2/2022

Pipeline Technology Journal

Decarbonization & Hydrogen

What's your purpose? Reusing gas infrastructure for Hydrogen transportation and storage!

Energy Transition And The Impact On Pipeline Integrity

Methane Emissions Reduction System in Pipeline Compressor Stations: ENAGAS & BAKER HUGHES Experience

Considering leak detection systems for carbon capture and storage (CCS)

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PTJ – Your Quality Pipeline Journal

Dr. Michael Beller
Chairman of the Editorial Board

Welcome to this latest edition of the Pipeline Technology Journal with a special focus on topics around decarbonization and hydrogen!

But before we dive into the interesting and important articles of this issue, let me spend a little time on the Journal itself.

It is a privilege and honour to have the opportunity to address you as the Chairman of the Editorial Board. Our team, made up of the members of the board, is excited to be involved with the Pipeline Technology Journal which is now in its 9th year of publication and reaching 20,000 readers around the globe.

The e-journal and the printed version are published quarterly, and each issue has a special focus regarding the topics and content of the articles included. Whilst our sister publication, the ptj-Newsletter covers news and up-to-date information, the Journal provides in-depth technical articles. On the one hand, the Journal makes use of the high-quality papers presented at the annual Pipeline Technology Conference, but on the other hand it is also open for contributions entered directly. To ensure the quality the publisher and the editorial board are aiming for, articles are reviewed.

Our vision and aim are to compile a pipeline technical journal for our readership which is of interest for you and adds value by enabling the dissemination of information. In order to achieve our goals, we would also like to reach out to you and ask for your feedback. Are we covering all the right topics around pipelines you are interested in? Is something missing? Please let us know! Your feedback and input is highly appreciated and will help us to continuously improve our effort. Thank You!

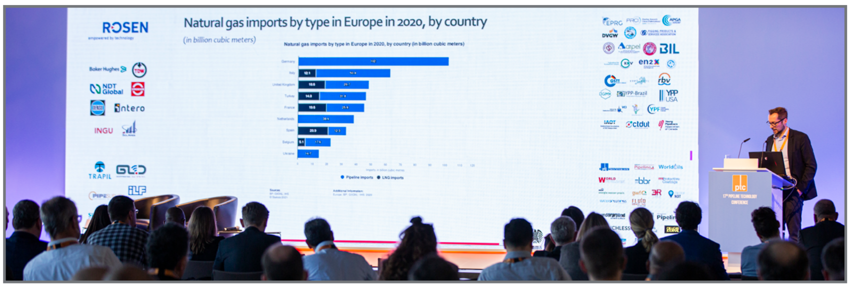
But now on to this issue. Climate Change is one of the major concerns of our time. In order to protect Earth, the planet we all live on, emissions must be reduced. Decarbonization and the use of future fuels is therefore of paramount importance. Unfortunately, recent events have also re-emphasized the importance of security of supply.

This issue of the Journal includes a number of highly interesting papers addressing a wide range of topics related to decarbonization and the transportation of future fuels.

The papers provide insight into a very broad scope of themes regarding the pressurized pipe itself and essential components such as valves.

Yours sincerely,
Dr. Michael Beller, Chairman of the Editorial Board

This Issue's
COMPLETE CONTENT


ROSEN
Natural gas imports by type in Europe in 2020, by country

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17TH PIPELINE TECHNOLOGY CONFERENCE
7 - 10 MARCH 2022, BERLIN, GERMANY
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nports by type in Europe in 2020, by country
Natural gas imports by type in Europe in 2020, by country (in billion cubic meters)
Germany
Italy
United Kingdom
Turkey
France
Netherlands
Spain
Belgium
Ukraine
102
12.1
50.8
18.6
29.7
14.8
31.8
19.6
25.8
38.4
20.9
12.3
5.1
17.6
14.7
Imports in billion cubic metres
Pipeline imports
LNG imports
Sources
Additional Information:
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VCI
YPF
IAOT
ctdut
Young Pipeliners Association of Canada
Pipeline
WorldOils
WORLD
bbr
Protective Coatings
energie | wasser-praxis
gwf
3R
NDT
WATERSOLUTIONS
FLUID
underground
Pipelin
CHLESS

International pipeline community met in Berlin for ptc 2022

Designed as a hybrid event, the 17th Pipeline Technology Conference and its exhibition attracted 659 participants from 49 different countries, including delegates from 62 pipeline operators and 53 exhibiting companies.

After two years of ptc Remote, hundreds of industry professionals – representatives of operators, technology and service providers, researchers, public services – were finally able to meet again directly in Berlin. They demonstrated from 7-10 March 2022 latest achievements, developments, and offerings in the industry, thereby consolidating the status of the ptc as one of the most prestigious international meeting places for exchange in the pipeline industry.

Reacting to Russia's attacks on Ukraine, the keynote speech given by Bengt Bergt, member of the Committee for Climate Protection and Energy of the German Bundestag, was dedicated to the topic "Security of Energy Supply in Times of Crisis: Short-Term Measures and Long-Term Implications" and gave insights into the current plans in German energy policy.

The program of the 17th Pipeline Technology Conference was enriched with its panel discussions which covered current challenges of the industry: cyber security, decarbonization, the issues of public perception and the shortage of skilled workers. Another important panel discussion covered the consumer point of view, where specialists from thyssenkrupp, Evonik, Nikola and en2x discussed future perspectives for pipeline-based infrastructures. However, the core of the conference was again the technical sessions with more than 100 different presentations.

Accompanying the conference, as always, was the ptc Exhibition with 53 exhibitors presenting their latest products and developments and inviting people to talk to them. The exhibition hall was the central meeting point for all participants with plenty of opportunities to talk, get to know each other and exchange ideas.

The 18th Pipeline Technology Conference and Exhibition will be held in Berlin from May 8-11, 2023.

**More news from the ptj newsletter:
www.pipeline-journal.net/news**

What's your purpose? Reusing gas infrastructure for Hydrogen transportation and storage!

W. MEESTER > INTERO INTEGRITY

Abstract

Existing gas infrastructure plays an essential and important role in today's energy transition for the transport and storage of Hydrogen. Studies show, natural gas infrastructure can be economically utilized for the transport and cavern storage of Hydrogen in future decarbonized energy systems. Repurposing existing pipelines and underground storage infrastructure is very cost-efficient and can keep future energy prices low and affordable.

Intero Integrity, as a global service provider, help infrastructure owners overcome the challenges they face with their infrastructure transformation journey. We have developed and utilized innovative mechanical and chemical cleaning technologies to improve the cleaning operations of oil and gas pipelines and accompanying process systems for reuse purposes.

Pipelines by definition are all unique. Therefore, we deliver customized solutions gained through deeper insights. In close consultation with the Client a cleaning program will be engineered in the most cost effective way and tailored to their current needs.

Our new products are highly concentrated blends of biodegradable surfactants and synthetic solvents capable of wetting and removing the most tenacious deposits encountered in oil and gas pipelines. The majority of the products used by Intero are environmentally friendly and biodegradable, this will minimize the cost for waste disposal. For our Clients these products provide a cost effective and easy-to-use approach to pipeline and system cleaning.

Our extensive service portfolio enables us to bundle our services into a unique single-contractor turnkey solution contributing to efficient and safe project execution. Intero Integrity is able to support asset owners build a strategic future-ready infrastructure based on their priorities and opportunities.

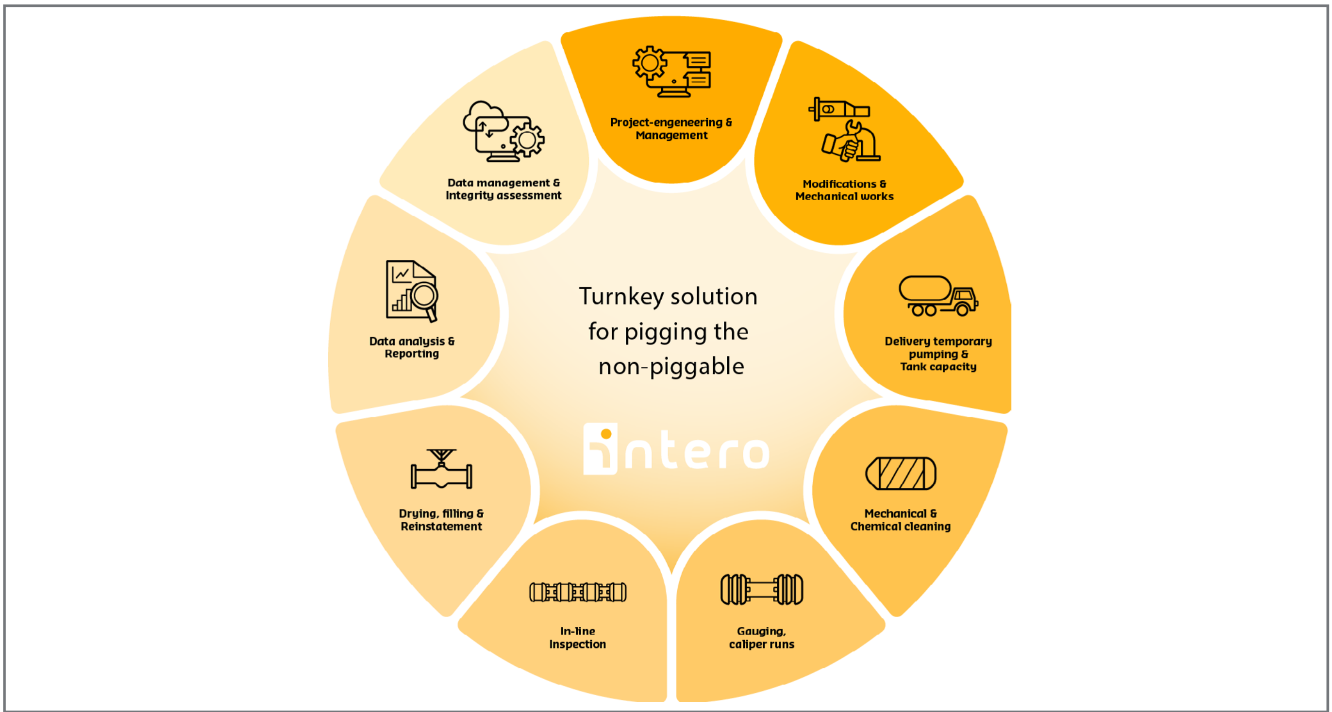

Figure 1: Turnkey solution for pigging the non-piggable

1. Introduction

There are many different reasons for cleaning pipelines for example for maintenance projects, production increase, abandonment, repurposing and for internal inspections. The most known cleaning methods used in the pipeline industry are: high pressure jetting, air blowing, flushing, sand jetting, chemical solvents and pigging. Determination of the optimal cleaning procedure depends on the product, type and amount of pollution and many more factors.

The pipeline history will give important information on the type and amount of pollution. It is of great importance to know if any previous cleaning or inspection programs have been performed in the past and which type of cleaning pigs have been used. Past cleaning runs, year of construction, information from pipeline operators, product samples can help to determine the cleanliness status of a pipeline. Important is also if recent modifications have been made on the pipeline. Modifications made on pipelines could indicate areas which are replaced by new pipe or supply information on the internal conditions of the pipeline. Most of the information is often difficult to find as pipeline owners often have not stored the information as they do not see its relevance.

With the expected type of pollution, flow rate and history and the size and length of the pipeline the amount of pollution can be estimated. The total amount of pollution determines the sequence of cleaning pigs and the number of cleaning runs. In case of high amounts of pollution precautions can be taken beforehand to overcome any delays and problems during the cleaning operation.

2. The Cleaning Process

The cleaning process assures the removal of contaminants such as dirt, water, filings, weld spatter or other foreign material from the interior of the pipeline system. This level of cleanliness is often referred to as 'commercially clean'. Contractual requirements or client specifications may require a more stringent cleaning process.

With the available information received from the client the cleaning program will be determined in the most cost effective way. If a more detailed proposal and a higher quality cleaning standard is needed the program can be evaluated and adjusted in close consultation with the end client (TSO).

In addition to the standard cleaning methods, Intero Integrity Services offers a broad range of chemical

Figure 2: Intero Chemical Cleaning Unit

cleaning services for the pipeline and process systems. Chemical cleaning is typically used to remove deposits like scale, corrosion, waxes, paraffin and asphaltene sediments in pipelines. The use of solvents and/or surfactant based cleaning chemicals are more effective than mechanical cleaning using only cleaning pigs. Chemical cleaning is widely used for commissioning , de-commissioning and repurposing of pipelines and process plants, to increase productivity (throughput) and efficiency, to improve inspection results and to maintain the quality of the product.

Chemical cleaning in conjunction with the mechanical action of pigging, greatly increases the effectiveness of the cleaning operation. Although not suitable for every problem, we have found that 'combined' chemical and pig cleaning operations for pipeline operators can solve many problems which mechanical pigging on its own could not.

In order to find out which cleaning method will have the best results debris samples of the various pipeline sections are analyzed and the type of pollution determined. On the basis of these analysis results it was confirmed that mechanical cleaning using brush/magnet pigs in combination with cleaning chemicals is the most effective method for the application to the referred pipeline sections.

The basic procedure for the cleaning of the pipelines is to run a number medium density brush pigs followed by pumping a pig-train with batches of detergent at pre-calculated concentrations and speed. BiDi brush and magnet pigs should be incorporated in the batches and propelled with Gaseous Nitrogen to minimise the volume of chemical waste. The batches should be followed by a water flush separated by BiDi pigs after which the drying can commence.

In drying with Nitrogen, soft foam pigs pushed by Nitrogen are used to absorb any free water remaining in the pipeline after the water flush batch. Dew-point reading will need to be made to determine when the line has been dried to the specified dew point. It will be necessary to give special consideration to laterals, by-passes, and valve body cavities as any free water trapped here could affect the final dew point readings.

During the cleaning program the used cleaning pigs and the amount of pollution removed by the cleaning pigs will be examined. According to the results of these examinations the cleaning program can be altered by changing the type of cleaning pigs and or by changing the cleaning pigging sequence. The type of chemical(s), the strength, contact time and overall procedure will be determined by the particular circumstances and will differ from one situation and/or pipeline section to the next.

Intero Integrity Services is utilizing new chemical cleaning technologies to improve the cleaning operations of oil and gas pipelines and process systems. The new products are highly concentrated blends of biodegradable surfactants and synthetic solvents capable of wetting and removing the most tenacious deposits encountered in oil and gas pipelines. The majority of the products used by Intero Integrity Services are environmentally friendly and biodegradable, this will minimize the cost for waste disposal.

3. The Scope Of Work

A typical pipeline cleaning scope of work can be summarized as follows:

- Project management and engineering
- Providing all relevant project documentation
- Participation in HAZID/HAZOP for all activities
- Supply and installation of all required equipment and materials
- Cleaning of the pipeline sections
- Drying the pipeline sections with gaseous Nitrogen
- Preparation of close out documentation (daily logs, final report)

To clean and dry the pipelines, the first step will be mechanical cleaning with brush pigs and a BiDi magnet. The mechanical cleaning will remove loose organic contamination.

After all the loose organic materials are removed Step 2 should commence. This step is preparing and running the chemical cleaning train. The purpose of this run is to remove grease, oil, organic contamination and to prepare the inner pipeline for Step 4. The complete chemical cleaning train will be received in buffer containers at the receiver side. The cleaning train will be propelled by gaseous Nitrogen.

The batch of Step 3 contains flushing water to remove the residual chemicals. All the flushing water will be collected in the buffer containers. These water batches will also be propelled with gaseous Nitrogen. Step 4 is to prepare and run the pickling (removing grease) train. The water with chemicals will be transferred through the pipeline by sending a BiDi pig train propelled by gaseous nitrogen.

After the pipeline is free from water, a soft foam pig train will be transferred through the pipeline to absorb any free water remaining in the pipeline after the water flush batch. Dew-point readings will need to be made to determine when the line has been dried to the specified dew point. It will be necessary to give special consideration to laterals, by-passes, and valve body cavities as any free water trapped here could affect the final dew point readings. Finally the residual gaseous Nitrogen will remain in the pipeline to create an Oxygen free atmosphere to avoid oxidation.

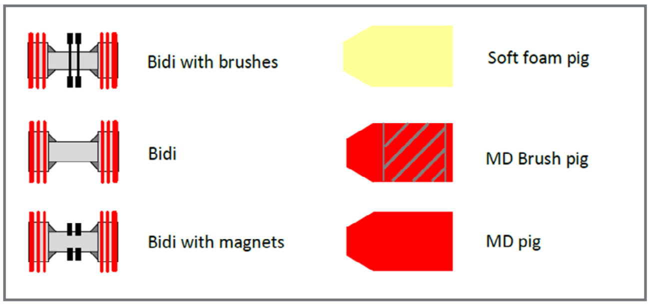

Figure 3: Overview of pig types

Before the cleaning operation can start Intero Integrity Services will install the required temporary equipment. During the site visit the route of the hoses/piping is discussed and agreed. Intero will install and connect the temporary storage tanks, water manifold, water and chemical pumping equipment and the Nitrogen spread. As an optional service Intero is able to supply temporary pig launcher(s)/receiver(s) if needed.

Step 1: Mechanical cleaning to remove loose particles like sand, stones and corrosion (Figure 4).

After arrival of the first cleaning run, analyse the amount of debris inside the receiver and storage tank. If due to the amount of debris an additional cleaning run is required repeat Step 1 until the result of the cleaning is satisfied.

Step 2: Chemical cleaning to remove oil, grease and organic contamination (Figure 5).

Step 3: Flushing with clean water until pH neutral (Figrue 6).

Step 4: Pickling and conservation to protect the pipeline for future use (Figure 7).

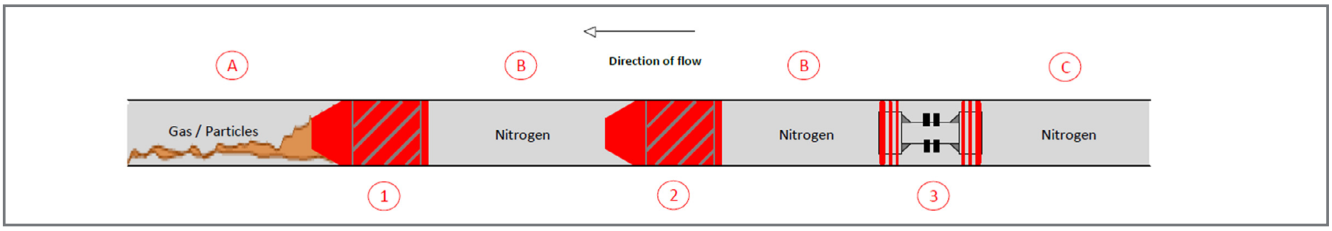

Figure 4: Mechanical cleaning to remove loose particles

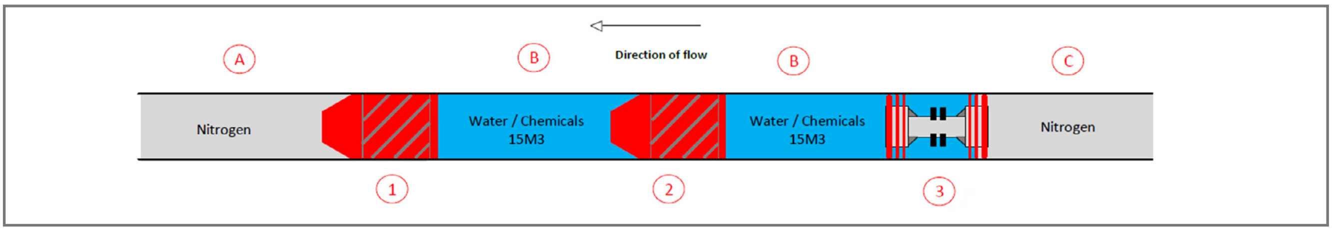

Figure 5: Chemical cleaning to remove oil, grease and organic contamination

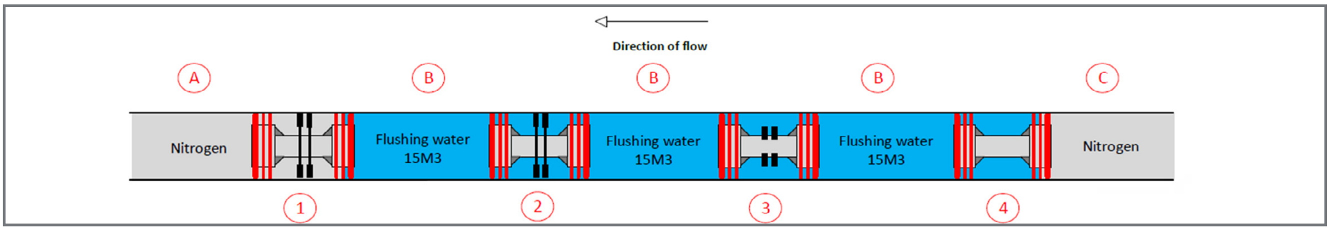

Figure 6: Flushing with clean water until pH neutral

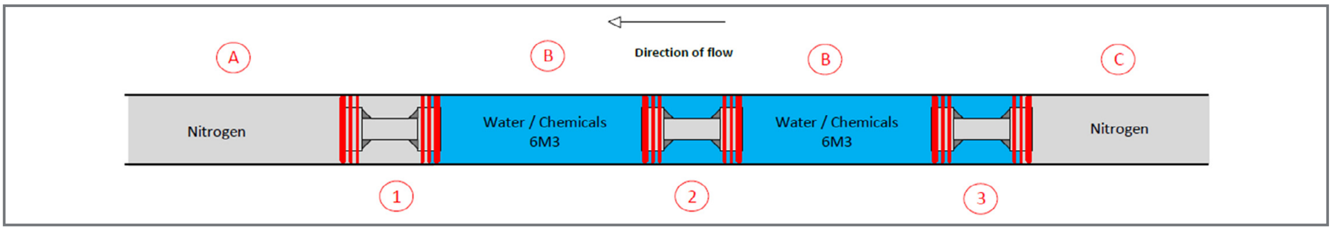

Figure 7: Pickling and conservation to protect the pipeline for future use

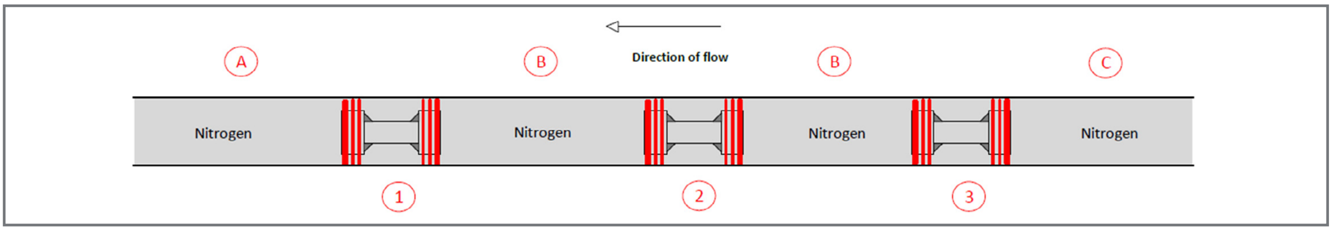

Figure 8: Displacement of the pipeline

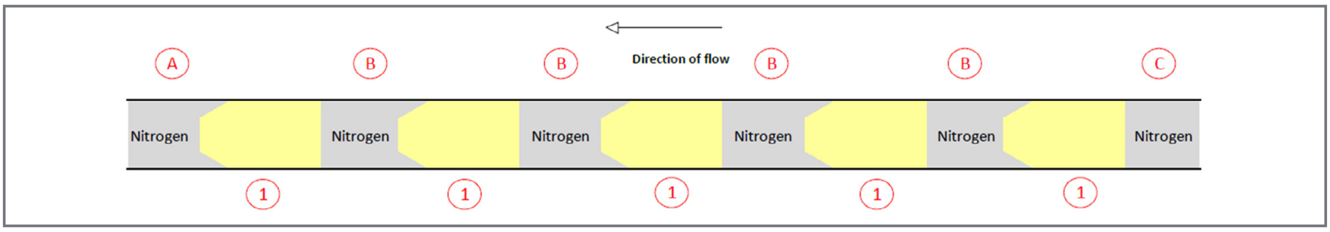

Figure 9: Drying of the pipeline

After Step 4 is performed the cleaning steps are completed and the pipeline displacement will commence. To clear the pipeline from 'free' water a BiDi train will be launched.

Step 5: Displacement of the pipeline (Figure 8).

Step 6: Drying of the pipeline (Figure 9).

4. Preserving

After the pipeline is dry and the dew point is accepted by the client, the pipeline will be free from oxygen and left at 1 – 2 bar(g) Nitrogen pressure. The inert atmosphere will prevent corrosion and prevents oxidation inside the pipeline.

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Enhancing the Availability of Oil Network using Focused Reliability Assessment of Critical Valves

DR. K.A. AL-JABR, DR. Q. AHMED, Z.A. AL-SUBAI, DR. D.M. AL-ANAZI > SAUDI ARAMCO

Abstract

The Reliability Focused Analysis Technique is a method of analysis that can be used to evaluate reliability for a specific system, and addresses availability and maintainability related issues. This approach is based on holistic reliability and evaluation and analysis of maintenance data, which involves reviewing maintenance strategies, system capacity to identify operational and maintenance gaps, and recommending and resolving chronic and critical issues.

A case study was conducted by using this technique to improve reliability and availability of critical valves in the Saudi Aramco Oil and Gas Supply Network. These valves are classified based on their criticality and failure consequences. A comprehensive reliability assessment was conducted for the top critical valves in the pipeline network. It addressed the chronic problems by validating the equipment criticality categorization, reviewing their maintenance strategies, analyzing valve data and failures modes, and identifying bad actor items and common failures. The reliability and maintenance data were benchmarked with other industry databases such as OREDA.

The implementation for the addressed recommendations of the Valve Reliability Assessment has improved the reliability for top critical valves by 10% and reduced their emergency maintenance cost by 43%. The study supported concerned organizations with developing the pipeline valves Reliability & Maintenance Databank, and selecting the appropriate valve types during the design stage.

1. Introduction

Saudi Aramco has the largest cross-country pipeline network for transporting the Kingdom's hydrocarbons with the highest standards of safety, reliability, efficiency and environmental responsibility by applying innovative methods and state-of-the-art technologies. Saudi Aramco runs the huge network of pipelines and valves with different sizes, applications and designs.

Figure 1: Saudi Aramco Pipelines

In general, all pipeline valves at Saudi Aramco are governed either by API 6D or other standards and specifications recommended by ASME B31.4 and ASME B31.8 codes, including ball, gate, plug and other types of valves. The most common types of valves found in the Saudi Aramco pipeline network are ball, gate and plug.

This paper covers technical issues for more than 6,500 valves and scraper doors representing 51% of the department total assets subject to this study. These items of equipment are considered some of the major components of any pipeline network and are essential assets needed to safely operate and maintain the pipeline network. As a focus review, a comprehensive reliability assessment was conducted for the top critical valves in the pipeline network.

This review was conducted by using the Reliability Focused Analysis Technique, which is an analysis that can evaluate reliability and availability for a specific system and addresses operational and maintenance related issues to improve reliability and availability for critical valves in the Saudi Aramco Oil and Gas Supply Network. The review addressed chronic problems by validating the equipment criticality categorization, reviewing their maintenance strategies, analyzing valve data and failures modes, and identifying bad actor items and common failures. The reliability and maintenance data were benchmarked with other industry database such as Offshore & Onshore Reliability Data Handbook (OREDA). As a result of implementing the outcome recommendations, the reliability of the critical valves subject to this study has improved by 8-10% and reduced emergency maintenance cost by 43% (from 70% to 40% of the total maintenance work orders).

Reviewing reliability elements is a critical element of any reliability study. It measures the impact of each component, which is a part of the overall system reliability. In this study, valves are one of the main components in the pipeline network and play a critical role in this system. Failure of a valve in a hydrocarbon network may cause a reduction in availability and reliability downstream of the failure location, and may create major incidents in the form of hydrocarbon releases, fire and/or explosions. Therefore, addressing the reliability of valves is very important and a useful tool for improving the reliability of hydrocarbon pipeline networks. A criticality assessment was carried out to identify the criticality of the valves for further study.

The remainder of the paper is structured as follows: Section 2 covers the assessment strategy to suggest how to utilize the available data. This section includes an equipment criticality assessment and use of equipment master data. Section 3 covers the reliability analysis based on the different criteria to cover all the critical assets. Section 4 explores the results and recommendations based on the analysis performed. Finally, conclusions are discussed in Section 5 of the paper.

2. Assessment Strategy:

2.1 Equipment Criticality Assessment

The equipment criticality assessment process constitutes the indicator that allows evaluating asset reliability impact and consequences on the overall business performance. A team used the four criticality criteria (failures, importance, reliability and utilization), which are defined in the Saudi Aramco Asset Criticality Assessment Best Practice. The Equipment Criticality Assessment (ECA) for all pipeline valves was conducted and classified the pipeline valves into three categories as described in Table 1. As a result of this assessment, it was recommended to consider the top two types of the critical valves as Class A in this study. They

Category	Meaning	Definition
A	Critical	A failure would lead to immediate safety or production loss
B	Important	A failure might lead to immediate safety or production loss
C	Normal	A failure would have no impact on safety or production

Table 1: Superiority of coextruded Tapes

Area #	Class 1		Isolation		Total	
Area 1	28	5%	84	14%	112	19%
Area 2	38	6%	112	19%	150	26%
Area 3	27	5%	29	5%	56	10%
Area 4	30	5%	84	14%	114	19%
Area 5	2	0%	25	4%	27	5%
Area 6	63	11%	65	11%	128	22%

Table 2: Critical Valves Distribution Based on Area

represent 9.0 % of the total valves, namely, Class I and trap isolation valves. Based on the data, there are 188 (2.9% of total and 32% of top critical) Class I calves and 399 trap isolation valves (6.1% of total and 68% of top critical) out of 6500 valves are under consideration in the study.

2.2 2.2 Reviewing Valves Operational & Maintenance Master Data

The data utilized in this study were provided by the specific facility after they were extracted from maintenance work orders in the SAP system. Also, more data were collected during multiple workshops with subject matter experts of pipeline management members, engineers, operators, valve technicians, instrument technicians and electrical technicians. Through these workshops, recent failures was discussed with reference to the critical valve databank, with major challenges associated with operating and maintaining pipeline valves.

The following table (Table 2) categorizes the valves based on allocated areas and recent valve criticality assessments. It describes the distribution for the critical valves in a facility based on the maintenance unit area. Indeed, the highest number of critical valves is located in Area 2 by 26%, followed by Area 6 (22%), then Areas 1 and 3 (19%). Area 4 has around 10% of the top critical valves while Area 5 has the lowest number of critical valves (5%). Around 19% of critical valves are trap isolation valves (112 valves) in Area 2. Then isolation valves in Areas 1 and 4 (around 14% for each). For the same valves, another classification was used to determine the services of the valves, which are oil, gas and product, as described in Figure 2. It shows that 60% of critical valves are used for gas services, 38% for oil services and 1% for the products while 1% of the critical valves weren't classified in SAP.

There are four types of actuator used to operate valves: Gas operated valves (GOVs), motor operated valves (MOVs), hydraulic operated valves (HOVs), and solar operated valves (SOVs). The type of actuators for the critical valves are shown in Figure 3. As can be seen, most of them are MOVs (47%) while there are 171 valve actuators (29%) unclassified in SAP. GOVs are represeted by 14% the top critical valves, and followed by SOVs (7%) and HOVs (2%).

To adress valve maintenance strategies, there are four major avenues that can be explored and applied to arrive at a suitable maintenance strategy for equipment and components. They can be summarized as follows: Unplanned Strategy: (Reactive Maintenance) and Planned Strategy: (Preventive Maintenance, Predictive Maintenance & Proactive Maintenance).

At Saudi Aramco, we are measuring the overall concept of the right mix, which is to minimize reactive (fix on failure) to be less than 15% of the total effort, and use the majority of time (in excess of 65%) on condition based activities where the health of

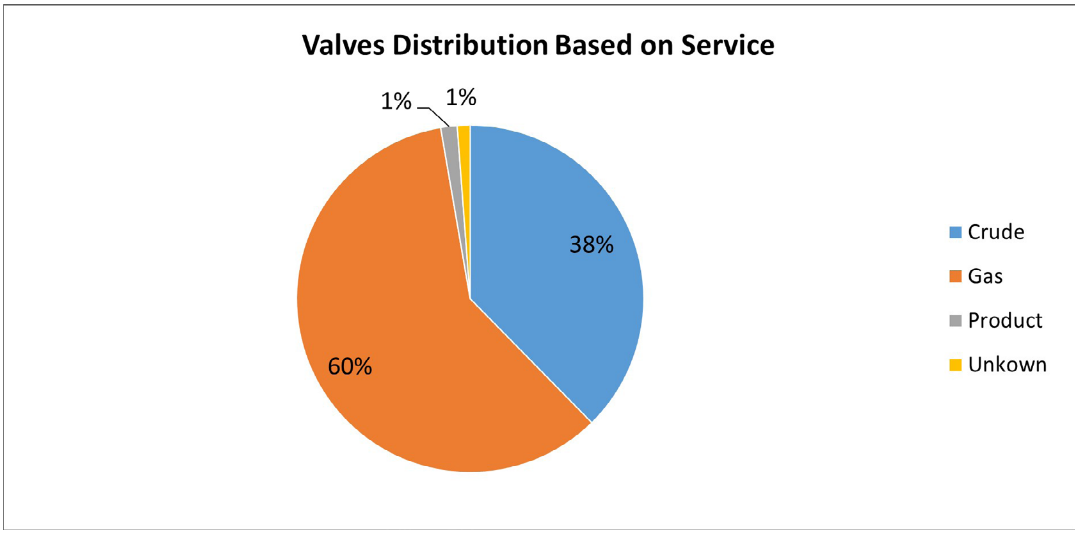
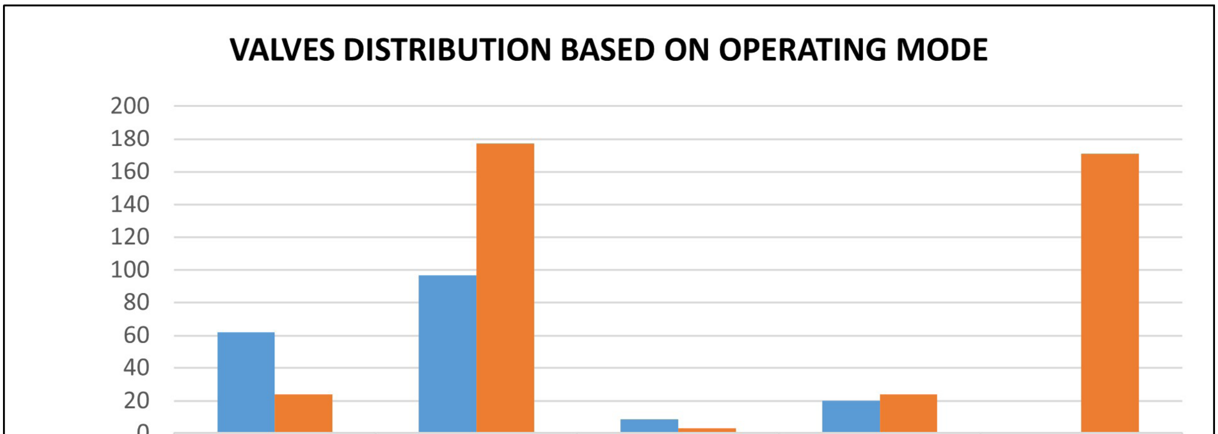


Figure 2 : Critical Valves Distribution Based on Services

equipment is monitored and problems are caught and fixed early on – thereby avoiding catastrophic failure and impacts on production or safety. The time-based preventive maintenance is recognized for its importance but should not consume more than 20% of the overall maintenance effort. Figure 4 illustrates the top critical valves, which are covered by the Preventative Maintenance (PM) Program. It shows that 75% of the critical valves are under the Preventative Maintenance Program while the remaining 25% are working without any preventative maintenance tasks as per the recent valve criticality assessment. This data also shows that all critical valves, which are without the PM program, are trap isolation valves.

3. Discussion and Analysis:

Dependability, or reliability, describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability is closely related to availability, which is typically described as the ability of a component or system to function at a specified moment or interval of time. In general, reliability is theoretically defined as the probability of success or availability. In summary, reliability engineering deals with the estimation, prevention and management of high levels of "lifetime" engineering uncertainty and risks of failure. This section discusses reliability analysis for valves based on the available maintenance data in SAP. Indeed, several elements



	GOV	MOV	HOV	SOV	Unclassified
Class I	62	97	9	20	0
Isolation	24	177	3	24	171

Figure 3: Critical Valves Distribution Based on Operating Modes

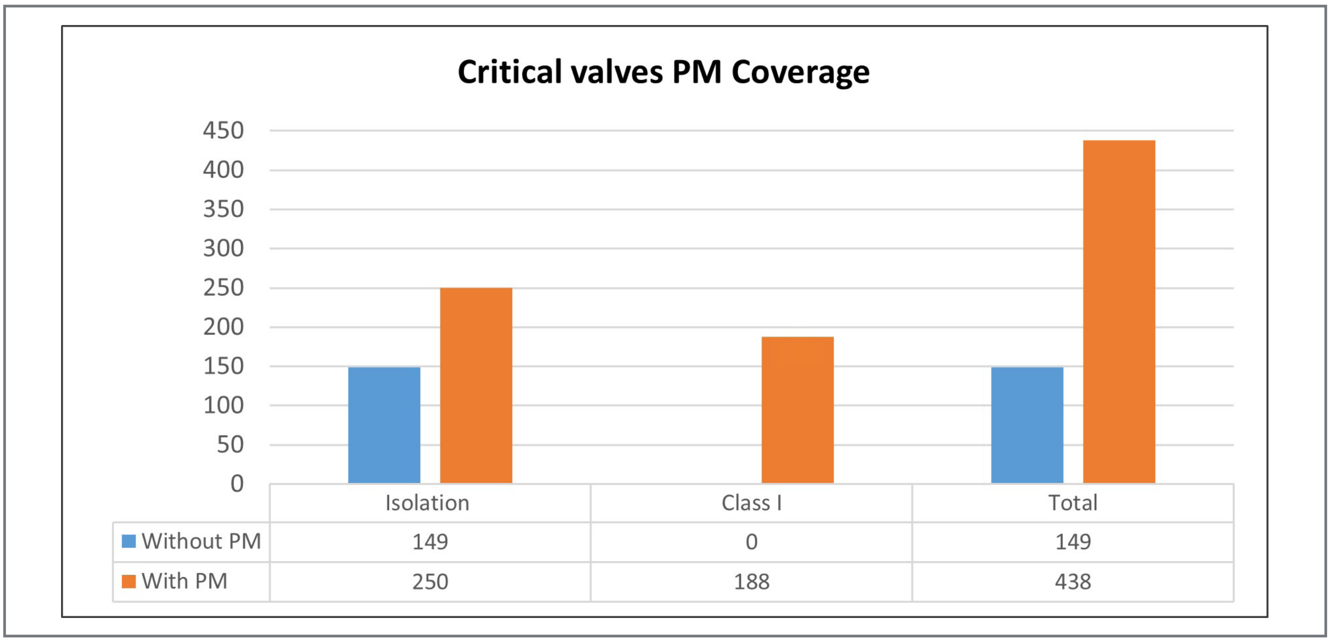


Figure 4: Critical Valves PM Coverage

over time have been developed to determine reliability, but we will discuss the major ones such as: Mean time between failure (MTBF), mean time to repair (MTTR), failure rate (FR), failure mode (FM), bad actor item and some analyses for the provided failure data. The collected data was filtered for Department A to be utilized for their different purposes such as investigation, support projects and other applications, and it can support central engineering to create databank for pipeline departments. As a summary of the data, there were 28 failures reported as M2 Notifications for Class I Valves and 96 failures for trap isolation valves in year 2017 (the total is 114 failures were occurred for the top critical valves).

3.1 Reliability Analysis for Class I Valves:

The data was analyzed and utilized to estimate and predict reliability key performance indicators (KPIs) for Class I critical valves as shown in the following figures in this section. Figure 5 represents the distribution for the failed Class I critical valves based on their service. It shows that 21% of the Class I valves that failed are in the crude oil service while 12% and 12.5% of them failed in the gas and product services, respectively. It

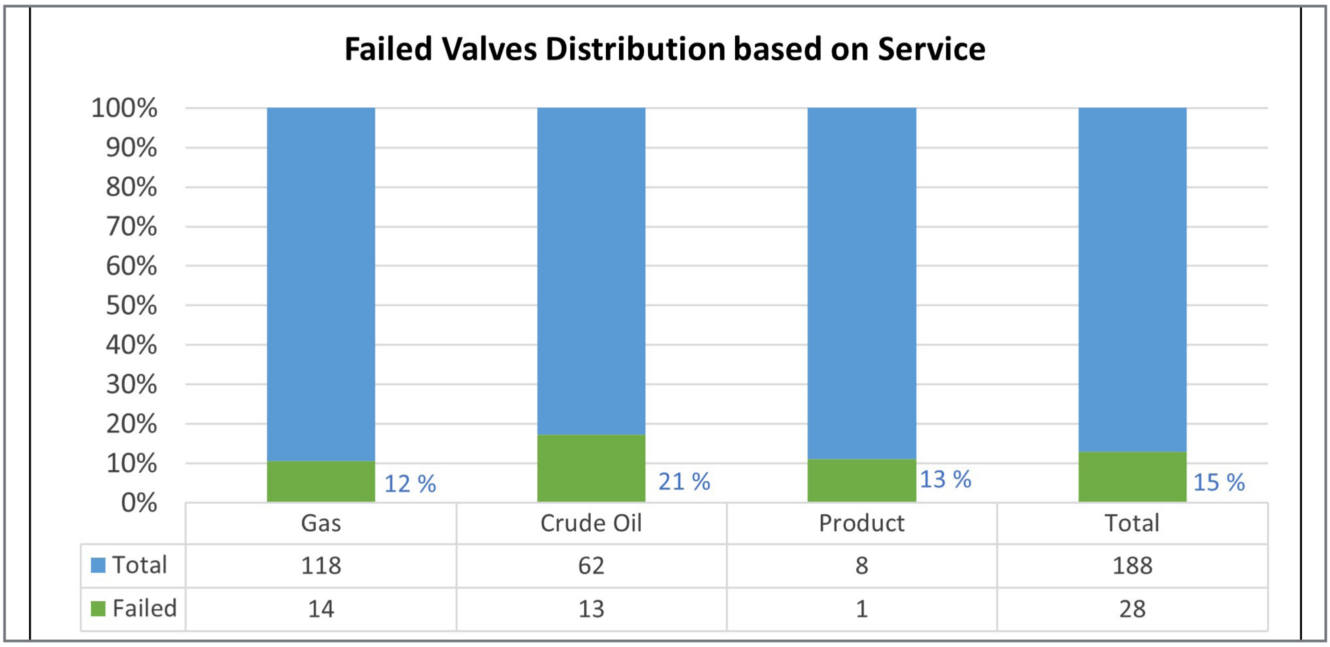


Figure 5: Failed Class I Valves Distribution based on Service

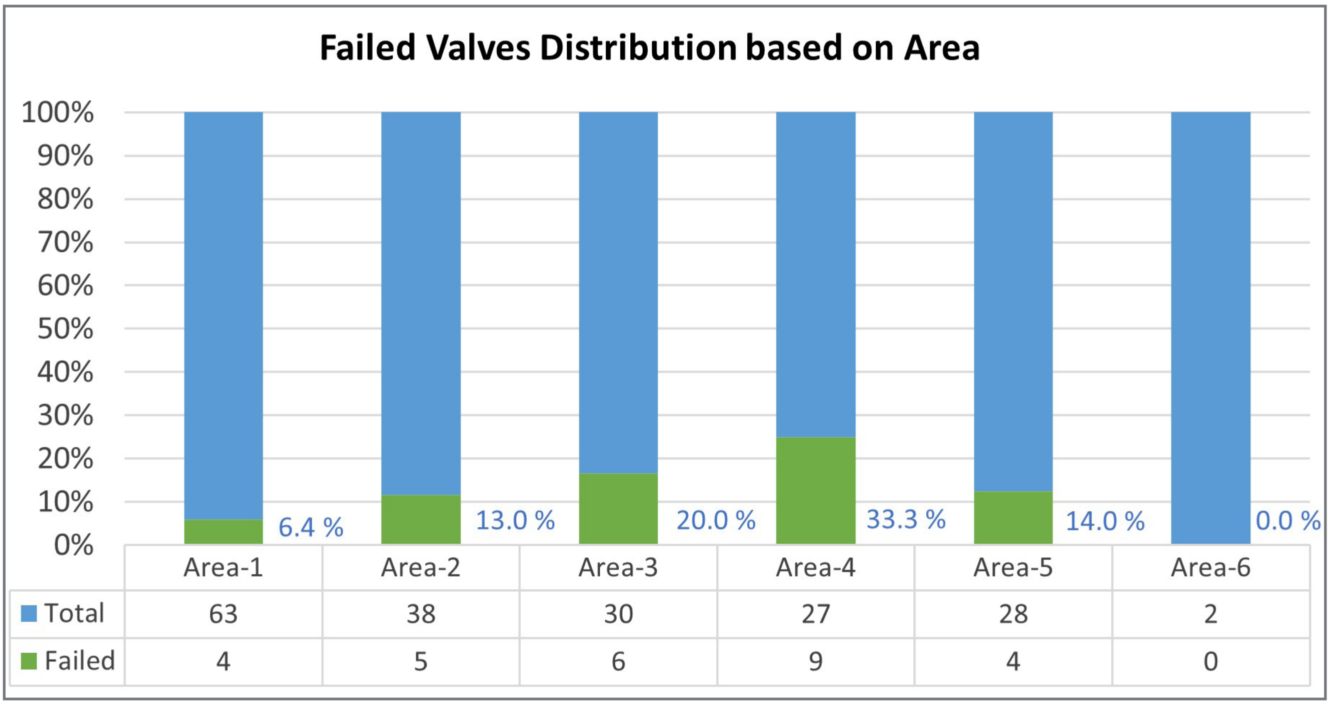


Figure 6: Failed Class-I Valves Distribution based on Area

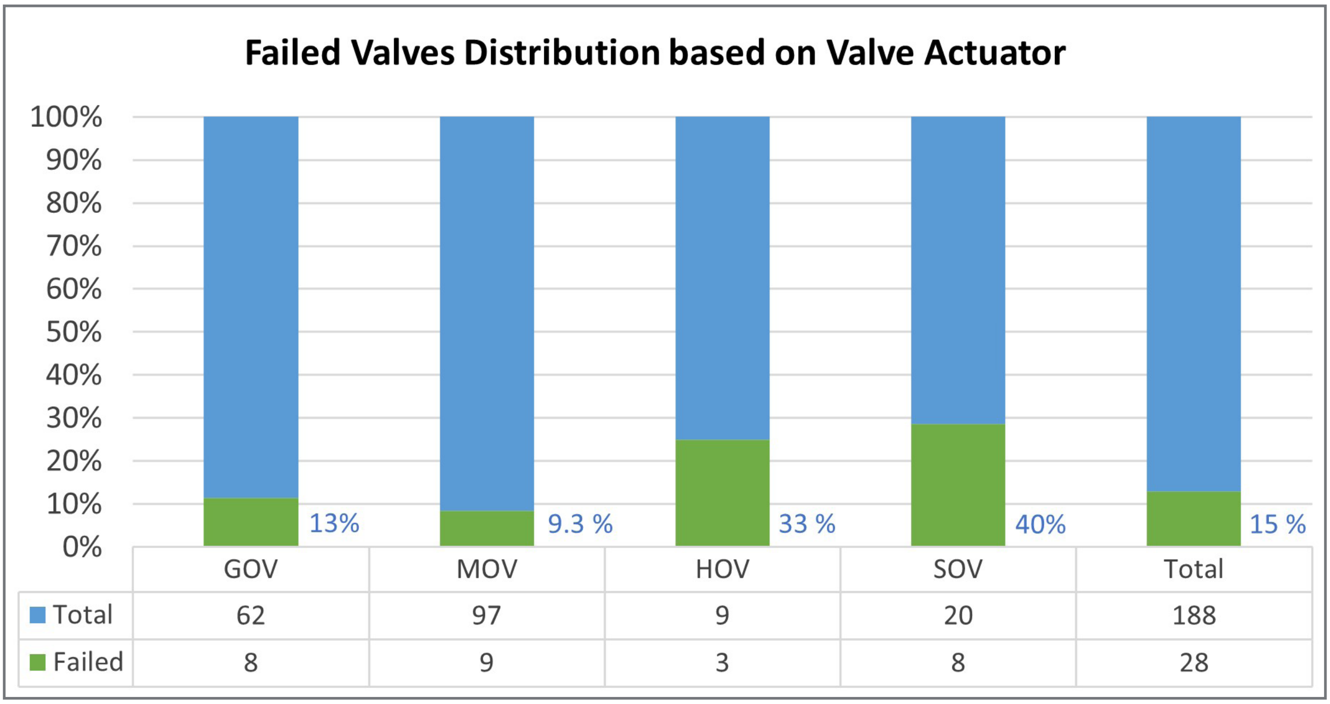


Figure 7: Failed Class-I Valves Distribution based on Valve Actuator

means that the critical valves in crude oil services need more attention than other services.

The distribution for failed Class I valves based on valve area is described in Figure 6. It shows that Area 4 has the top failures of Class I Valves with 33% (9 valves) followed by Area 3 with 20%. Both Areas 2 and 5 are close to the average of Class I valves failures. It was also observed that Area 1 historically shows a very low frequency of failures based on the analyzed data. Also, Area 6 is doing very well but with a small number of samples from just two valves. Figure 7 is representing distribution for the failed Class I valves based on the valve actuator. It shows that the SOVs have the highest

Area	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Total
Total number	63	38	30	27	28	2	188
Failures (#)	4	5	6	9	4	0	28
%	6.25	13.16	20.00	33.33	14.29	0.00	14.81
MOV (#)	3	2	3	0	1	0	9.00
%	75.00	40.00	50.00	0.00	25.00	0.00	32.14
SOV (#)	0	0	0	8	0	0	8.00
%	0.00	0.00	0.00	88.89	0.00	0.00	28.57
GOV (#)	0	2	3	0	3	0	8.00
%	0.00	40.00	50.00	0.00	75.00	0.00	28.57
HOV (#)	1	1	0	1	0	0	3.00
%	25.00	20.00	0.00	11.11	0.00	0.00	10.71
Unclassified (#)	0	0	0	0	0	0	0.00
%	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3: Bad Actor List for Class I Valves

percentage of failures at around 40%, followed by HOVs with 33%. It is an unacceptable ratio compared with MOVs, which have just 9.3% of failures. It is below the average.

3.2 Bad Actor Items for Class I Critical Valves (80/20 Rule):

From the previous figures (5-7), we can conclude that this analysis can provide a clear picture for reliability engineers to conduct the root cause analysis for common failures in each area. For example, Area 4 has eight (8) critical Class I valves, which failed in 2017, representing 29% of all failed Class-I valves in Department A. All of them were operated by SOVs. This means that 100% of the failures for SOVs were due to the valves in Area 4. Thus, we can say that SOVs are bad actor items for Area 4 (refer to Table 3). If the reliability efforts will be invested in this item, the number of failures will be minimized and maintenance costs will be reduced. Thus, the modified PM should be utilized for those valves to switch from reactive to proactive modes and their spare parts should be available to reduce its MTTR and enhance their reliability.

3.3 Bad Actor Items for Trap Isolation Critical Valves (80/20 Rule):

By using the same previous analysis, with the trap isolation valve filtered database (Table 4), we can conclude that Area 2 has 112 critical trap isolation valves and 26 valves failed. As a drill down, we found 71% of

Area	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Total
Total number	65	112	84	29	84	25	399
Failures (#)	16	26	15	12	18	8	96
%	24.62	23.21	17.86	41.38	21.43	32.00	24.06
MOV (#)	9	19	8	3	9	6	54
%	56.25	73.08	53.33	25.00	50.00	75.00	30.51
SOV (#)	2	2	1	5	1	0	11
%	12.50	7.69	6.67	41.67	5.56	0.00	45.83
GOV (#)	0	0	2	2	3	0	7
%	0.00	0.00	13.33	16.67	16.67	0.00	29.17
HOV (#)	0	0	1	0	0	1	2
%	0.00	0.00	6.67	0.00	0.00	12.50	66.67
Unclassified (#)	5	5	3	2	5	1	21
%	31.25	19.23	20.00	16.67	27.78	12.50	21.88

Table 4: Bad Actor List for Trap Isolation Valves

these valves (19 valves out of 26 failed valves in Area 2), which are operated by MOVs, failed. Also, the failed valves in Area 2 are representing by 35% of all MOVs.

The failures of MOVs in both Area 1, 3, and 5 represent 48% of the failed MOVs in Department A. Thus, we can say that MOVs in Area 2 are bad actor items. The MOVs in Areas 1, 3 and 5 will be come as a second bad actor items. Thirdly, switching from reactive to proactive modes, by utilizing the modified PM procedures and keeping spare parts in all areas for MOV valves, will reduce maintenance costs and emergency work orders, enhancing pipeline reliability and availability.

4. Results and Recommendations:

The calculations will be discussed to estimate the reliability KPIs for the top critical valves (Class I and trap isolation valves). Benchmarking with an international database such as OREDA (Offshore and Onshore Reliability Data, 6th Edition, 4.4) and the Weibull Database (Machinery Failure Analysis and Troubleshooting, 2nd Edition) will be covered.

The reliability value can be calculated as following equations:

$$R(t) = e^{-\left(\frac{t}{MTBF}\right)}$$

$$MTBF = \frac{\sum(Uptime - Downtime)}{Number\ of\ failuers}$$

$$FR = \frac{1}{MTBF}$$

$$Uptime = \sum Examined\ Period = t$$

$$Downtime = \sum(MTTR + PM)$$

Based on the collected data for maintenance history and interview validation workshops, the MTTR =10 days was used (15 days were considered in OREDA for all valves) for all failure modes including spare part delivery and 1-2 days for PM activities. The reported data considered 28 failures for 188 Class I valves and 96 failures for 399 trap isolation valves. Based on the above valves, the reliability values for Class I valves were estimated to be 0.86 and 0.78 for trap isolation valves. These values are unacceptable if they are benchmarked with an international database as described in Table 5. For example, based on OREDA the average of reliability value for valves is estimated to be around 0.86 while the Weibull distribution parameter database estimated the reliability average for valves at 0.89. This means Class I Valves in Department A for year 2017 equaled the average in terms of reliability. The reliability value for trap Isolation valves is unacceptable, which is below the average. In general, the reliability value for both kinds of critical valves in Department A is 0.81. There is a big area to improve valve performance to reduce maintenance cost, enhance availability and reduce failure problems.

4.1 Recommendations

Based on the analysis, the following are the recommendations for enhancing the availability of the valves:

- Eliminate bad actor items by conducting a full RCA for each kind of failure mode based on its probability and criticality.
- Keep the critical spare parts available in a closest facility store to reduce their MTTR.
- Add all critical valves to the PM Program.
- Report any new findings during PM as a different maintenance notification to enhance data logging and support future reliability analysis for critical valves.

Reference	Reliability Value Average
Saudi Aramco/Department A (Class I Valves)	**0.8604**
Saudi Aramco/ Department A (Trap Isolation Valves)	**0.7838**
Saudi Aramco/ Department A (Top Critical Valves)	**0.8076**
[redacted]	
OREDA (Valves)	**0.8555**
Weibull Database (Valves)	**0.8876**

Table 5: Summary of benchmarking between reliability values for valves

- Adapt new predicative maintenance strategies to predict failures and troubleshoot valve problems.
- Conduct a campaign to resolve all passing valves issues.

5. Conclusions:

By using the 80/20 rule, the reliability value for the highlighted bad actors for Class I and trap isolation critical valves for critical valves were managed and enhanced. For example, facilities can eliminate SOV Class I valves in Area 4 (eight failures) by avoiding their root causes, and the reliability value for Class I will be changed from 86% to 90%. Also, it will reduce the cost for unnecessary emergency maintenance. The reliability value for trap isolation valves will be changed from 78% to 88% if the facility can resolve the issues for MOV trap isolation valves in Areas 1-3 and 5. This means that it will improve the total reliability for critical valves from 81% to 89%. The cost avoidance for critical valve M2 maintenance notifications can be reduced from 70% in year 2017 to 40% for valves (around 71/124=0.43% down) if the bad actor items can be managed and eliminated. In conclusion, a focused reliability assessment provides an opportunity to perform structured assessment using the maintenance data and its proper analysis. This methodology can be applied to a wide range of reliability issues to address them efficiently with an optimized use of resources.

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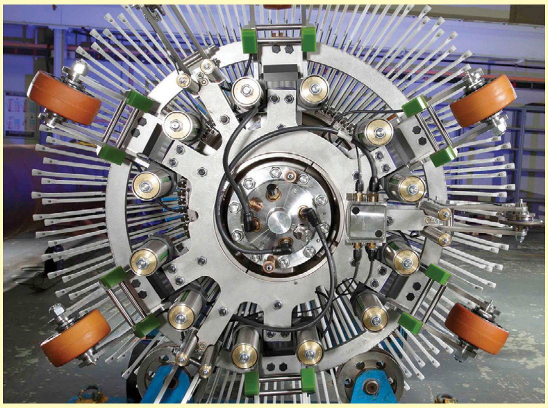

Energy Transition And The Impact On Pipeline Integrity

N.GALLON, M. HUMBERT, M. TEWES > ROSEN GROUP

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.

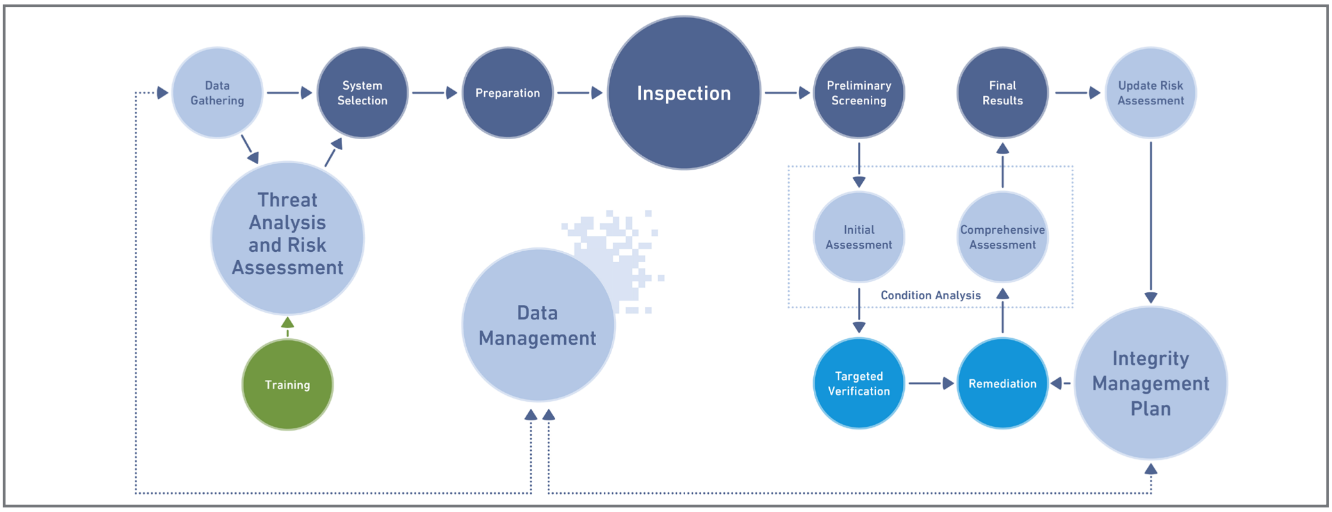

Figure 1: Example of a Hydrogen Integrity Management Framework

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 CO_2 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 CO_2 lead to additional challenges for ILI, mainly for the elastomer parts of the ILI tools. Fortunately ILI in CO_2 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 CO_2 pipelines with a cumulative length of over 2.800 km, thus solutions are available to overcome the challenges.

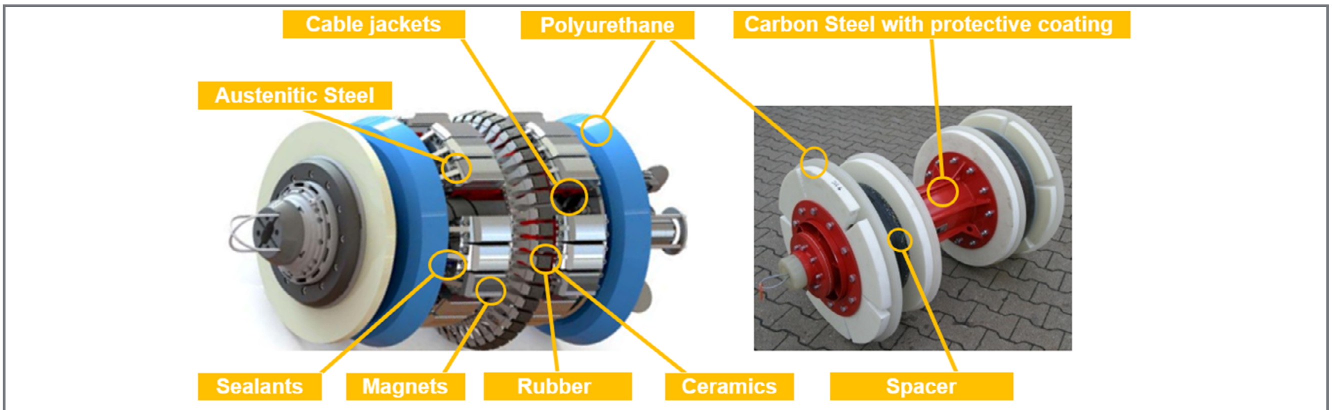

Figure 2: ROSEN Tool design - commonly used types of material

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 H2, CO2, 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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Applications of Vibroacoustic Technology to support pipeline assets re-use, integrity management and energy transition projects

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Abstract

Vibroacoustic technology, developed by Eni, is a consolidated approach for pipeline monitoring applications. Today, e-vpms® is protecting about 1800 km of pipelines worldwide, with a commitment to constant technological evolution and continuous improvement. In this framework, the work presents some notable cases experienced over the monitored network, which led to successful campaigns saving both costs and time for the pipeline operator, reducing downtime of the pipeline.

The first case is a real-time application for which vibroacoustic system is exploited with a novel approach to detect very small defects on an operational pipeline. Such defects are considered critical to detect, in real time and in both shut-in and transfer states by conventional leak detection systems. The capability showed by e-vpms® allows to lower the threshold of detectability to a level where integrity management aims at detecting damage from corrosion-related phenomena.

The second case presented in this work is focused on a pipeline which was shutdown during COVID-19 pandemic peak period, which, as other pipelines experienced worldwide, caused volumes reduction in the entire industry. The technology proved to efficiently detect very small leakages of product out of the pipeline which would have been very difficult to detect with other equipment, given its nature.

A third case is entirely focused on the capability to assess the sealing grade of in-line valves on ageing pipelines. As sealing grade worsens over the years, e-vpms® can perform fast reliable measurements of the capability of the in-line valves to retain the product. This application can also be used in life-extension applications or to assess if the pipeline in-line equipment is fit for new roles to be played by the asset during the current energy transition phase.

All cases demonstrate capability to work in different conditions and for pipelines re-use, with the outcome of costs and downtime reduction.

1. Introduction

The current installations of the e-vpms® system span the globe covering more than 1,800 km of pipelines in many regions of South America, Nigeria and especially Italy, where the vibro-acoustic technology protects nearly 100% of the whole product pipeline network.

The technology is currently used in various scenarios to monitor oil and gas pipelines in real time. The non-invasiveness, cost-effectiveness, and the ease of installation for retrofitting existing transport lines are the strengths of the e-vpms®. In fact, with very few sensors, the entire system can protect hundreds of kilometers, against leaks [1][2][3][4], illegal activities or accidental events [5][6][7], which can undermine the asset integrity.

The e-vpms® is also immune to sabotage attempts, because if anything happens, the processing software will reconfigure itself on-the-fly. One of the winning features is also attributed to the very low FAR (False Alarm Rate), which, according to the statistics of actual pipelines secured over the years, is less than one false alarm per year per 100 km pipeline.

The vibro-acoustic platform includes many integrity management technologies for varied applications. By exploiting the powerful of the vibro-acoustic wavefield, a full range of capabilities have been added over the years, such as leak detection, third party interference recognition (i.e., digging close to the pipeline, impacts, illegal tapping and so on), real-time PIG tracking, valve status assessment, failure detection during hydraulic tests and earthquake detection [8][9][10][11][12].

The e-vpms® is a real advantage for all pipeline operators through its scalability and unprecedented adaptability to any form of operating situation; it is capable of completely integrating with existing equipment and SCADA/DCS control system and operating with almost any pipeline diameter in onshore and offshore scenarios, any pressure condition, and any kind of fluid.

This is integrated by the possibility for a client to request a temporary e-vpms® installation and analysis, like one of the three cases reported in the paper. In both cases of permanent or fixed installation, the e-vpms® technology is particularly effective in facing the modern operative issues for energy transition applications: Integrity Assessment, Predictive Maintenance and Second Life Asset Reutilization, without need for shutting-down the pipeline.

2. Basics of e-vpms®

In general, the e-vpms® is composed of a multipoint array of vibro-acoustic sensors, placed along a pipeline, telecommunication system for data transferring and a central processing server. In particular, the sensor groups are devoted to the sensing of the complete elastic-dynamic wave field; total/acoustic pressures and vibrations contribute to provide deep information on the physical phenomena responsible for the generation of the elastic perturbation [13][14][15][16].

Acoustic and elastic waves are produced from a local source whenever something happens and travel in both directions at the speed of waves in the crossed media. The e-vpms® sensors record such waves and a remote-control unit sends continuously data chunks to the processing server. This central server is responsible for the advanced digital processing chains, such as non-linear filters, real-time noise estimation, detection, and multi-channel localization (Figure 1).

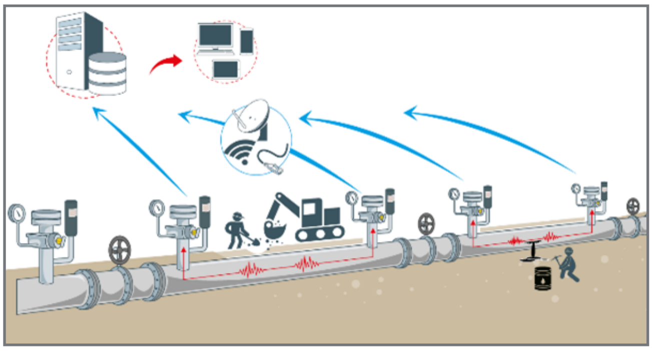

Figure 1: The sketch of the whole e-vpms® hardware. When any kind of mechanical perturbation (such as a spillage, an impact, a digging operation) interacts with the pipeline, a propagating vibro-acoustic wave-field is produced. The anomaly reaches the sensors, which are also responsible of sending data to a central processing unit.

The processing system primarily processes pressure waves together with micro-vibrations and sound data. In fact, combined information makes it possible to identify and accurately locate an anomalous source of noise, carrying information on second order events. To detect such weak and informative vibrations, the developed e-vpms® equipment is very sensitive and the signal processing algorithms are highly advanced.

From the point of view of wave physics, the pipe is a very effective wave-guide system. The acoustic pressure field can travel for kilometers inside the fluid if the pressure is at least 1 bar gauge, while vibrations propagate through the solid shell according to the elastic-dynamic laws.

These features give to the e-vpms® technology a level of detection performance, that cannot be reached by a simple pressure-based system (e.g., well-known NPW systems – Negative Pressure Wave). Generally, the sensors are typically installed on existing hydraulic derivations, without the need of hot tapping and this makes the system suitable for retrofitting existing pipelines (Figure 2). Sensors that are in contact with the fluid are ATEX certified (Ex i) and can work even with sour fluids (mixtures with H_2S).

Figure 2: An existing derivation exploited for installing an e-vpms® sensor block.

The power required by the on-field devices is less than 20 W and can be supplied by solar panels, fuel cells or connected directly to the mains. One of the more interesting aspects of the vibro-acoustic systems is the capability of running for days on 12 V battery. This feature, very useful in case of pilot projects or demonstrations, was exploited for the development of a portable version of the whole system.

Data gathered by the digital control units, placed in the field, are transmitted in real-time to the central processing server. For the sake of completeness, network data transfer exploits any kind of available communication channel, such as LAN, wifi, ADSL, UMTS, Satellite and consumes less than 20 kbit/s (Figure 3).

3. Success cases of re-use of pipelines after e-vpms® integrity management

Three success cases are here presented where the e-vpms® system was effectively applied and allowed to support interventions on operative Oil & Gas pipelines of various kinds and functions. After such intervention, the pipeline could return to its previous use or switch to a new use such as an energy transition project.

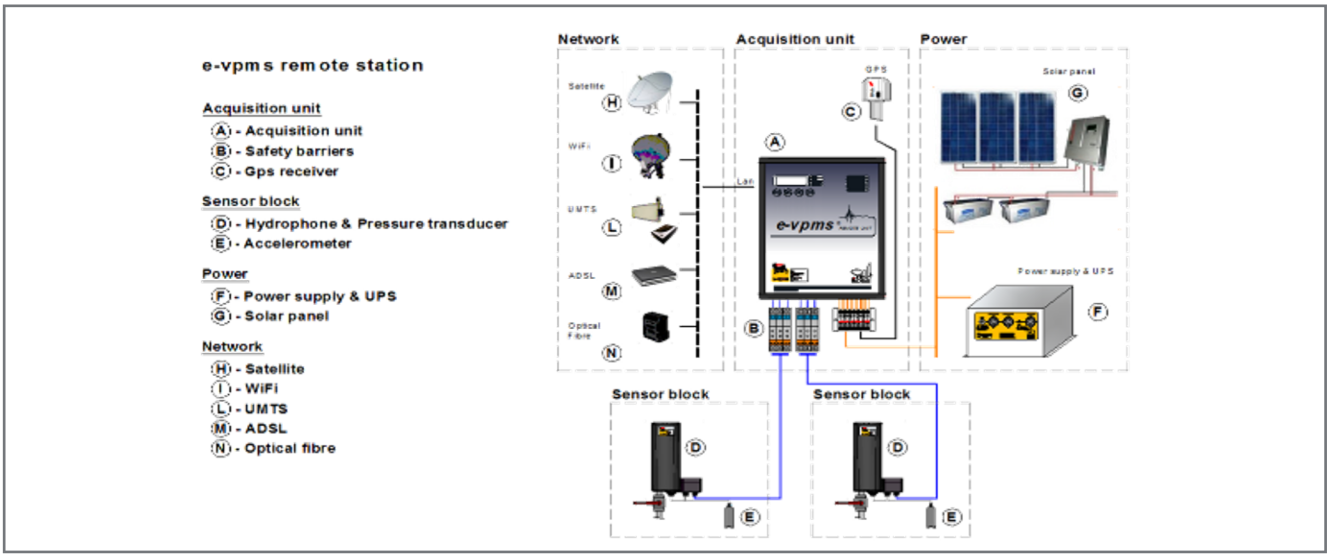

Figure 3: The acquisition unit and its interfaces. The acquisition unit is synchronized by a GPS device, power supplied by different types of energy sources and the external communications are performed exploiting any kind of networking system and protocol.

3.1 Case 1: Localization of an existing leak during pressure test by portable e-vpms® system

The first case presented regards a water injection pipeline operating in a small oil field in Northern Italy. The pipeline operator had realized that there was a leak out of a buried, 3 km long, pipe segment, because the pressure was not sustained when the two segregating valves were shut. Therefore, the operator asked for an on-demand temporary leak detection e-vpms® service. The e-vpms® staff provided three e-vpms® temporary stations and installed them on the available taps (no hot-taps were needed) over the 3 km leaking segment. Two at the two ends and one intermediate: measurement Points A, B and C. A sequence of pressure tests were executed, during which the e-vpms® system recorded the pressure measurements at Points A, B and C, and sent them to the remote e-vpms® server (

Figure 4). A few days later, the e-vpms® specialists detected and predictively localized, by means of advanced processing and correlations techniques, a noise source compatible with the acoustic emission of a leak, at 230 m from Point A and about 520 m from Point B and informed the pipeline operator. The pipeline operator began the excavations starting from the predicted position and a leak was finally found at less than 25 m from the prevision. The area of the leak hole has been measured as about 25 mm² (Figure 5).

Figure 4: e-vpms® measurements at Points A, B and C: acoustic and total pressure during a pressure test.

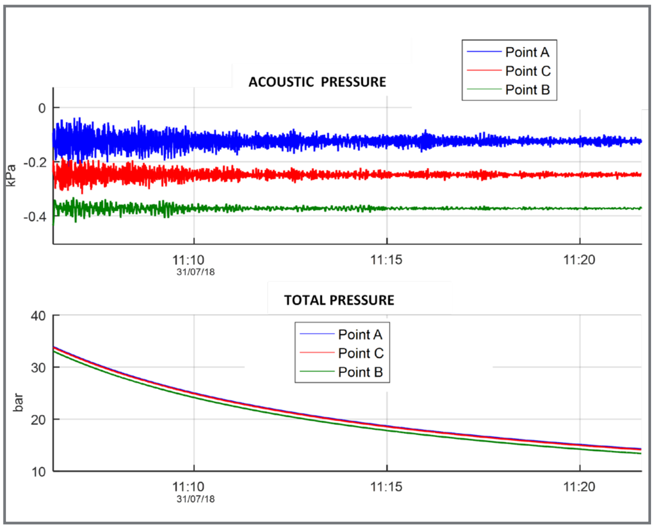

Figure 4: e-vpms® measurements at Points A, B and C: acoustic and total pressure during a pressure test.

3.2 Case 2: Detection of micro-vents in a pipeline before reactivation

The peak COVID-19 pandemic period in 2021 decreased the energy demand and forced many pipelines to reduce the flow rates or even shut-down. When the reactivation must be planned, the operator is concerned with the possibility that a flaw might have occurred, not noticed, during the shut-down period and it could provoke unwanted effects at the reactivation.

The second presented case deals with an oil pipeline in central Italy, already protected by the e-vpms® system which had been shut-down for several months. Before the reactivation, the pipeline operator asked the e-vpms® provider to check the integrity of its old asset.

Figure 5:The flaw detected by the e-vpms® system

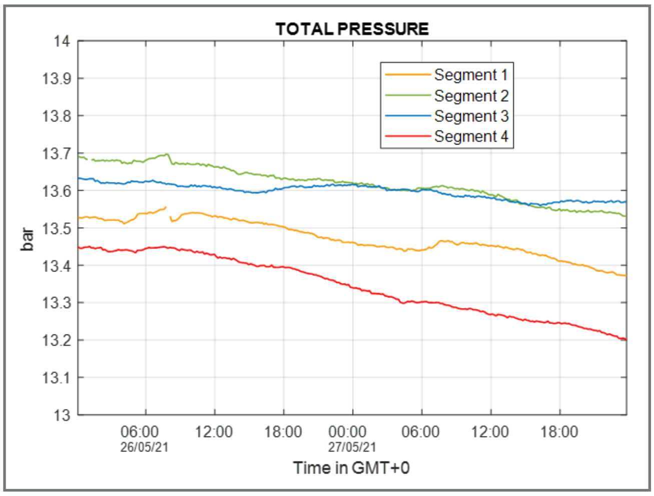

Figure 6: Pressure time-series of the pipeline segments during pressure test. Pressure drop at Segment 4 is relevantly higher than the other segments.

The e-vpms® staff supported the operator with planning pressure tests with suitable segregation of the 90 km long pipeline, by means of shut-down valves, and configured the e-vpms® system in a way suitable for the requested monitoring. In particular, four e-vpms® stations were installed in four consecutive pipe segments, segregated one another by closed valves, so that the pressure measurement of each station was representative of the segregated pipe segment, labelled 1 to 4 in Figure 6.

The data processing of the local measurements (1-4 points) by e-vpms® stations during the pressure tests (Figure 6), evidenced a critical pipe segment (Segment 4) where the pressure drop was anomalously higher (about 10 mbar/h) compared to the other pipe segments (about 5 mbar/h).

A deeper analysis, by means of tools of e-vpms® Computational Fluid Dynamics, provided hints sustaining the hypothesis of a leak, though very small, in the suspected critical segment. The e-vpms® staff therefore delivered its conclusion to the operator which carefully inspected the pointed segment. The inspectors indeed found a micro-vent on a pipe derivation at the arrival depot, in correspondence of a hydraulic derivation (Figure 7). The pipeline operator had then the micro-vent fixed and asked for a new check service to the e-vpms® staff. The pressure measurements (Figure 8) showed that, the pressure drop at Segment 4 had decreased to about 4 mbar/h, the same level as the other stations.

The-e-vpms® analysis therefore confirmed to the operator that the pipe was no longer leaking, and the integrity of the old pipeline was fully restored. The operator

Figure 7: Micro-vent detected by the e-vpms® system

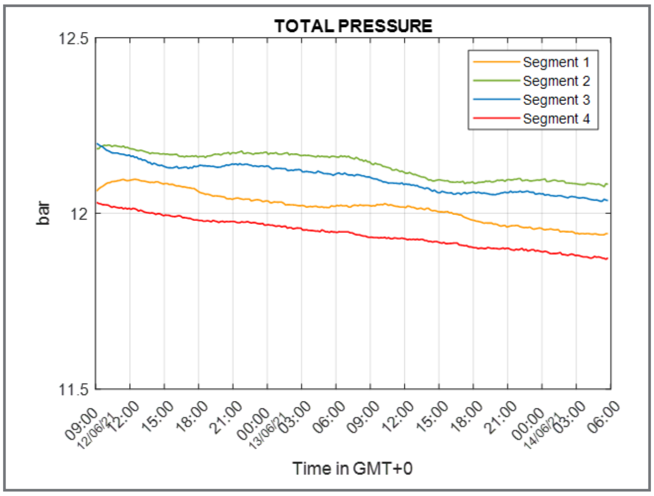

Figure 8: Pressure time-series of the pipeline segments during pressure test. Confirmation that the integrity was restored: the pressure drop at Segment 4 has decreased to the level of the other segments.

therefore was satisfied for the whole operation that, thanks to the support of e-vpms® system and assessment control, allowed to fix a micro-vent and to be finally confident that the pipeline was sound, before restarting the oil transportation service.

3.3 Case 3: Monitoring of valve tightness

The degree of tightness of a shut-down valve is an important parameter to be frequently monitored because, in case of accident, it might make the difference between a near miss and a severe accident.The ageing of the vast old pipeline asset worldwide is likely to produce a decay in the tightness degree of many shut-down valves. Such a decay is not easy to detect.

The e-vpms® technology allows the provision of a service able to measure the tightness degree of valves, taking advantage of multiple working principles, namely pressure analysis and acoustic reflectometry. The success case involves an oil pipeline in Northern Italy which is protected by the e-vpms® system; a set of shut-down valves (ball valves) were put under test because doubts had arisen about the tightness of some of them. The test procedure consisted in the following two operations:

- pressure test, in such a way to produce a pressure difference across the valve under test.
- generation of acoustic sources to trigger acoustic waves propagating to and scattered by the valve under test (acoustic reflectometry, Figure 9).

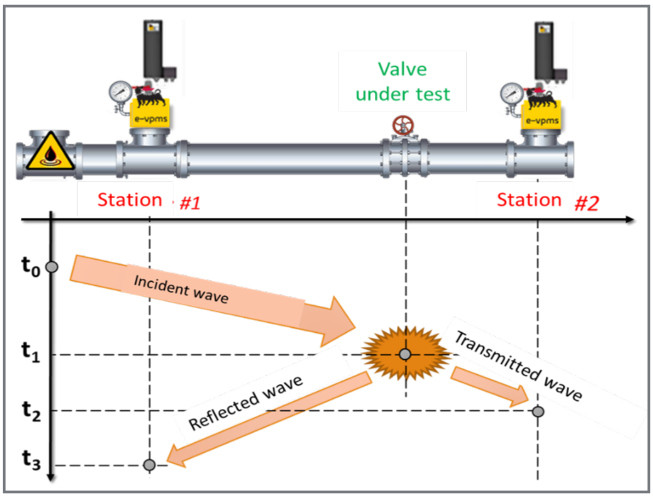

Figure 9: Working principle of acoustic reflectometry with e-vpms® system

Acoustic waves generations (f) were obtained through spills of product out of the pipeline (Figure 10) and were performed in correspondence of different levels of opening (by means of a manual handle) of the ball valve.

The scheme of the pipeline layout is shown in Figure 10, with the tested valves (red circles), the spill point and the e-vpms® stations. The e-vpms® service was delivered without need for additional e-vpms® hardware of software components.During the diagnostic tests, the e-vpms® sensors allowed to measure the occurring physical phenomena that are the input for the estimation of the valve tightness. For testing VLM14 valve, it was completely closed, while VLM12 and VLM13 were open to propagate acoustic waves in the line. A quick (about 5 seconds) spill test was performed at V11 valve.

Figure 11 shows, on the left, the signal produced by the spill when measured at station VLM13 (after propagation). This is representative of the signal incident to VLM14 valve. On the right, figure shows the signal as measured at VLM16, after transmission through VLM14. The transmitted signal (right) is much lower than the incident (left), but its relative amplitude is nonetheless one order of magnitude higher than expected for a signal passed through a closed valve. The static pressure measured at the e-vpms® stations provided additional information about the interdependent trend of the pressure in proximity of the tested valve. The cross-validation of acoustic reflectometry and pressure analysis (aided by methods of Computational Fluid Dynamics) allowed to classify the tested valve as non-perfectly-sealing, notwithstanding the operator considered it to be so. Therefore, the

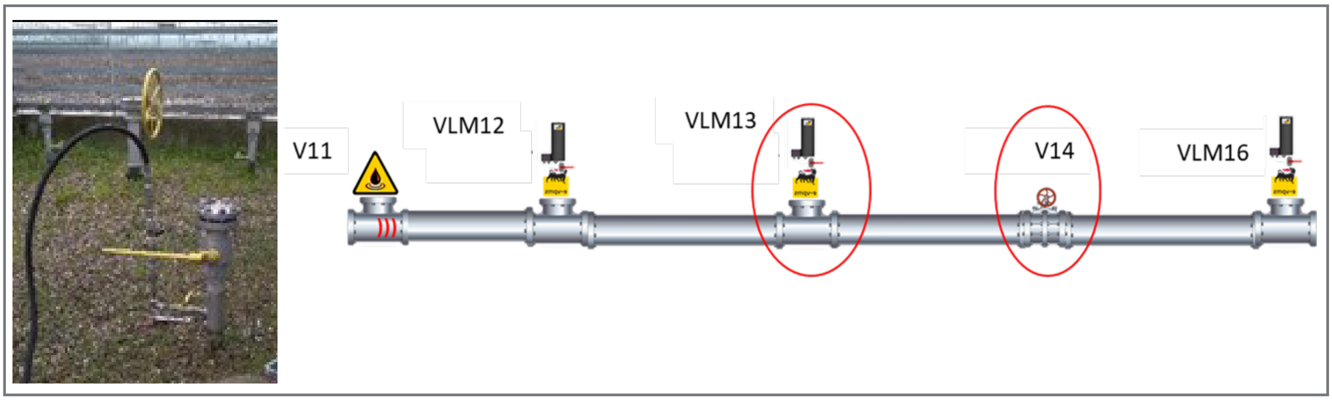

Figure 10: Scheme of the pipeline with the tested valves (red circles) the spill point and the e-vpms® stations (right). Spill equipment for generation of acoustic waves in the pipeline (left)

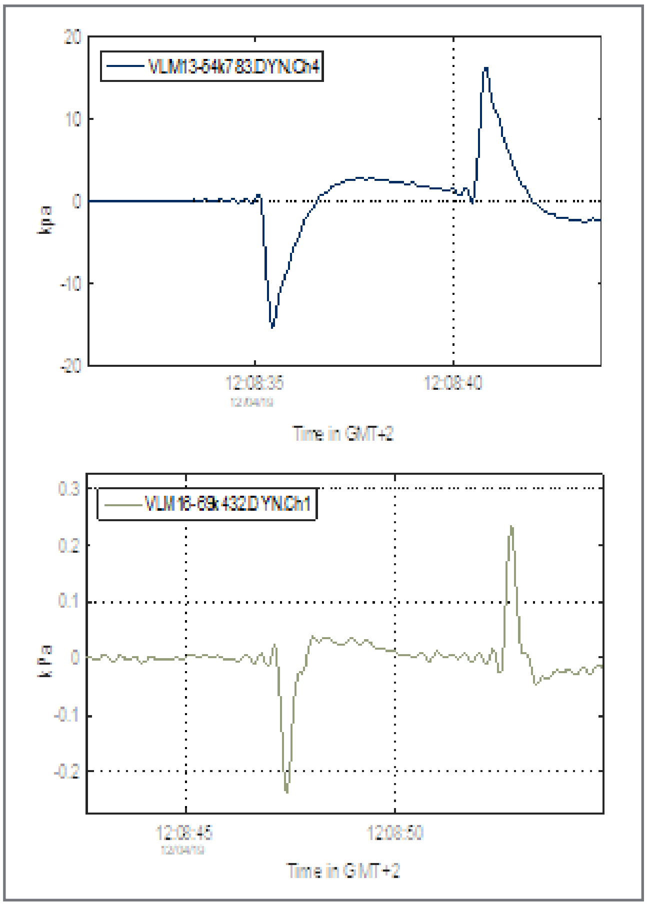

Figure 11: Signal produced by the spill measured at station VLM13(left) and at station VLM16 (right).

operator benefitted of this valuable assessment and restored the full tightness of the valve. He was therefore able to restart the operational status by using the same pipeline with the confidence that the valve performances are compliant with the safety requirements.

4. Discussion and conclusions

This paper presented three success cases where the e-vpms® technology was used in different operative scenarios, not for the flagship Leak and TPI Detection applications, but for responding to assessment issues in the context of energy transition. The e-vpms® technology, compared to many competitors, is advantageous because it is non-invasive, cost-effective, and fully integrable with the existing facilities. Notably, the e-vpms® can respond to the operative issues even without need for shutting-down the operational service of the pipeline.In the first success case, e-vpms® as a service, was agilely and quickly installed for localizing a very small leak in an old, buried pipeline. The pipeline integrity could then be revamped to kept in use.

In the second case, the e-vpms® technology supported the integrity monitoring of a pipeline to be reactivated after a shut-down period. The technology provided fundamental information for identifying a micro-vent which prevented the integrity of the pipeline. This is considered as an example of the second-life reutilization of an asset. The third case showed a unique application of the e-vpms® system which combined different working principles to identify a worn ball valve which needed maintenance to make the asset fully compliant with the safety requirements.

This was an example of Predictive Maintenance that can be periodically performed on the asset which is endowed with the e-vpms® technology. In conclusion, whether a permanent or a fixed installation on the assets, all cases shown the capability of e-vpms® system to reduce costs and downtime, particularly when facing the modern operative issues for energy transition program: Integrity Assessment, Predictive Maintenance and Second Life Asset Reutilization.

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METHANE EMISSIONS REDUCTION SYSTEM IN PIPELINE COMPRESSOR STATIONS: ENAGAS & BAKER HUGHES EXPERIENCE

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Abstract

Methane is the second most abundant anthropogenic greenhouse gas (GHG) after carbon dioxide: it is estimated1 that its concentration in the atmosphere is approximately 2.6x higher than the pre-industrial levels and this contributes for at least 25% of the global warming.

As methane is the main component of natural gas, a strong reduction of its emissions in the atmosphere is paramount.

The turbomachinery normally used in the gas industry can release emissions of natural gas: its recovery represents both a challenge and an opportunity.

Baker Hughes has developed a methane emissions recovery system able to reduce emissions capturing gas vent flows as primary vents of centrifugal compressor seals and the compressor loop blowdown vent and reinject it into a plant live section for its reuse.

As part of Enagás' Decarbonization Strategy, this system has been successfully installed and commissioned in Spain at the Enagás' Lumbier station and is capable to save about 3,400 tCO_2e per year[2].

1. Introduction

1.1 The Methane Cycle and its Effects in the Atmosphere

Methane is one of most abundant GHG. Globally, it is estimated that more than half of total methane emissions come from human activities[1]. According to the Climate and Clean Air Coalition (CCAC)[1], human sectors that mostly generate methane are agriculture (42%); fossil fuels (36%); waste landfilling (18%) and others (4%).

Methane emissions have a direct influence on climate, acting either as a GHG and also indirectly, due to the formation of ground-level ozone, affecting human health, crop yields and the productivity of vegetation.

The Intergovernmental Panel on Climate Change (IPCC) research[1,2], shows that around a quarter of the current rise in temperatures is linked to methane emissions. Methane has a global warming potential (GWP) higher than CO2. The GWP of methane is in the range 84-87 in a 20-year perspective (GWP20) and 28-36 when considering its impact over a 100-year timeframe (GWP100).

It is estimated that human-caused methane emissions could be reduced by as much as 45% within this decade[3]: this would avert nearly 0.3°C of global warming by 2045, helping to limit global temperature rise to 1.5˚C and putting the planet on track to achieve the Paris Agreement (COP 21) targets. Due to its atmospheric lifetime of around 12 years, methane can also be considered a short-lived climate pollutant. This is why reducing methane is considered to be a fast way to keep under control the global warming, while in parallel tackling CO2 challenge.

1.2 The Global Methane Pledge (GMP) and main ongoing initiatives

In September 2021 the 17 Major Economies Forum (MEF) meeting invited countries from all around the world to support the Global Methane Pledge (GMP)[4,5] subsequently launched at COP 26 held in November 2021 in Glasgow, UK.

The GMP is a collective goal of reducing human-made methane emissions by at least 30% from 2020 levels by 2030. The 30% target itself is considered insufficient to limit global warming to 1.5° C, in fact as said a 45% by 2030 would be needed. In addition, countries supporting the GMP also committed to improving inventory methodologies to quantify methane emissions, particularly from high emission sources. Currently, GMP is supported by over 110 countries, representing approximately 50% of global anthropogenic methane emissions and over two thirds of global GDP.

Since methane is the main component of natural gas and methane emissions occur across the complete gas value chain, from production to final consumption, Oil and Gas sectors have a crucial role to play in reducing them. Today technology allows to implement mitigation measures for all the segments of the oil and gas value chains. The gas industry has three incentives to avoid methane emissions:

1. Safety and well-being of personnel and the general public;
2. Commercial value, as the additional methane captured in upstream can often be monetised directly, emission reductions could result in economic savings or be carried out at low cost; and
3. Sustainable development of natural resources.

In the case mainly of the upstream segment, avoided methane emissions can bring important economic benefits to Oil and Gas operators: in fact, the International Energy Agency (IEA)[6] estimates6 that "based on average natural gas prices from 2017-21, almost 45% of current oil and gas methane emissions could be avoided at no net cost by abatement measures which cost less than the market value of the additional gas that is captured". Overall, IEA[6] estimates that global oil and gas related methane emissions "could drive over 70% of technically available methane emissions abatement options". Therefore, in the current scenario and with the available technologies, there are ongoing important efforts to reduce methane emissions, such as:

- The "Mineral Methane Initiative" strategy adopted by CCAC1, a voluntary partnership of governments, intergovernmental organizations, businesses, scientific institutions and civil society organizations committed to protecting the climate and improving air quality, set an aspirational goal of:

  - 45% emissions reduction in methane emissions over estimated 2015 levels by 2025,
  - 60-75% reduction by 2030.

- The Oil and Gas Methane Partnership (OGMP) is a multi-stakeholder initiative launched by United Nation Environment Programme (UNEP) and the CCAC to report methane emissions, it consists on a report framework that will improve the accuracy and transparency of methane emissions reporting, it includes a quality seal "Gold Standard" to reward companies for their efforts in methane quantification.

- The International Methane Emissions Observatory (IMEO) was launched in the COP26, it will initially focus on methane emissions from the energy sector and it will bring global reporting to a new level, it will do a global report of methane emissions, obtaining information from OGMP 2.0, direct measurements from independent studies, data from satellites and national inventory reports.

- In addition, the European Commission adopted in October 2020 the strategy to reduce methane emissions in the EU. This Strategy announced binding rules to manage and reduce methane emissions in the energy sector. In December 2021, the Commission published the proposal for a Regulation to reduce methane emissions in the energy sector, which covers oil and gas exploration and production, gas transmission, distribution, storage and LNG terminals as well as active and abandoned coal mines. The future regulation will set standards for monitoring, reporting and verification of methane emissions, as well as for mitigation through LDAR campaigns and restrictions on venting and flaring. For imports, requirements will be set to increase the transparency of methane emissions information (database and monitoring tool).

1.3 Enagás' Decarbonization Strategy

Enagás is the main gas infrastructure company in Spain and the Technical Manager of the Spanish gas system. The company's activities include the management, operation and maintenance of gas infrastructure. In Spain Enagás has approximately 12,000 km of gas pipelines, 19 compressor stations, 493 regulation and metering stations, and 3 underground storage facilities. It also owns 4 LNG regasification plants, and it is the main shareholder of other two.

Enagás has announced its commitment to achieving carbon neutrality by 2040 through more than 50 energy efficiency projects. In 2013, the company voluntarily started to annually calculate and verify its Carbon Footprint, which constitutes the base for its decarbonization strategy. Quantification of methane emissions is a part of that process, which is subject to an independent third-party verification in accordance with standard ISO 14064. From 2013 to 2020 Enagás has managed to reduce its methane footprint by 62% (78% fugitive emissions and 37% venting emissions).

The Enagás' methane emissions strategy is based on three pillars:

- Implementation of best available techniques
- R&D efforts and close collaboration with scientists
- Collaboration with the industry and associations to raise awareness and commitment

In 2019 Enagás committed to reduce its methane emissions by 45% in 2025 and 60% in 2030 compared to 2015 in line with the Global Methane Alliance initiative of UNEP. In 2020, the company joined the OGMP2.0 (Oil & Gas Methane Partnership) initiative, which is the new gold standard reporting framework to improve the accuracy and transparency of methane emissions reporting in the oil and gas. In 2021 Enagás obtained the Gold standard distinction awarded by OGMP 2.0 and has been recognized for its commitment to reducing methane emissions, as well as for its plan to improve the reliability of data on these emissions[7].

The company also participates in various projects and partnerships, collaborating in the preparation of research and publications relating to methane emissions, among others:

- Enagás is currently coordinating and leading together with GERG, the GERG Project on Technology Benchmark for site level methane emissions quantification, an innovation project to improve methane emissions quantification, assess some site-level technologies and reconcile its measurements with bottom-up technologies.[8]

- Satellites – Collaboration with SATLANTIS to detect and measure methane emissions from satellites.[9]
- Enagás joined some years ago the Methane Guiding Principles. During the last years, Enagás has been collaborating in the preparation of case studies and best practice guidelines on methane emissions reduction and quantification.
- Collaboration and production of documents and technical guides in European associations as GIE, MARCOGAZ and GERG.

Among the measures aimed at reducing and eliminating methane emissions, the following stand out:

- Annual campaigns to detect and repair leaks (LDAR campaigns) at all the installations.
- Boil-off gas (BOG) compressors in regasification terminals.
- Use of air-operated or electrically operated devices instead of gas pneumatic devices
- Replacement of electric pumps at all the facilities
- Minimization of vents and flaring

This project between Enagás and Baker Hughes is key to reduce vents in compressor stations, the main source of methane emissions in this type of installations. The following section of the paper describes the Baker Hughes technology developed to capture methane emissions from gas compressor stations and installed by Enagás in their station located in Lumbier, Spain.

1.4 Main sources of methane emissions from Pipeline Compressor Stations

The traditional turbomachinery used in the Pipeline sector release emission of natural gas. As it has already been explained, its recovery and valorization represent one of the many challenges and opportunities the industry has. Future technical developments and new equipment and machinery can contribute to mitigate and if possible to eliminate the gas emissions. This is an important step in order to comply with increasing regulatory limits as well as to perform voluntary actions.

The main sources of natural gas emissions from compressor stations are related to the centrifugal compressors and in particular:

- All compressor station blowdowns during emergency shutdown,
- Emissions from the sealing system and specifically from the Wet Seals or Dry Gas Seals (DGS),
- Vent of the compressor loop during a maintenance or a prolonged shutdown.

The sealing system (shaft end seal) has the task to contain the process gas within the casing minimizing the emissions of process gas from the compressor to the atmosphere; for this reason the seal system is an integral part of the compressor package and in turn forms part of the process system. The seal system is formed by a sealing device (usually an integral system or cartridge) installed inside the compressor and an auxiliary system (or support system) that has the task to supply a properly controlled seal /barrier gas to the sealing device and to provide vent and drainage systems.

Into pipeline station application the vent of DGS system is a small but continuous emission of gas at atmospheric pressure which is released directly in atmosphere causing the emission of a significant amount of gas. It is estimated as 200 tCO2e per year[10] for the Lumbier compressors station. The compressor loop volume normally consists of the suction and discharge process piping up to the respectively isolation valves, the anti-surge line, the compressor flow path itself and eventually the suction scrubber and/or the cooling equipment.

Into pipeline compressor station during a shutdown, due to main maintenance activities or in case of prolonged shutdown, the gas entrapped in this volume is typically released to atmosphere. Being this gas entrapped at pressure between suction and settle-out one, thus around 45÷60 bar, the amount of gas released is typically consistent, bringing to emit many tens of tons of equivalent CO2 for any blowdown event. For Lumbier station it can be estimated into a cumulative value of 3200 tCO2e per year[11].

In order to capture and valorize the compressor process leakages rather then send it in atmosphere Baker Hughes developed a proprietary solution called "Methane Emissions reduction and recovery system", able:

- to recover by capturing gas vent flows such as primary vent of centrifugal compressor dry gas seals and the compressor loop blowdown vent
- to reinject it into a plant live section, as station suction header, at the required pressure specified by customers, instead of discharging on atmosphere or burning in a flare
- to reuse part of this gas vent flow for preheating the gas to fuel the gas turbine

This methane emissions reduction system has been successfully installed and commissioned for Enagás, at the Lumbier compressor station and will save about 3,400 tCO2e per year[11].Lumbier compressors station, own and operated by Enagás, is an important infrastructure related with the interconnection between Spain and France gas system throughout West Pyrenees, which is placed in Navarra region 40 km far away from the French border. The station consists of two 20 MW compression units supplied by Baker Hughes and composed by aeroderivative gas turbine driven turbo-compressors.

Figure 1: Lumbier compressor station general overview

1.5 Methane emissions Reduction System

The recovery solution proposed consists in one reciprocating compressor skid (Methane Leakage Reduction skid) able to recover the primary vent from two centrifugal compressors (TC1 & TC2) and to evacuate the gas entrapped inside the compressor loops (within the suction and discharge isolation valves) following a pressurized shutdown.

These two services could be executed with the same equipment because, from an operational point of view, are completely complementary to each other: the primary vent shall be recovered when the pipeline compressor is pressurized and is in operation, while the gas inside the compressor loops could be recovered when the unit is not in operation. The recovered gas is reinjected into the pipeline suction branch or in another live plant section. When the turbo-compressor unit is

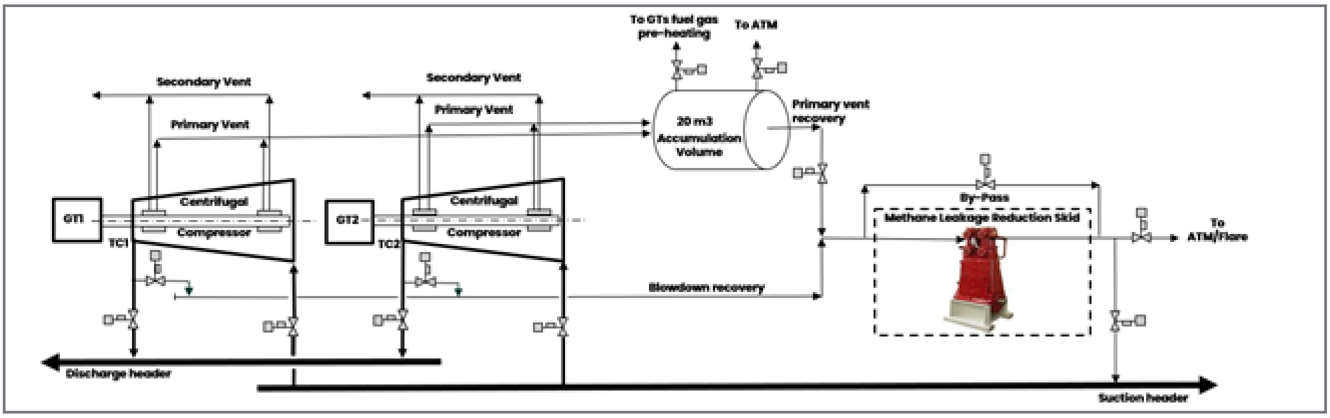

Figure 2: Simplified process schematic drawing

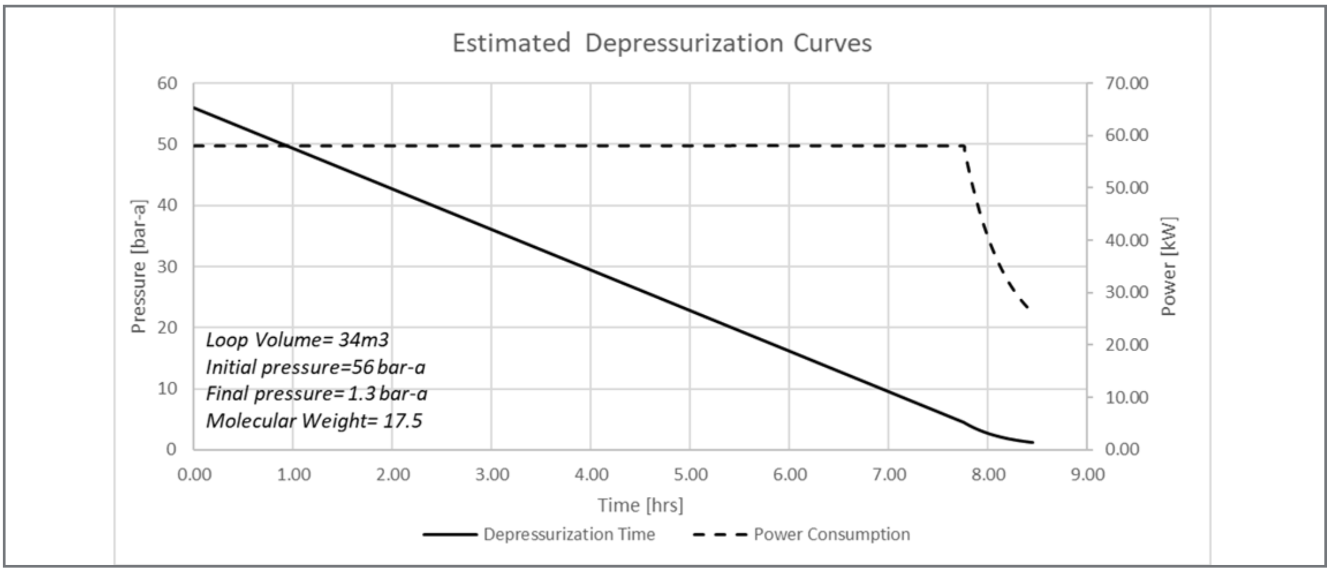

Figure 3: Centrifugal compressor loop depressurization curves

running, the DGS primary vent leakage will flow into an external accumulation volume (around 20 m3 for Lumbier station case) which is directly connected with the gas turbine fuel gas pre-heating system. . When gas pressure will reach 4.5 bara, the recovery system will start-up to reinject the gas into the station suction heater. Therefore the system has an intermittent operation starting when pressure in accumulator reach 4.5 bara and stops when pressure arrives at 1.5 bara.

The accumulation volume sizing allows the recovery system to maximize the time between start-ups. In fact, the starting frequency depends on the speed with which the primary vent will fill the accumulation volume: therefore, it depends on the consumption flow of the fuel gas heater, the size of the accumulation volume itself and the wear level of the DGS (the vent of the DGS increases with increasing wear of the seal) The recovery system is able to recirculate the primary vent of multiple compressors running together (2 for the Lumbier case) with guaranteed seal gas leakage flow rate. In case of recovery system malfunction, the primary vents will be redirected to the vent stack, as per existing arrangement, in order to avoid spurious trip or loss of production.

When the centrifugal compressor loop shall be depressurized, the reciprocating compressor will start-up. To limit the absorbed power, specially at initial stage of the depressurization, the suction pressure will be decreased to a certain pressure (e.g 4.5 bara in this installation), therefore the skid will be equipped with a suitable pressure control valve (PCV) to be installed upstream the compressor within the recovery system skid. Once reached such a pressure the PCV will go in full open position and the system will run until the lower pressure limit of 1.5 bara will be achieved. One recovery system is able to depressurize all CC loops in the required time (about 8÷9 hours in the Lumbier case) but not contemporary (only one at a time). In case the recovery system is reinjecting the accumulated gas inside the vessel to the suction header and a loop depressurization is ongoing, the primary vent recovery will be interrupted for the time strictly necessary to complete the compressor depressurization. In that time, the primary vent will be redirected to the vent stack as per existing arrangement.

During the loop depressurization the injection of an external gas flow, for buffering the primary seal to avoid any chance of DGS contamination, increments the emptying time because part of such a flow migrates into the centrifugal compressor and therefore in the volume we aiming to empty. In Lumbier experience, in order to avoid this adverse condition, a properly tuning to seal injection system has been done with the results to reduce the external seal gas flow and don't excessively penalize the blowdown recovery duration.

2. RECOVERY SYSTEM COMPRESSION PACKAGE DESCRIPTION

The recovery system skid consists into a single open frame with a vertical reciprocating compressor and its auxiliaries, suitable for heavy hydrocarbon duty in hazardous area.The reciprocating compressor technology has been selected thanks to its high pressure ratio and low flow rate that matches perfectly this type of duty. The compressor is oil free and is composed by two cranks with double effect pistons working in three stages.

The first stage is composed by both the effects (crank end and head end) of the first cylinder, while the second and third stages are obtained respectively with the head end and the crank end effect of the second cylinder. The interstage and outlet gas is cooled though an air cooler, fan multi coils type.

The selected electric motor is 75 kW, low voltage induction type linked to the compressor with a belt coupling and equipped with soft starter device. The cylinders are not lubricated type and they are cooled with water in closed circuit while the bearings are lubricated with lube oil. The lube is cooled with water and the cooling of water itself, which is kept circulating by means of a dedicated electric pump, is achieved using the same air cooler used for interstage and delivery gas streams.

The noise pressure is lower than 85db(A) at 1 m distance. The control panel, which is located close the compressor station control room, is divided in two sections but in a single cabinet, one for auxiliary power supply management, and one for compressor control & monitoring by means of a PLC (Programmable Logic Controller). The skid has been assembled and tested in Italy in a workshop qualified by Baker Hughes.

3. SOLUTION INTEGRATION WITH EXISTING AND NEW EQUIPMENT

The recovery system integration with the rest of the plant equipment is a key aspect of the project, as it will have interactions with the Centrifugal compressor sealing system, thus with the system assigned to prevent a loss of containment with a safety and operational function.

A study aimed to verify if existing centrifugal compressor system needs to be modified due to the installation of the recovery system is normally performed. In particularly for this installation the following task has been performed:

- Checking existing alarm and shutdown thresholds;
- Verifying the correct mixture of air/process gas in the outboard seals;
- Checking the seal gas primary injection system equipment suitability;
- Designing the revamped logics and relevant operation philosophy.

The list of changes and solutions are discussed and agreed with Enagás. In order to minimize the logic revamping into distributed control system (DCS) almost all the upgrades are implemented within recovery system control panel. The operations philosophy is shared with Enagás for a smooth commissioning with a stable and flawless plant operation.

Figure 4: Recovery System Skid

4. CONCLUSION

Methane is the second most abundant anthropogenic greenhouse gas (GHG) after carbon dioxide (CO_2) and it represents at least 25 % of global warming. Over 36 % of anthropogenic methane is emitted by the fossil fuel sector, including the gas sector: as methane is the main component of natural gas, a strong reduction of the emissions in the atmosphere by the gas industry is paramount. Baker Hughes developed a proprietary methane emissions reduction and recovery system able to reduce emissions capturing gas vent flows, reuse part of them for preheating the gas to fuel the gas turbine and reinject the remaining part into a plant live section.

Following the Enagás decarbonization strategy, with includes ambitious objectives such as 45 % reduction in the methane emission levels by 2025 and 60% by 2030 compared to 2015, Baker Hughes system was implemented in the Enagás Lumbier Plant. In the Lumbier Station the vent for the DGS system is small but continuous emission of gas of about 200 tCO2e per year, the gas emitted in the compressor station during a shutdown, due to main maintenance activities or in case of prolonged shutdown has a cumulative value of 3,200 tCO2e per year. Which makes 3,400 tCO2e per year that will be saved from emission thanks to the Baker Hughes system.

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10. Or 6 Nm3/h x 1500 hours/year. Figures depend on utilization time of the compressor and other factors: machine size, seal maintenance status, aging effect, etc.
11. This is an yearly estimation based on the average historical emission since beginning of compressor station operation until 2020, as per old compressor loop volumen

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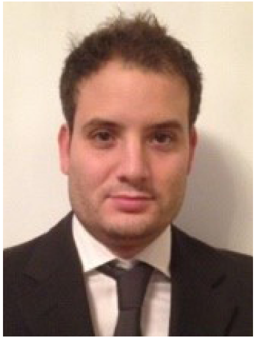

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Considering leak detection systems for carbon capture and storage (CCS)

D. SHORT > ATMOS INTERNATIONAL

Abstract

At COP26 countries were asked to come forward with ambitious 2030 reduction targets that align with meeting net zero emissions by the middle of the century (UK COP). Governments have also agreed to keep global warming well below 2C and make efforts to keep it to 1.5C. Carbon capture and storage (CCS) is going to play an important role in decarbonizing the energy industry and capturing the carbon dioxide (CO_2) in the atmosphere to meet these targets.

Pipelines are crucial to this shift, as the cheapest way of transporting CO_2 in large quantities. This paper looks at some of the key trends in CCS and why leak detection systems (LDS) are crucial for mitigating the risks associated with a leak or rupture on a CO_2 pipeline.

1. Introduction

To help curb climate change, efforts are being ramped up for decarbonization. In 2021, at COP26, countries were asked to come forward with ambitious 2030 reduction targets that align with meeting net zero emissions by the middle of the century[1]. Governments have agreed to keep global warming well below 2C and make efforts to keep it to 1.5C. Energy transition plays an important role in helping to achieve these targets.

Methods such as carbon capture and storage (CCS) reduce the carbon emissions from industrial processes that would otherwise release large amounts of the greenhouse gas carbon dioxide (CO_2) into the atmosphere.

There are three core steps[2] to CCS:

1. Capture - the CO_2 is separated from other gases produced by industrial processes
2. Transport - transported, often via pipelines or road transport and ships to a storage site
3. Storage - the CO_2 is injected into rock formations deep underground for permanent storage

Once the CO_2 has been captured, transport by pipeline is the cheapest way of transporting CO_2 in large quantities onshore and offshore3. The storage of CO_2 involves the injection into rock formation deep underground, although there are several types that are suitable, deep saline formations and depleted oil and gas reservoirs have the largest capacity[3].

2. The current state of CCS

North America is currently leading the number of CCS projects globally with 36 of the 135 CCS projects, the large increase in facilities has led to project capacity levels not seen since 2011[4]. Naturally, pipelines are integral to the success of these projects, with some arguing natural gas pipelines should be repurposed and others opting to construct purpose-built networks.

Blue hydrogen projects require CO_2 emissions to be captured and permanently stored underground if fossil fuels are used as part of the process. In the UK, the hydrogen will provide clean fuel to help decarbonize other local businesses, with the CO_2 stored beneath the North Sea. The projects include:

- Equinor's Saltend hydrogen project
- BP developing a hydrogen plant as part of the Net Zero Teeside network
- HyNet North West leading an industrial decarbonization project
- Philips 66 developing a blue hydrogen project at its Humber refinery[4]

CCS is an essential way for many global industrial industries to decarbonize. The cement sector for example emits approximately 4.1 billion tons of CO_2 each year globally[4]. While iron and steelmaking is another large contributor, producing 2.6 billion tons of CO_2 emissions in 2019[4]. Northern Lights in Norway is part of a full-scale CCS project that aims to capture CO_2 from one or two industrial capture sources[5]. Once captured, the CO_2 is transported by ship and then pipelined to a subsea structure and injected into a geological formation around 2,500 meters below the North Sea for storage. Projects like this are becoming increasingly crucial to help decarbonize industries such as cement, iron and steel that are responsible for such a large amount of carbon emissions.

3. CCS vs CCU: Driving economic value with carbon?

Aside from the obvious climate change objectives, the advancement of the hydrogen economy is a key driver of CCS projects. Clean hydrogen can be produced in three ways:

1. From fossil fuels with CCS (blue hydrogen)
2. From biomass
3. From electrolysis powered by renewable energy sources (green hydrogen) or nuclear power[4]

During the production of blue hydrogen, CO_2 is generated through the fossil fuels used. Energy companies therefore need to capture and store all CO_2 that arises

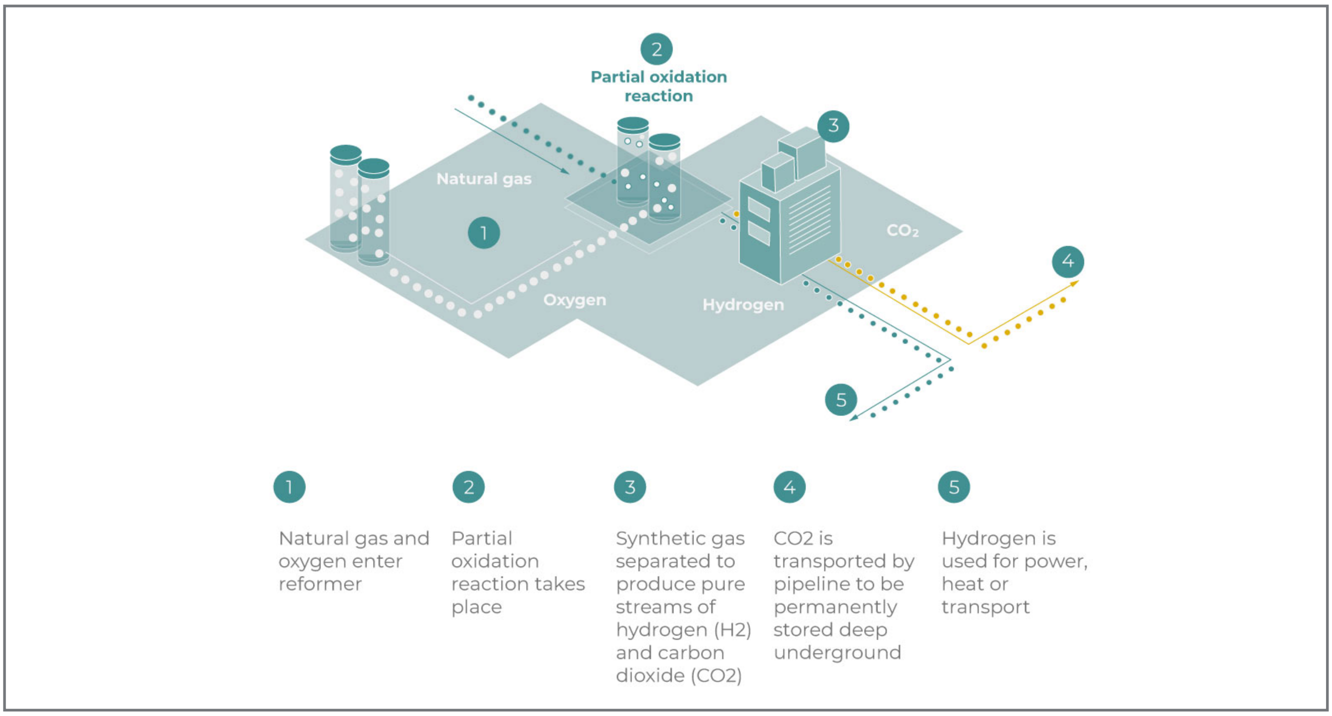

Figure 1: Hydrogen production using CCS

from the hydrogen production, for the energy source to truly be net zero.

As an initial idea CCS is the key solution to safely ensure large quantities of CO_2 don't enter the atmosphere, however more recently the concept of carbon capture and utilization (CCU) has been formed. This creates a circular economy, where waste is kept to a minimum by reusing materials and products for as long as possible.

The aviation industry is exploring how sustainable aviation fuel (SAF) can be created using carbon captured directly from the atmosphere, so that it can be fed into the gas fermentation process to produce low-carbon ethanol[6].

The ethanol is then converted into SAF using Alcohol-to-Jet (AtJ) technology. Compared to traditional jet fuels, SAF gives a reduction of up to 80% in carbon emissions over the lifecycle of the fuel[7]. CCU initiatives like this demonstrate that there are uses for CO_2 that can drive economic value, rather than just being waste.

However, how effective CCS and CCU are in terms of tackling climate change very much depends on the level of CO_2 emitted by the processes associated with each activity.

4. The role of pipelines in CCS

The CO_2 that is captured from CCS can only be stored in sites that meet a specific set of geological characteristics and standards. Due to this fact, pipelines are an inevitable and vital component of an efficient CCS project as in some cases, the CO_2 may need to travel long distances to reach the storage site.

Global plans to build CCS plants have increased dramatically in the past couple of years. 2021 saw a spike in the number of CCS projects in development, growing to a 111 Mtpa capacity, a 48% increase from 20204. This increase in projects will have a direct correlation with the number of pipelines being required to transport CO_2 and demonstrates how important CCS is for the energy sector to work towards the goals set out in COP26. To meet the demand for CCS, it's highly likely new pipelines will need to be commissioned. If for example the US is to deliver the net-zero ambitions to bury or use 1 billion tons of carbon per year by 2050, it will need 19,000 kilometers of carbon dioxide pipelines[8]. There are arguments for repurposing existing natural gas pipelines, however this also comes with safety concerns.

Transporting carbon dioxide efficiently through pipelines requires a pressure of up to 2,600 pounds per square inch (psi). This is a much higher pressure than that required to efficiently transport natural gas, which operates at about 800 to 1,200 psi[8]. This would mean that in redeploying natural gas pipelines for carbon dioxide, the operator would either need to pump at a lower pressure or reinforce the infrastructure so that it will cope with the increased operating pressure. Running at a higher pressure than the pipeline's original design increases the risk of leaks and ruptures.

The material for CCS pipelines also needs to be carefully considered. CO2 is corrosive if contaminated with just even a small amount of water, reacting to form carbonic acid. This means the pipelines used to transport CO2 need to be manufactured and maintained to a higher standard. It also means monitoring the purity of the CO2 is crucial.

Arguably making modifications to existing pipeline networks is much more cost-effective than starting from scratch. However, some are opting for the latter, Wolf Midstream for example is building new networks rather than converting old ones, announcing last year that they will be building a pipeline to move carbon dioxide from Archer-Daniels-Midland Co's Iowa ethanol plants to a sequestration site about 563 kilometers away[9]. Whether using existing pipelines that are repurposed or specially constructed networks, it's vital to implement a leak detection strategy for CO2 pipelines.

5. Why pipeline leak detection is crucial for CCS

Safety is a key concern for CCS pipelines. The CO2 is either handled as a gas, or a supercritical phase fluid (sCO2) at extremely high pressure. Due to the higher pressure involved in transporting the CO2, explosive decompression of a CCS pipeline releases more gas, much faster than the equivalent explosion in a natural gas pipeline.

The effects of a leak or rupture on a CO2 pipeline can be catastrophic, both to people and the environment. Although CO2 might seem harmless because it's something people breathe out, in high concentrations it is an asphyxiant. A leak or rupture of a CCS project pipeline is also counterproductive, releasing the greenhouse gas back into the atmosphere.

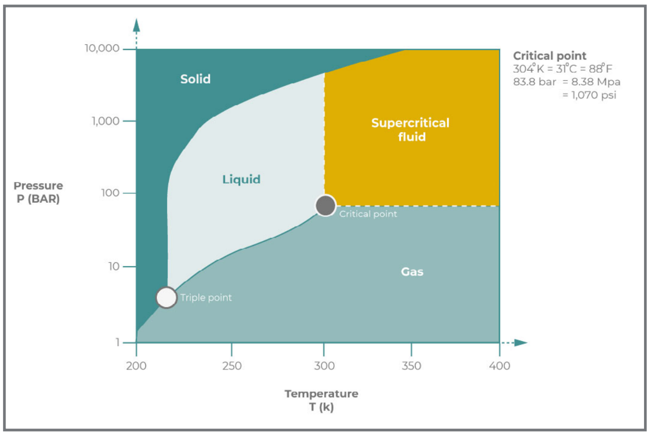

Figure 2: CO2 as a supercritical fluid[10]

Key effects of a leak or rupture of a CCS pipeline:

- Groundwater contamination for onshore sections
- Threat to life
- Greenhouse gasses released back into atmosphere
- Impact on the environment
- Hazardous to health[9]

In 2020, a CO2 pipeline ruptured in Mississippi, demonstrating the high consequences associated with what can happen when large quantities of carbon dioxide are released close to residential areas.

Given the number of projects in development and the large scale plans for CCS, pipeline leak detection will play a vital role in detecting and locating leaks in the pipelines as quickly and efficiently as possible.

6. Types of leak detection systems suitable for CO2 pipelines

The scale of CCS needed to meet targets means that investment in both onshore and offshore CO2 pipelines is required. Due to the human and environmental impacts of CO2, it is crucial to have an effective leak detection system (LDS) to monitor the pipelines. There are a variety of methods that can be used to work with both CO2 as a gas and as a supercritical fluid.

Since its release as the first statistical volume balance system in 1995, Atmos Pipe[11] has been at the forefront of leak detection technology. Atmos Pipe uses the powerful sequential probability ratio test (SPRT) method, which is effective for both gas and liquid pipelines. Using flow and pressure data from control room systems like the supervisory control and data acquisition (SCADA), Atmos Pipe will detect leaks quickly and effectively.

Atmos Pipe can be finely tuned to meet the sensitivity requirements to detect a CO2 leak on large complex pipelines. This is important, since many larger scale CCS projects capture CO2 from industrial sources and transport the liquified substance to an offshore subsea location for permanent storage. When used offshore, Atmos Pipe is configured to take account of both the hydraulic profile of the pipeline and the seawater outside the pipeline.

Alternatively, the multi-method Atmos Wave Flow[12] may be used which includes both a volume balance and a negative pressure wave (NPW) algorithm. The multi-method model of the LDS helps to reduce uncertainty and improves performance, providing an accurate leak detection and location in a short time. Factors like this are crucial to consider for CO2 pipelines where the gas is released into the air extremely quickly due to the amount of pressure used to transport it in the pipeline. In addition, deploying multiple methods of leak detection helps to increase the confidence of pipeline operators, who must decide on a suspected leak. Since CO2 pipelines is still a relatively new area, there's a gap in experience for many, making an accurate and reliable LDS extremely important.

7. Conclusion

CCS is becoming an increasingly important step of decarbonization for the energy industry. Truck and rail transportation methods simply aren't going to handle the large quantities of CO2 for CCS to make a significant impact, so the need for pipelines to support these projects is inevitable.

However, it is vital to consider the risks and uncertainties CCS carries.

Rolling out CCS projects on a large scale will increase the need for effective CO2 pipeline leak detection for the safe operation. The key drivers for CCS include the development of the hydrogen economy and reaching the 2050 climate targets set out in COP26. However, gaps in the infrastructure remain and therefore investment in improving the pipeline networks is likely to be required. It's vital that the pipeline infrastructure is engineered to the right standard and that the purity of the CO2 is closely monitored to avoid the issues surrounding carbonic acid.

Technologies like Atmos Pipe and Atmos Wave Flow can help pipeline operators mitigate the risks associated with CO2 leaks and ruptures, supporting pipeline operators by accurately detecting and locating them to ensure that they can be handled as quickly as possible.

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Liderroll
Brasil
www.liderroll.com.br

LogIC
France
www.logic-sas.com

MAX STREICHER
Germany
www.streicher.de/en

MTS Microtunneling Systems
Germany
www.mts-tunneling.com

Petro IT
Ireland
www.petroit.com

Prime Drilling
Germany
www.prime-drilling.de

Vlentec
Netherlands
www.vlentec.com

Construction Machinery

Maats
Netherlands
www.maats.com

VIETZ
Germany
www.vietz.de

Worldwide Group
Germany
www.worldwidemachinery.com

Engineering

ILF Consulting Engineers
Germany
www.ilf.com

KÖTTER Consulting Engineers
Germany
www.koetter-consulting.com

Inspection

3P Services
Germany
www.3p-services.com

A.Hak Industrial Services
Netherlands
www.a-hak-is.com

Ametek – Division Creaform
Germany
www.creaform3d.com

Baker Hughes
United States
www.bakerhughes.com

Dacon Inspection Technologies
Thailand
www.dacon-inspection.com

Eddyfi Technologies
Canada
www.eddyfi.com

EMPIT
Germany
www.empit.com

INGU
Canada
www.ingu.com

Intero Integrity Services
Netherlands
www.intero-integrity.com

Kontrolltechnik
Germany
www.kontrolltechnik.com

NDT Global
Germany
www.ndt-global.com

Pipesurvey International
Netherlands
www.pipesurveyinternational.com

PPSA - Pigging Products and Services Association
United Kingdom
www.ppsa-online.com

PIPECARE GROUP
Switzerland
www.pipecaregroup.com

Romstar
Malaysia
www.romstargroup.com

Rosen
Switzerland
www.rosen-group.com

Integrity Management

Associated Technology Pipeline Ltd
United Kingdom
www.atpuk.co.uk

Metegrity
Canada
www.metegrity.com

Pipeline Innovations
United Kingdom
www.pipeline-innovations.com

Leak Detection

AP Sensing
Germany
www.apsensing.com

Asel-Tech
Brazil
www.asel-tech.com

Atmos International
United Kingdom
www.atmosi.com

Entegra
United States
www.entegrasolutions.com

Fotech Solutions
United Kingdom
www.fotech.com

GOTTSBERG Leak Detection
Germany
www.leak-detection.de

Hifi Engineering
Canada
www.hifieng.com

Liwacom
Germany
www.liwacom.de

MSA
Germany
www.MSAsafety.com/detection

OptaSense
United Kingdom
www.optasense.com

Pergam Italia
Italy
www.pergamitaly.eu

PermAlert
United States
www.permalert.com

Prisma Photonics
Israel
www.prismaphotonics.com

PSI Software
Germany
www.psi.de

SENSOTOP
France
www.sensotop.com

SolAres (Solgeo / Aresys)
Italy
www.solaresweb.com

Materials

Vallourec
France
www.vallourec.com

Monitoring

Airborne Technologies
Austria
www.airbornetechnologies.at

Fibersonics
United States
www.fibersonics.com

Krohne Messtechnik
Germany
www.krohne.com

PHOENIX CONTACT
Germany
www.phoenixcontact.com

Teren
United States
www.teren4d.com

Operators

OGE (Open Grid Europe)
Germany
www.oge.net

Transneft
Russia
www.en.transneft.ru/

TRAPIL
France
www.trapil.com

Pump and Compressor Stations

TNO
The Netherlands
www.pulsim.tno.nl

Qualification & Recruitment

YPI - Young Pipeliners International
International
www.youngpipeliners.com

Repair

CITADEL TECHNOLOGIES
United States
www.cittech.com

Clock Spring NRI
United States
www.clockspring.com

T.D. Williamson
United States
www.tdwilliamson.com

Research & Development

Pipeline TransportInstitute (PTI LLC)
Russia
www.en.niitn.transneft.ru

Safety

Dairyland
United States
www.dairyland.com

DEHN & SÖHNE
Germany
www.dehn-international.com

OVERPIPE
France
www.overpipe.com

Signage

Franken Plastik
Germany
www.frankenplastik.de

Trenchless Technologies

Bohrtec
Germany
www.bohrtec.com

GSTT - German Society for Trenchless Technology
Germany
www.gstt.de

IMPREG GmbH
Germany
www.impreg.de

Rädlinger Primus Line
Germany
www.primusline.com

TRACTO-TECHNIK
Germany
www.tracto.com

Valves & Fittings

AUMA
Germany
www.auma.com

Franz Schuck GmbH
Germany
www.schuck-group.com

Zwick Armaturen
Germany
www.zwick-armaturen.de