Energy Transition And The Impact On Pipeline Integrity

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Abstract

The climate emergency and energy security are some of the biggest challenges humanity must face in the 21st century. The advancing global energy transition faces many challenges when it comes to ensuring a sustainable, reliable and affordable energy supply. The energy industry is currently going through its biggest change in living memory, despite this gas and its valuable infrastructure continue to play a major role in the future. Scaling up the transportation of renewable and low-carbon gases in our global pipeline network is essential to deliver a reliable and affordable transition to climate neutrality.

This paper will illustrate the important role of pipelines in an integrated future energy system, and explore the implications of pipeline transportation of renewable and low-carbon fuels and their associated products. In particular, the implications for pipeline integrity and inspection will be investigated.

1. Introduction

Achieving the ambitious goals of energy security and EU climate policy will require significant investments in energy efficiency, renewables, new low-carbon technologies and grid infrastructure. It will also necessitate the close integration of the electricity and gas sectors and their respective infrastructures. A decarbonized Europe will be based on an interplay between renewable electricity and renewable and low-carbon gases in an integrated energy system to transport, store and supply all sectors with green energy to deliver a reliable and affordable transition to climate neutrality. A number of studies have shown that the existing gas infrastructure and knowledge can support the transition to net-zero in the most efficient manner. As the energy transition advances, the valuable pipeline system will provide efficient transportation and storage capacity for renewable energy in the form of molecular energy carriers, making the energy system more flexible and resilient [3].

Low-carbon gases and their associated products can reliably and efficiently be transported, stored and distributed in our global existing and new build pipeline network. Pipelines will also be used in assisting carbon capture, utilization and storage (CCUS) projects by transporting carbon dioxide safely from emission locations to permanent storage or end use locations. For this reason, pipelines continue to be important and will play a critical role in an integrated future energy system. The transportation of these fuels through pipelines will require general as well as specific integrity threats and damage mechanisms to be considered to ensure a safe and efficient operation. These challenges can only be managed with a comprehensive integrity management system. Only then can effective inline inspection technologies be specified to target the specific threats and damage mechanisms accurately. This article investigates the implications of future fuels and their associated products on the integrity of pipelines and inline inspection solutions.

2. INTEGRITY THREATS

If future fuels (or indeed any fuels) are to be transported through pipelines, pipeline integrity must be assured to allow for long-term safe operation. This concept of integrity management is not new to pipeline operators, as demonstrated by the long, proud and overwhelmingly safe history of the existing pipeline network, but it is worth revisiting in the context of future fuels. In essence the key points of interest for any pipeline integrity management system are:

- Pipeline condition - What are the time-dependent threats? Which type of defects should I tackle? Where? How severe?
- Integrity Remaining Life- How safe is my pipeline operations? How long?
- Consequences- What are the consequences of loss of containment?
- Management - Can I safely manage pipeline operations?

The introduction of different fluids into pipelines will not change how Integrity Management (IM) should be tackled, but it will introduce its own specificities and challenges. It is therefore necessary to consider each fluid in turn, identify the relevant threats and outline how these threats can be monitored, inspected and managed. The management of these threats is best understood in the context of an integrity framework, and example of which is shown in Figure 1, the concept of which is further outlined in [4].

3. General Threats (non-specific to service)

For any pipeline, the likelihood of internal-time dependent threats are generally directly related to, and result from, the fluid being transported. However, certain threats and defects could arise irrespective of the nature of the transported fluid.

The transported fluid will have only a peripheral impact on the occurrence of external threats, particularly in the case of external corrosion, 3rd-party damages, and geohazards. This also (generally) applies to the occurrence of external Environmentally-Assisted Cracking (EAC) (i.e. external Stress-Corrosion-Cracking, Hydrogen-Induced Stress Cracking (Cathodic Protection-related)). Equally, certain flaws could be directly introduced during manufacturing and construction regardless of the intended service; and can pose an integrity threat on their own right. These threats need to be inspected for, and managed, regardless of the pipeline service.

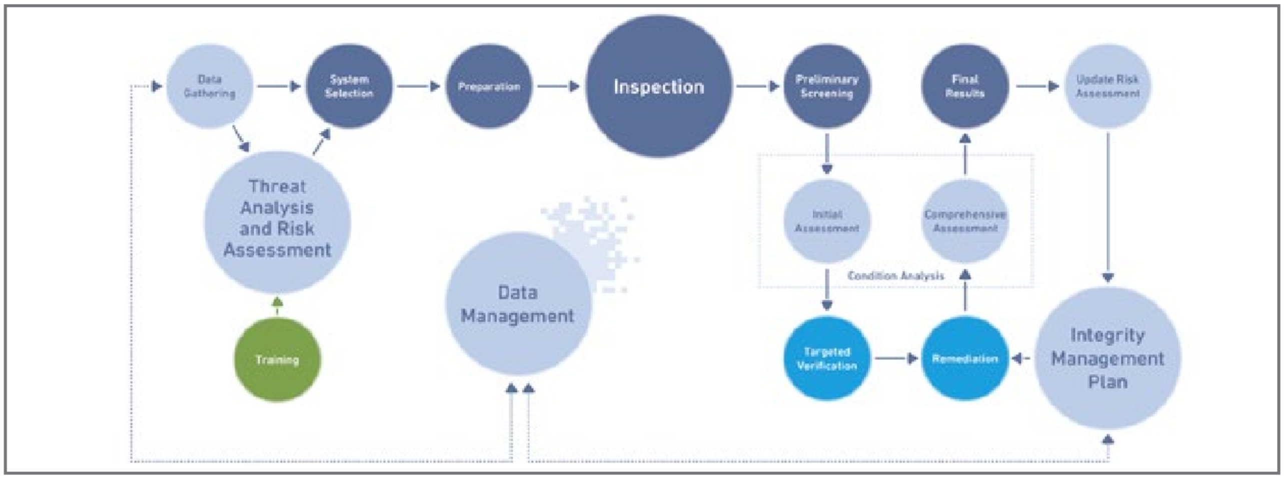

Figure 1: Example of a Hydrogen Integrity Management Framework

Threat	Feature type	ILI technology examples
External corrosion	Metal loss	RoCorr MFL-A, RoCorr UTWM
Third-Party Damages	Dents, gouges	RoGeo-XT
GeoHazard	Bending strain	RoGeo-XYZ
Manufacturing / Construction (materials & welding)	Crack like / cracks	RoCD EMAT-C, UT-C
External EAC (ext. SCC / HISC)	Cracks	

Table 1: Main ILI technologies for the management of 'General' Integrity threats (irrespective of service)

In addition to these 'general' threats, it is known that methane is essentially inert with respect to pipeline carbon steels. In contrast, gases such as hydrogen or CO2 can interact with the pipeline either by means of hydrogen embrittlement or corrosion (in the presence of water). It is therefore a truism to say that changing the service of a pipeline from natural gas to a future fuel will never make anything better from an integrity point of view, and may well make things more challenging. The natures of these challenges, and approaches to manage them, are explored further below.

4. Hydrogen

As has been noted many times, hydrogen pipelines are not new technology and gaseous hydrogen has been successfully manufactured, transported and stored in carbon steel infrastructure for hundreds of years [4], [6].

Despite this, there are important differences between hydrogen and natural gas pipelines. In summary the major effects of hydrogen on material properties are to reduce ductility, reduce fracture toughness and increase fatigue crack growth rate in hydrogen compared to air. The magnitude of these effects varies widely in the literature but there appears to be a clear agreement that there is a strong microstructural dependency [9]. To help quantify the effects of gaseous hydrogen, ROSEN have developed a dedicated gaseous hydrogen test laboratory which will be operational in 2022.

Existing hydrogen pipeline design codes are significantly more restrictive than their natural gas equivalents [12] in two major respects. Firstly, hydrogen codes tend to require lower allowable utilisation factors (the hoop stress as a proportion of SMYS) and secondly hydrogen codes are significantly more restrictive in terms of material properties, strongly encouraging the use of lower grade (=<X52 / L360) steels and requiring more extensive testing and more restrictive chemical compositions. The cumulative effect of these restrictions is that existing hydrogen pipelines generally operate at lower pressures than their natural

Region	km	miles
U.S.	2608	1621
Europe	1598	993
Rest of World	337	209
World total	**4542**	**2823**

Table 2: Existing Hydrogen Pipelines by Region

Threat	Feature type	ILI technology examples
Material Embrittlement	Low fracture toughness under H_2 [Note 1]	RoMat PGS [Note 1]
Hydrogen - Cracking damages [Note 2]	Cracks	RoCD EMAT-C
Additional considerations	Hard spots [Note 3]	RoMat DMG
	Geom. Anomalies [Note 3]	RoGeo-XT
	Bending strain [Note 3]	RoGeo-XYZ

Note 1: Defining material population profiles will be key to proceed to sampling and fracture toughness testing under H_2 [6] [13]
Note 2: Refer to [13]
Note 3: These features will increase susceptibility to embrittlement and cracking in H_2

Table 3: ILI technologies specific to the management of Integrity threats in hydrogen service

gas equivalents. If existing natural gas pipelines are to be repurposed to hydrogen then it will be necessary to (at least) maintain their existing operating pressures to maintain energy throughput. This in turn means that hydrogen specific threats (principally cracking) need to be understood, so a robust understanding of both existing crack-like defects and material properties in the pipeline is required.

Table 3 shows the inspection technologies that should be necessary through the conversion process and future operations, specific to hydrogen service. This is further discussed in detail in [6] [13].

5. Carbon Dioxide

The sequestration of carbon dioxide, whether as part of "blue hydrogen" production or as part of another form of CCUS project, is likely to be integral, at least in the short term, to any future decarbonised energy supply. This sequestration will require pipelines, and for economic reasons it would be very advantageous if the carbon dioxide could be transported in its dense phase rather than as a gas.

In essence the principal time dependent threats specific to CO2 pipelines are internal corrosion (if water is present) and potential stress corrosion cracking (SCC) (if water and either CO or H2S are present in addition to CO2) . This dependence on the presence of free water means that these risks can be controlled operationally, and indeed this has been done successfully in existing CO2 pipelines. It should however be emphasised that the existing total length of CO2 pipelines is less than 10,000 km, cumulative operational experience of CO2 pipelines is therefore significantly less than for their hydrocarbon equivalents and the pipeline industry has a long and painful history of operational upsets.

Although not strictly speaking an integrity threat, the other aspect of CO2 pipelines that has been the subject of intense interest is fracture control, in particular long-running ductile fracture in dense phase pipelines [16]. Understanding this threat again needs an in-depth knowledge of material properties.

Table 4 shows the inspection technologies that should be necessary through the conversion process and future operations, specific to CO2 service. This is further discussed in detail in [16].

6. INSPECTION TOOL REQUIREMENTS

Knowing the integrity threats for pipelines related to hydrogen or other future fuels we can acknowledge that different kind of In-line Inspection (ILI) technologies can support the integrity management of such pipelines.. In the following section, we will discuss

Threat	Feature type	ILI technology examples
Ductile Fracture	Low Material toughness	RoMat-PGS [Note 1]
Internal corrosion	Metal losses	RoCorr MFL-A
Internal SCC	Cracks	RoCD EMAT-C
	Hard spots [Note 2]	RoMat-DMG
	Geom. Anomalies [Note 2]	RoGeo-XT
	Bending strain [Note 2]	RoGeo-XYZ

Note 1: Defining material population profiles will be key to proceed to sampling and fracture toughness testing [16]
Note 2: These features will increase susceptibility to SCC

Table 4: ILI technologies specific to the management of Integrity threats in CO2 service

challenges for inspections in the before mentioned products and how inspections can be realized.

ILI tool components

A main challenge for ILI in future fuels are the properties of such fuels and the impact on ILI tool materials, and the different operational conditions when running.

Commonly used types of material are described in Figure 2.

Elastomer parts, like polyurethane (PU) discs and cups, cable jackets and O-rings are usually more affected by pipeline fluids than metal parts, particularly during decompression. Fortunately this is normally only an issue at the completion of the inspection, therefore data quality is not affected, however some components may need to be replaced after each run. Another important aspect for the preparation of any ILI in hydrogen and CO2 are the high flow rates and expected survey conditions due to the fluid's density. For some technologies, the preferred tool run velocity is lower than for other technologies. In general the more stable and smooth the tool velocity is, the better the captured data quality. To allow the pipeline operator to continue operations with high flow rates during inspection, the utilization of permanent bypass or of smart speed control units (SCU) in e.g. MFL and EMAT ILI tools have proven in gas pipelines. The capabilities of the SCUs in future fuels are under review at the moment and results will be shared in future publications. The control of a batch operation (necessary for UT inspection in a gas line), which implies speed control of both sealing and inspection pigs, can therefore be very challenging if not impossible.

7. Carbon Dioxide

The particular properties of dense phase CO2 lead to additional challenges for ILI, mainly for the elastomer parts of the ILI tools. Fortunately ILI in CO2 is not a very new challenge and experience has been gathered in the last 10 to 20 years. Indeed ROSEN has inspected more than 30 CO2 pipelines with a cumulative length of over 2.800 km, thus solutions are available to overcome the challenges.

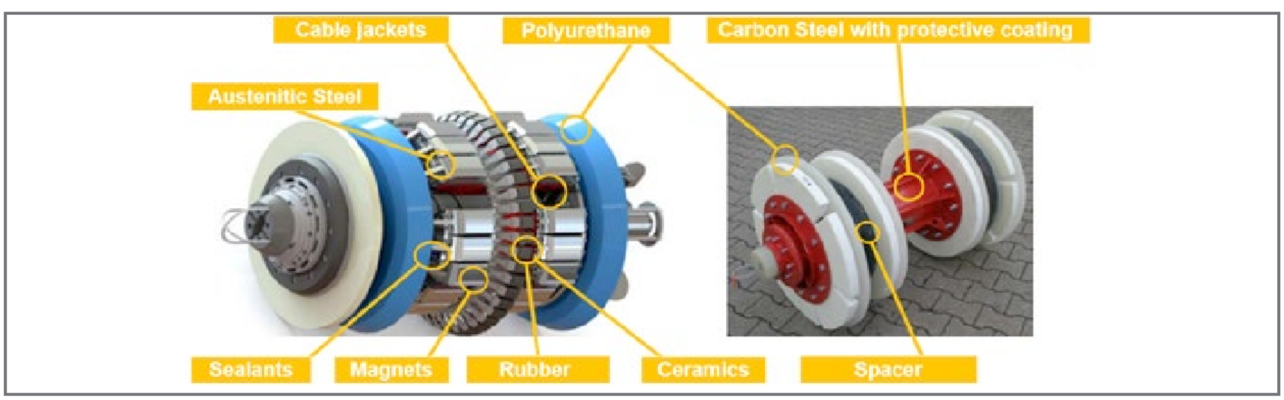

Figure 2: ROSEN Tool design - commonly used types of material

CO_2 Case Study

A 24 inch diameter and 116 km long dense phase CO_2 pipeline was inspected with a geometry and Magnetic Flux Leakage (MFL) tool in two separate runs. The pipeline was operated at 131 bar, with a launching temperature of 16° C and a very low flow rate. The inspection duration was about 180 hours. After the runs the tool conditions were assessed. The wear of the cups and discs was in a normal range and were not significantly affected after the relatively long run and long exposure time. A few hours after tool receipt plastic and rubber parts started to swell and bubbles appeared. This was a first indication of the decompression effect and of the performance of different materials. For both runs the data was recorded and collected successfully. Hence, both runs have been successfully accomplished.

8. Hydrogen

Apart from the effects that hydrogen can have on pipeline materials, it can also affect the materials within ILI tools, in particular magnets. To quantify these effects, ROSEN has conducted Hydrogen exposure tests at 100 bar, in 100% Hydrogen. The tests have verified that ROSEN tool components are resistant to Hydrogen. No visual defects were noted after the exposure test including a high decompression rate of 20 bar per minute. The functionality of sensors, cables and connectors remained unaffected. Polyurethane samples showed no loss of material properties. O-rings showed no significant changes in dimension and mechanical strength. Applied protective coating on magnets have proven successful and the magnets' properties were not affected. With the opening of ROSEN's dedicated hydrogen test facility, if new materials or components are developed, or further testing is required, this can be supported in-house.

Hydrogen Case Study

In 1996 a new 10 inch diameter and 19 km long pipeline segment was installed for the transportation of hydrogen. In 2015 the pipeline operator approached ROSEN for a method to safely inspect the line segment using hydrogen as the propellant with a combination of geometry and magnetic flux leakage technologies. Due to the harsh product, the tool was set up with non-standard cups, differing in Shore hardness. For the standard tool set up, a minimum pressure of 30 bar is typically requested. However, the operator was only able to provide a pressure of ~20 bar and a flow rate of 11 MMscfd. In order to reduce excessive velocity peaks from pressure build-up in installations while still providing enough seal to propel the tool through the line, various bypass holes and notches were applied. Finally, protective measures for the magnet circuits were taken. After the run, when the tool was received, there was no damage, and the cups showed minimal wear. While the tool did experience a few spikes in velocity, the data quality was acceptable for evaluation. The operator returned to ROSEN when it was time to re-inspect the line segment. This time the operator was able to provide a pressure of ~24 bar while maintaining the same flow rate. Once again, the cups showed minimal wear, and the tool was in good condition after the run. 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 resulting in more stable inspection conditions. The data was again at 100% sensor coverage for both the geometry and MFL portions and the data was collected and recorded successfully.

9. Conclusions

The climate emergency, existing international situation and need for decarbonisation are real. If international targets are to be met significant investments in energy efficiency, renewables, new low-carbon technologies and grid infrastructure are required. In particular, the existing pipeline infrastructure has a key role to play in enabling this energy transition. In practice this means that ageing pipelines must be converted to transport fluids very different from those they were originally designed for. A comprehensive integrity-led approach is required to maintain safety during this transition. As developed by ROSEN, this integrity framework involves a detailed understanding of the different threats inherent in different gases together with the use of appropriate inspection tools to quantify these threats. Existing knowledge and experience in low carbon gases can be applied to enable the energy transition. Specific questions still remain with respect to quantifying the effects of gaseous hydrogen on specific material properties, but there are being addressed through testing programmes in dedicated hydrogen laboratories, including ROSEN's newly developed test facility. In terms of ILI specifically, the service life and compatibility of the ILI tool parts strongly depend on the tool run conditions, the chemical composition of the fluid and the exposure time. Tool setups are optimized for typical conditions in oil and gas pipelines. Tests have been conducted with different fluids under the umbrella of future fuels. Available solutions are suitable to enable ILI in H_2, CO_2, ammonia and other future fuels. Finally, the proposed inspection technologies for pipelines transporting future fuels will need to be assessed for each pipeline within the context of an integrity framework, however it appears likely that high resolution corrosion services, crack detection services and material properties services will be required. ILI vendors will need to provide these services in the environment of future fuels.The energy transition requires a combined approach by the entire industry if it is to be safely managed. ROSEN believe that the use of an integrity framework approach combined with appropriate inspection technologies is the best way for the industry to address these challenges.

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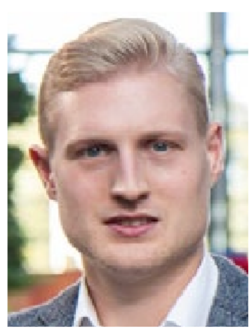

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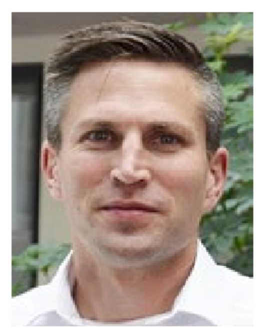

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