hydrogen and steel is determined by the spe-

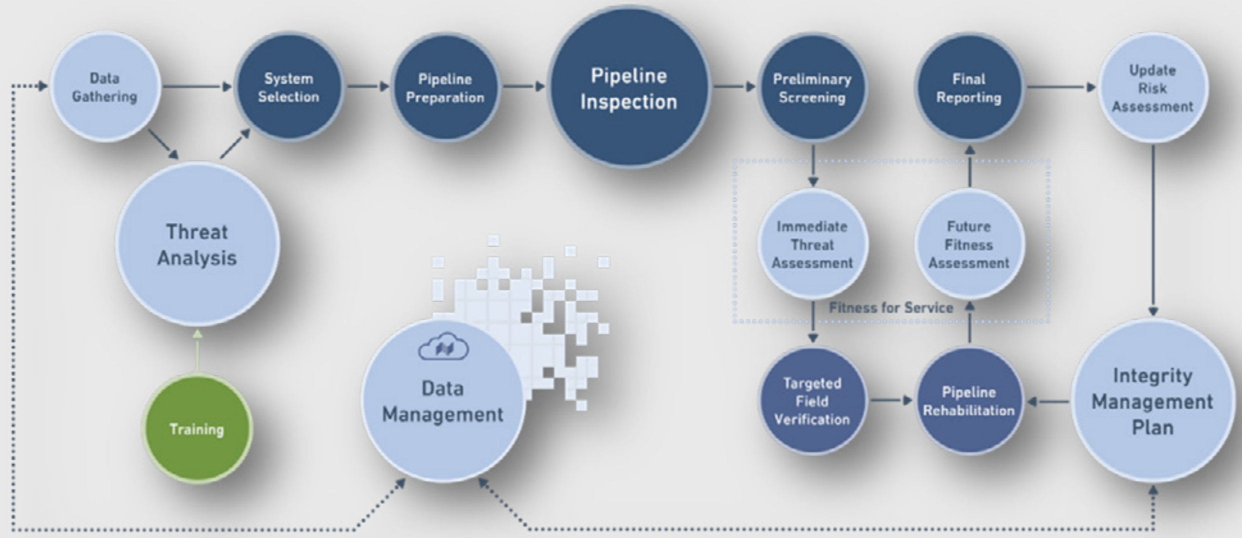

Figure 1*: A systematic approach for de-risking the introduction of hydrogen in existing (natural gas) pipelines*

cific nature of the steel microstructures and chemistries [2], not just the grade.

A detailed knowledge of existing materials, both in air and in hydrogen, is therefore fundamental to any conversion study. This is recognized in ASME B31.12, which requires destructive testing of samples at a rate of one per mile (1.6 km) if a pipeline is to be repurposed.

ILI Inspection Strategy for HYydrogen Lines

As for natural gas lines, it is important to develop a suitable inspection strategy for hydrogen. In relation to the aforementioned typical threats related to hydrogen, emphasis is placed on an understanding of the material's "DNA" as well as on crack detection. These aspects are at the core of conversion and integrity management strategies. Therefore, crack detection technologies such as EMAT and materials properties ILI such as ROSEN's RoMat PGS and DMG services are likely to be integral to the inspection and conversion of hydrogen pipelines.

Crack Detection

Before converting a pipeline from natural gas to hydrogen, it is essential to understand the condition of the line. This includes identifying joints that need to be exchanged or repaired and setting a sound baseline against which the condition of the line can be assessed within a given time interval.

In-line inspection (ILI) of pipelines by smart tools provides detailed information for input into a framework for managing the threat of crack-like defects, such as fatigue cracks and stress-corrosion cracking (SCC). Several technologies based on magnetic flux leakage (MFL), eddy current (EC) or ultrasound are applied to address a wide range of different types of defects to support the discrimination and sizing of cracking. The most promising technology for direct detection and sizing of cracking in gas pipelines has emerged in the past few years [3,4,5]: electro-magnetic acoustic transducer (EMAT) technology allows for generation of ultrasonic horizontal shear waves in the pipe wall by either of two physical phenomena resulting from alternating currents in a static magnetic field: Lorentz force and magnetostriction. The EMAT ILI system is set up to generate ultrasonic waves consisting of lower- and higher-order modes, which propagate in the circumferential direction of the pipe wall without the need for a coupling medium. EMAT can therefore be used in gas pipelines including hydrogen. EMAT technology applied in pipeline inspection tools can identify and size linear anomalies in the pipe wall while also being able to determine and identify the condition of external pipeline coatings.

Where cracking is identified as a credible threat, consideration must be given to the deployment of an inspection system that can detect the cracks that may develop or demonstrate that cracking has not occurred. Existing pipeline inspection crack detection systems such as electro-magnetic acoustic transmission (EMAT) or ultrasonic testing (UT) have been developed to primarily detect fatigue cracks associated with seam welds, as wells as stress-corrosion cracking affecting the pipe body and close to the seam weld. These systems have successfully been used in the past (for 15+ years in the case of EMAT), and while it is recognized that there are limitations to all forms of ILI, both EMAT and UT are well accepted by the industry. They are established methods for the detection and sizing of various types of linear crack-like anomalies. However, the types of cracking and critical crack sizes associated with hydrogen service are still the subject of research. To address this, ROSEN is working with operators to understand critical crack dimensions (depending on local material properties) and associated crack detection requirements. Once this groundwork has been completed, test samples can be created and combinations of technologies tested to identify how best to complete reliable inspections.

The correct combinations of technologies can be used to identify, for example, areas of high stress or past plastic deformation that may also need thorough consideration before conversion to hydrogen service.

Figure 2*: The ILI tool upon arrival at the receiver*

For pipeline systems that already contain hydrogen, ROSEN has tools tested and approved up to 100 % hydrogen and 100 bar at ambient temperature using special tool setups regarding sealing, material of discs and cups, and H2-proved electronic components, alloys and magnets.

Understanding the Pipe DNA

As discussed earlier, knowledge of material properties in hydrogen is essential for the safe operation of the line. Therefore, ASME B31.12 requires destructive material testing at a frequency of one test per mile when an existing line is repurposed. Understanding pipe properties without having to perform frequent digs is essentially important to the industry. As opposed to investigating at a predetermined frequency, which can result in missing single joints or small populations with different properties, the approach of identifying existing populations in a given line and performing destructive testing in each of these populations is more efficient and can lead to improved overall safety.
This can be achieved by ROSEN's material verification service (the Pipeline DNA process), which provides a comprehensive view of the pipeline makeup. The process combines multiple ILI datasets, including PGS, MFL, geometry, mapping, material properties and other pertinent information, to establish "populations" of pipe within a pipeline and identify any outliers or rogue pipes.

Pipe Grade Determination

Traditionally, ILI has not been able to provide strength data, but with the addition of ROSEN's Pipe Grade Sensor (PGS) technology, strength is measured for every pipe and a grade assigned to each pipe population. This approach was developed to demonstrate that required strength levels are met for pipelines where records have been lost or destroyed – typically older pipelines. However, it is equally applicable for the identification of pipes with a higher-than-expected strength that may be more susceptible to the threats posed by hydrogen service and should be evaluated before conversion.

Hard Spot Detection

Steels with high tensile strength and hardness are known to be susceptible to hydrogen-related damage, such as hydrogen-induced cracking (HIC). ASME B 31.12 recommends the use of steel grades up to 358 MPa SMYS for pipes transporting hydrogen. Additionally, the hardness is a limited to 237 BHN. Pipe material can exhibit localized areas of increased hardness, referred to as hard spots in API 5L [4]. This increase in hardness is often caused by local variations in microstructure. Hard spots are of concern in combination with hydrogen because they can promote cracking; this is recognized in ASME B31.12, which prohibits hard spots (or "metallurgical notches," as they are called).
ROSEN understands the need for inspection in accordance with API and uses well-established axial Magnetic Fux Leakage (MFL) technology combined with Eddy Current (EC) to find locations with increased hardness along the entire pipeline. This RoMat DMG service offers a unique capability of hardness inspection, which boosts the safety of the pipeline and maximizes efficiency by avoiding unnecessary excavations.

Case Study

A 12-mile pipeline segment set up for the transportation of hydrogen was installed in the US in 1996. The operator approached ROSEN in 2017 for a method to safely inspect the line segment in hydrogen with a combination of geometry and magnetic flux leakage (MFL) technologies.

Due to the properties of the product, the tool was set up with non-standard components, including cups, designed to lower the risk of static electricity, resist decomposition and allow for proper resistance to uneven wear. Additional alterations were made to the tool to reduce the potential risk of hydrogen damage to the tool itself (e.g. the magnets). Although the standard tool setup required a minimum of 435 PSI, it was necessary to move forward with a pressure of ~270 PSI and a flow rate of 11 MMscfd for the first inspection. In order to reduce excessive velocity from pressure buildup in installations while still providing enough seal to propel the tool through the line, various bypass mechanisms were incorporated.
After completion of the run, there was no damage to the tool or its components, and the cups showed minimal wear. The resulting data from the combination tool showed 100 % sensor coverage for both the geometry and the MFL portion, and magnetization levels were within the predicted ranges. Given the success of the first inspection, the operator returned to ROSEN in 2019 for a reinspection of the line segment. This time, the system pressure provided was at ~340 PSI, while the same flow rate was maintained. (***Figure 2***)

During the data review, it was noted that the tool still experienced a few velocity spikes, but the increased pressure allowed for an overall reduced speed and a more stable inspection. The data was again at 100 % sensor coverage for both the geometry and the MFL portions, which was acceptable for evaluation. The data was used to determine the integrity status of the pipeline segment. It will be possible to apply the experience gained to other ILI technologies in the future.

Conclusions

The conversion of existing infrastructure to hydrogen brings unique integrity management challenges. However, the experience gained operating natural gas and existing hydrogen pipelines can be adapted to meet these challenges. Management strategies will revolve around understanding material "DNA," testing and the deployment of in-line inspections to address pipeline fitness for service.
For hydrogen lines, some of the major time-dependent integrity threats are associated with potential hydrogen embrittlement of the pipeline steel – and the consequent threat of cracking. ILI of hydrogen pipelines can also be challenging due to the different physical and flow characteristics of hydrogen compared to natural gas. Despite this, inspections can be done, and ROSEN has a proven track record in the successful inspection of hydrogen pipelines.
Besides adapting existing technologies and services to the special requirements of a hydrogen grid, ROSEN's services for hydrogen assets are integrated into a holistic integrity management framework that addresses hydrogen-related threats, interactions and defects. Pipeline operators are thus able to make sustainable decisions for the conversion of their existing gas grids to hydrogen, ensuring hydrogen-transport operations that are reliable in all aspects of performance, safety and security.

References

[1] ASME, ASME B31.12, Hydrogen Piping and Pipelines, New York, 2019

[2] Sandana D., Gallon N., Andrews, R.A., Palmer-Jones R., Crack management of hydrogen pipelines, International Conference of Hydrogen Safety, Edinburgh, 21-24 September 2021

[3] Gallon, N., Van Elteren, R., Existing pipeline materials and the transition to hydrogen, Pipeline Technology Conference, Berlin, 2021

[4] American Petroleum Institute API, API 5L

KEYWORDS:

AUTOREN

Dr. **MARION ERDELEN-PEPPLER**
Principal Engineer World-Wide Special Assignment
ROSEN Germany GmbH, Lingen (Ems)
Tel. +49 591 9136-9567
merdelenpeppler@rosen-group.com

NEIL GALLON
Principal Engineer
ROSEN Group

MICHAEL TEWES
Regional Business Line Manager Advanced Pipeline Diagnostics
ROSEN Group