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Pipeline Technology Journal

Leak Detection & Monitoring

Leak Detection for Energy Transition

Real-Time Monitoring of Critical Flanges

Fiber Optic Sensors

Third Party Interference Damage

Ageing Pipelines

Illegal Hot Tapping

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e-ISSN 2196-4300 / p-ISSN 2751-1189

PTJ EDITORIAL

Mike Kirkwood
Director, Integrity Engineering and Emerging Energy
T.D. Williamson

Welcome to the new issue of the Pipeline Technology Journal (ptj). I am honoured to sit on the ptj Editorial Board and am pleased to introduce this issue's editorial theme: leak detection and monitoring.

The latest CONCAWE Performance of European Cross-country Oil Pipelines report highlights that since 1971 (the start of the CONCAWE data), improvements in leak detection and monitoring systems have translated to better leak detection in liquid pipelines. The report identified that systems have detected 25% (as a moving average) of leaks over the last five years.

With the technology used in leak detection improving year-on-year, it's interesting to examine what's changes and what the future trends are especially with the move to net zero and emerging fuels. There will be new products flowing in our pipeline infrastructure, and detection and monitoring systems will need to address new challenges, including hydrogen, carbon dioxide and even ammonia.

In this issue, ptj looks at how the industry is gearing up for the future. We have a great line-up of papers, including an interesting in-line inspection approach to detecting theft, which has increased in recent years and is likely to be a continuing issue as energy prices soar. There's also a paper on an extended, real time transient approach that uses continuous monitoring and pattern recognition to spot leaks in difficult products such as hydrogen and carbon dioxide. Two papers focus on the use of fibre optic cable applications; one is about external detection and the other describes a novel use of fibre inside the pipe. Finally, an article about leak prevention introduces a plastic mechanical protection system that sits over the pipeline to reduce the impact of third-party damage.

We hope you enjoy this edition, and that it will educate you on the status of current and future technologies for leak detection and monitoring.

Your sincerely,

Mike Kirkwood

Director, Integrity Engineering and Emerging Energy

T.D. Williamson

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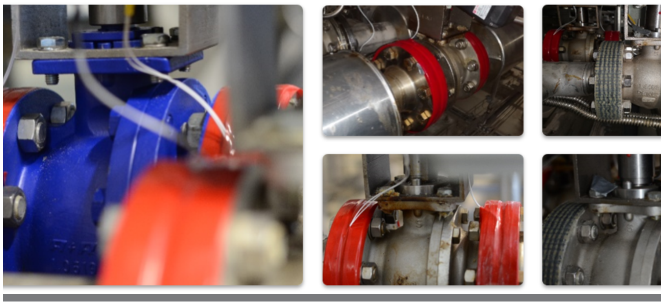

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Editorial Board

www.pipeline-journal.net
ptj@eitep.de

PUBLISHER
Euro Institute for Information
and Technology Transfer GmbH
Marie-Jahn-Straße 20
30177 Hannover, Germany
Tel: +49 511 90992-10
URL: www.eitep.de

ISSN
e-ISSN: 2196-4300
p-ISSN: 2751-1189

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Register Court: Amtsgericht Hannover
Company Registration Number:
HRB 56648
Value Added Tax Identification Number
DE 182833034

EDITOR IN CHIEF
Dennis Fandrich
E-Mail: d.fandrich@eitep.de
Tel: +49 511 90992-22

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ptj Editorial Board

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EDITORIAL MANAGEMENT
Marian Ritter
E-Mail: m.ritter@eitep.de
Tel: +49 511 90992-15
Constantin Schreiber
E-Mail: c.schreiber@eitep.de
Tel: +49 511 90992-20

ADVERTISING
Rana Alnasir-Boulos
E-Mail: r.alnasir-boulos@eitep.de
Tel: +49 511 90992-19

EDITORIAL STAFF
Mark Iden
Daniel Onyango

Joining YPPE has opened up a network of likeminded pipeliners. I feel part of a movement that wants to make a difference - all whilst having fun!

Kirsty McDermott, Senior Engineer

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Cause

pth Analysis of the Energy Crisis in Europe: es and Remedies — Dr Carole Nakhle

The prevailing energy crisis in Europe has exposed the EU's underlying problems that were overlooked for many years.

According to an energy economist, Dr Carole Nakhle, CEO of Crystol Energy, an advisory, research, and training company in London, Russia's invasion of Ukraine only amplified the already existing problem that was brewing over the years, explaining how the problem has been in the making for years and how the current crisis can be resolved and averted in the future.

Dr Nakhle broadly categorized the causes of the current energy crisis in Europe into three: the development of gas markets, dependence on Russian energy supplies, and confusing policy signals.

About Dr. Nakhle

Dr Carole Nakhle specializes in international petroleum contractual arrangements and fiscal regimes; upstream oil and gas regulations; petroleum revenue management and governance; energy policy, security, and investment; and world oil and gas market developments.

With a unique breadth of experience, she has worked with oil and gas companies (NOCs and IOCs), governments and policymakers, international organizations, academic institutions, and specialized think tanks on a global scale.

She is a regular contributor to Geopolitical Intelligence Service on energy matters, a program advisor to the Washington-based International Tax and Investment Centre, and a Participant in the OECD Policy Dialogue on Natural Resource-based Development. She is also active on the Advisory Council of the Natural Resource Governance Institute (NRGI).

Read the full interview: www.pipeline-journal.net

Leak Detection for Energy Transition

M. IHRING, D. VOGT > KROHNE SOLUTIONS

Abstract

With a shift from fossil-based energy production and consumption to renewable sources also comes a shift for the transportation. To guarantee safe and efficient monitoring of pipelines, leak detection systems (LDS) must be adapted to the new requirements.

The article describes how existing LDS can handle the requirements of energy transition applications with optimal performance. This is shown by examples in hydrogen pipeline as well as carbon capture applications. One of the hydrogen examples is a power-to-gas application producing green hydrogen which is then injected into a pipeline. The other application is a supercritical CO_2 application where CO_2 is removed from natural gas before liquefaction to LNG and then injected into wells.

The different requirements of these applications for leak detection are described. With real examples of model based LDS in energy transition applications it is shown how a long term efficient performance was guaranteed and how challenges were overcome.

1. Introduction

With a shift from fossil-based systems of energy production and consumption to renewable energy sources also comes a shift for the transportation. This is also true for pipeline leak detection systems. To guarantee the safe and efficient monitoring of the pipelines, leak detection systems must be adapted to the new requirements coming with the shift.

While there are pipelines transporting 100% hydrogen, there are others transporting a blend of hydrogen with natural gas. In carbon capture applications, the captured CO_2 is transported to sites where the CO_2 is stored or utilised. This CO_2 can be transported as gas, liquid or in supercritical state. As a result the leak detection system needs to be able to work with these different mixtures and phases.

For classical leak detection systems this is often a problem. Negative Pressure Wave leak detection systems are affected due to damping in gas. Classical statistical systems are affected due to compressibility and linepack changes. This leads to long detection times or high thresholds. The systems will react with a loss of sensitivity or in the worst case with false alarms.

Different mixtures and phases in the same pipeline are a typical application for Real-Time Transient Model technology (RTTM) based systems, which try to consider all blends of different products and pipeline properties in its calculations. However, if the fluid cannot be accurately modelled by the system this leads to false results. Unforeseen operating conditions will also lead to false alarms. The Extended Real-Time Transient Model technology (E-RTTM) can compensate for these disadvantages. The following chapter shows how the technology works.

2. Principle of E-RTTM (Extended Real-Time Transient Model)

E-RTTM is a leading technology for continuous internal monitoring of pipelines. It was developed by KROHNE, a manufacturer of measuring technology and established supplier of systems for the pipeline industry.

The E-RTTM introduced here is the basis of the PipePatrol leak detection system by KROHNE. With more than 35 years of experience with the technology and over 430 installations, the system has proven itself in monitoring liquid and gas pipelines (including liquefied gas and supercritical products) and meets all the requirements of TRFL and API RP 1130. Requirements of recent publications like API 1175 are also met. Next to the vertical combination of the virtual pipeline with pattern recognition, a horizontal approach combining different API 1130 methods into one system is present.

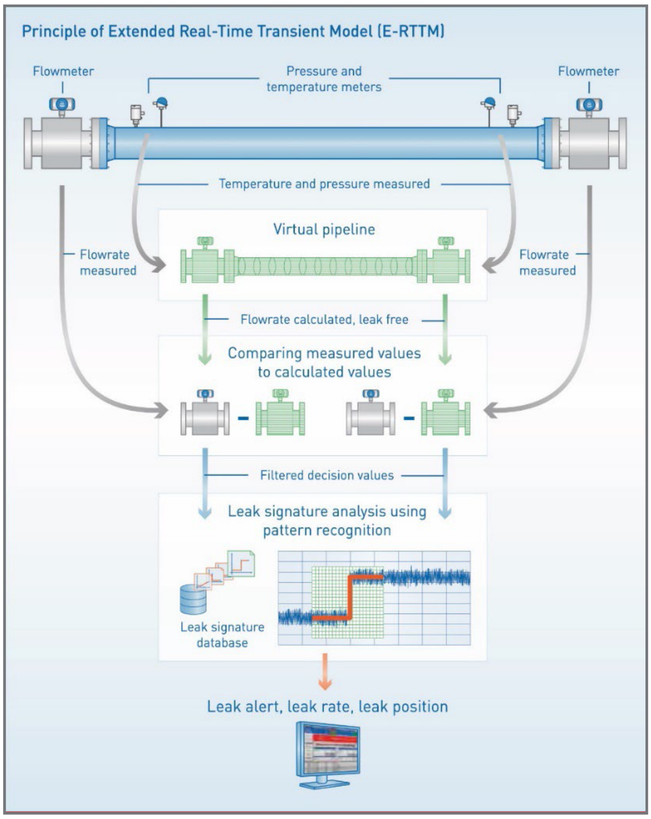

Figure 1: Basic functional principle of E-RTTM

E-RTTM extends a feature generation module with leak signature analysis using leak pattern detection: an E-RTTM leak detection system creates a virtual image of a pipeline based on measured data. Measured values from flow, temperature and pressure sensors installed at the inlet and outlet of the pipeline and along the pipeline in places such as pump and valve stations are crucial. The flow, pressure, temperature and density at each point along the virtual pipeline are calculated from the measured pressure and temperature values. The model compares the calculated flow values with the actual values from the flow meters. If the model detects a flow discrepancy, the leak signature analysis module then determines whether it was caused by an instrument error, a gradual leak or a sudden leak.

The Signature Analysis also makes the system less sensitive against inaccuracies in RTTM calculations, for example caused by blends of different products. Thus challenging pipeline conditions, product parameters or mixtures, e.g. hydrogen blends, that lead to these inaccuracies become less important. In PipePatrol, the RTTM is only used for filtering purposes, but leaks are detected by pattern recognition techniques.

E-RTTM provides a high degree of sensitivity and quick leak detection with real-time comparison of existing measuring results against leak signatures, which are stored in a database. Comparing of measured values with the leak signatures is also critical to the reliability because it provides a high degree of protection from false alarms.

E-RTTM-based leak detection systems can handle transient conditions that are not recognized by less sophisticated internal leak detection systems. An E-RTTM-based leak detection system works with dynamic values, which also boosts robustness, the system becomes independent of the absolute accuracy of the virtual pipeline. It can adapt automatically and very quickly to changes in the operating conditions such as sensor failure, communications failure, a valve closing or a product change in the pipeline. Practical examples are given below.

This does not only improve sensitivity and robustness, but also allows better individualization and optimization in energy transition applications.

Smallest detectable leak rates are typically 0.5% and below. Leak detection time in seconds, confirmation within minutes It has an exceptionally low false alarm rate due to onsite optimization. Due to the pattern recognition process it detects smallest leaks reliably and delivers repeatable results over a long period.

Leak size information is statistically refined and the leak localization is best-in-class by Gradient Intersection Method and Extended - Negative Pressure Wave Method.

3. Leak Detection System for Hydrogen

The leak detection system was installed on a hydrogen Power-to-Gas project in Germany which was the world's first demonstration plant for storing wind energy in the natural gas grid. The plant stores electricity generated by wind turbines. Around 360 Sm^3/h of

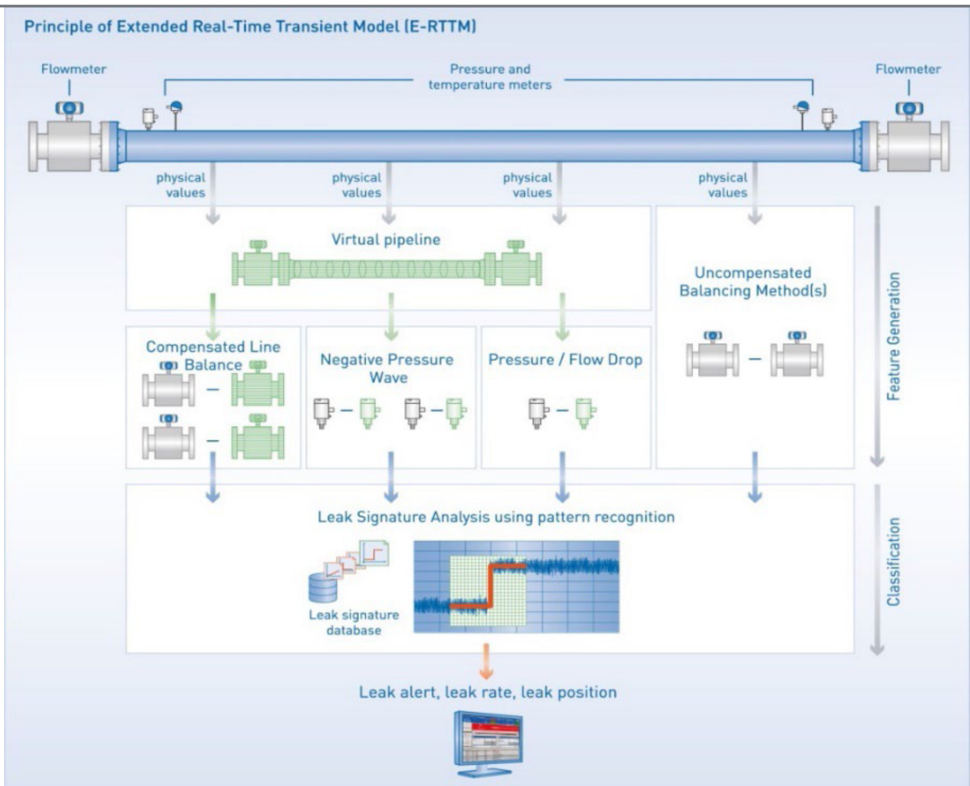

Figure 2: Extended functional principle of E-RTTM

Figure 3: Energy transition also means de-carbonisation: Electrolysis Systems in Power-to-Gas applications use electricity generated by wind turbines

hydrogen is generated by means of electrolysis and fed via a 1.6 km hydrogen pipeline into the gas grid.

As the leading leak detection system provider in Germany, KROHNE had been recommended by an independent 3rd party authority to be the supplier for the leak detection system which monitors the hydrogen pipeline connecting the alkaline electrolysis with the natural gas grid. The E-RTTM technology was selected due to its ability to measure a supercritical product even in small leak quantities and the model was adapted to the hydrogen properties. This was the first Power to Gas Application equipped with a PipePatrol leak detection system in 2013. Since then, PipePatrol has been installed on several hydrogen pipelines.

With all pipelines, a leak test was done under 3rd party review of TÜV, resulting in a swift leak alarm from PipePatrol. Since beginning of operation, the system has secured the transport of over 10 million kWh of hydrogen ("WindGas") fed into the grid.

4. Leak Detection System for Carbon Capture

The second application takes place in Western Australia: natural gas from the Gorgon gas field contains around 14% naturally occurring CO2. Prior to converting the natural gas to LNG by cooling it to -162°C / -259.6°F, the CO2 is removed. To minimize the environmental footprint, the separated CO2 is not vented but injected in a storage formation.

> **'With energy transition, product blends in pipelines have become more common, and this is often a problem for classical leak detection systems.'**

A 7 km long underground pipeline transports the CO2 from the LNG liquefaction plant to the CO2 injection wells.

The CO2 is transported in supercritical phase at elevated pressures. The underground pipeline has a diameter of 300 mm / 12". Three compressor modules feed CO2 in the pipeline that transports it to nine injection wells at three drill centers. The measurement requirement for this project was to provide a pipeline leak detection system that provides timely and accurate leak information for the three pipeline-segments between the LNG plant and drill-centers.

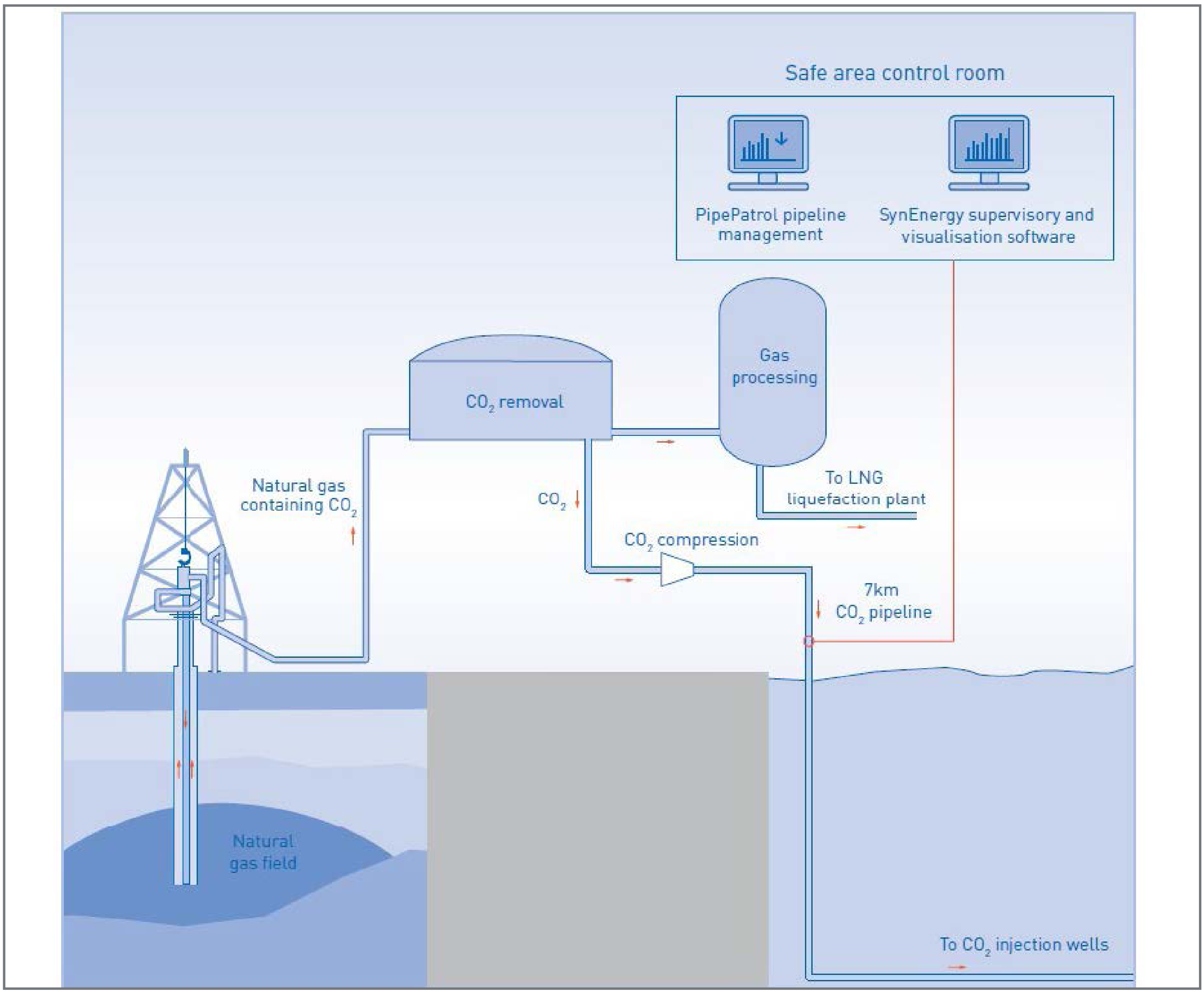

Figure 4: Process scheme: leak detection on a CO2 pipeline from LNG plant

KROHNE provided the E-RTTM based leak detection system. Based on flow, pressure and temperature measurement at inlet and outlet of the pipeline, and a digital twin of the pipeline, the system calculates the flow, pressure and temperature at any given position in the pipeline, using Real Time Transient Modelling.

In case calculated flow, pressure and temperature start to deviate from actual measured value, a proprietary algorithm (pattern recognition) developed to avoid false alarms, is used to distinguish between a sensor drift and a true leak. The project involved unique conditions, such as the specific thermophysical properties of CO2 in the supercritical phase and the flow measurements done by orifice plates with a limited rangeability.

A pipeline leak detection system based on E-RTTM supports the safe management of the CO2 transport pipeline's operations. In case of a leak, whether spontaneous or a small creeping leak, PipePatrol will alarm the customer accordingly.

5. Summary

The E-RTTM technology, which has proven to be a leading technology for continuous internal monitoring of pipelines, has been successfully adapted to energy transition applications. Through the possibility to adapt the model to the different requirements the overall result is better. The installation and configuration demands on the modelling part are dramatically reduced. Due to the Signature Analysis the system is less sensitive against inaccuracies in the process and modelling of the fluid.

The technology is industrial proven for hydrogen as well as carbon capture applications and is ready for the energy transition. Smallest detectable leak rates are typically 0.5% and below. Leak detection time in seconds, confirmation within minutes It has an exceptionally low false alarm rate due to onsite optimization. Due to the pattern recognition process it detects smallest leaks reliably and delivers repeatable results over a long period. Leak size information is statistically refined and the leak localization is best-in-class by Gradient Intersection Method and Extended - Negative Pressure Wave Method.

AUTHORS

Maximilian Ihring
KROHNE Solutions
Product Group Manager,
Pipeline Management Solutions
m.ihring@krohne.com

Daniel Vogt
KROHNE Solutions
Business Unit Manager,
Pipeline Management Solutions
d.vogt@krohne.com

Real-Time Monitoring of Critical Flanges via Hydrocarbon Leak Detection

J. FRANK, M. HONNÉ, K.BAHRAMI, J.SCHOENE > HENKEL AG & CO. KGAA

Abstract

Ensuring the safe operation of flanges is critical to the integrity of piping systems in the oil and gas industry. Given the intense conditions that process equipment often experiences, flanges are subject to a variety of defect mechanisms, such as corrosion, scratching, gouging, pitting, or denting. These defects can lead to flange leakages that pose a hazard for both machinery and for facility personnel, waste costly resources or lead to an unplanned shutdown in the case of severe leaks.

In order to detect leaks as early as possible, various leak detection systems including both hardware and software-based methods or biological based detection methods are being utilized by operators of the oil and gas industry. Most of the methods don't fulfil all criteria such as cost efficiency, sensitivity, continuous and ease of use and operation at the same time.

Therefore, the following paper describes a technology-based procedure of a real-time hydrocarbon leak detection for critical flanges. This smart leak detection system consists of an innovative hydrocarbon detection sensor placed non-intrusively within the flange gap, a secondary containment and a device that connects to the sensor. The device uploads the measured signals to a cloud-based platform. In case of a leakage, the user will be informed through a notification message in a user application. This allows real-time monitoring of critical flanges to create an additional level of safety by contributing to the detection of leakages before the medium can escape into the environment and cause major damage.

1. Introduction

Hydrocarbons are of great technical and economic importance, especially in the oil, gas and petrochemical industries, due to their use as fossil fuels and in organic synthesis. The oil, gas and petrochemical industries are mainly characterized by the production and processing of hydrocarbons. For this purpose, pipes and flanges are ubiquitous in all areas of upstream, midstream and downstream piping systems. In this context the industry is facing one common challenge: Preventing flange leakage as a particular weak point for leakage of hydrocarbons to the enviroment [1]. A refinery can emit more than 600 tons of volatile organic compounds per yer from leaking equiment and in more than 90% of these cases the connecting flanges are accountable for this.

There are several possible causes for flange leakages. For example unequal or insufficient bolt loads can affect the required compression load level of the gasket. Those conditions can lead eventually to leakages, as well as the influence of varying temperatures and ageing influences on the heavily loaded bolts. Also improper flange alignment, unequal gasket compression or local overload causes subsequent leakage [1, 2]. Various damages to flanges in the form of dirt, scaling, internal and external scratches, protrusions, and weld spatters result in flange leakage [2, 3]. Also, the flanges with warped seating surfaces increase the chances of leakage. Thus, there are many different reasons for flange leakages and this can lead to serious consequences. [1, 2, 3] Hydrocarbons are volatile and flammable, any possible failure of the containing or carrying equipment could lead to catastrophic events. Detecting hydrocarbon leaks at an early stage is critical to reduce the risk of fire and explosion accidents [1]. This is especially important for flammable liquids and gases that can form explosive mixtures with air. But the economical aspect of it is also important. Besides the safety related consequences, leakages come with directly accountable costs for loss of products, pressure or heat energy as well as costs for inspection,downtime, environmental cleanup cost and possible fines and legal suits from habitants [1, 2]. Besides this, there are also labor and material costs for the reactive repair of a leakage and a risk of loss in reputation. If a severe leak or the repair of it causes an impact on the operational production process (e.g. product quality) or an unplanned downtime of a subprocess or even the whole plant, the accountable damages can result in millions of dollars [1].

For example, the incident of a leakage on a pipe in a refinary in Philadelphia, USA in 2019 injured five people. The critical (elbow) pipe was not monitored periodically and there was a major loss of primary containment on the hydrofluoric acid alkylation unit at the refinery resulted in a large fire and subsequent explosions. More than 307 tons of hydrocarbons and two tons of highly toxic chemical were released to atmosphere. The refinery shut down shortly after incident, filed for bankruptcy.[8, 9]

If leakages could be detected with a high confidence and reliability at that very moment they occur, this would considerably decrease the probability of severe consequences and therefore costs of unplanned downtime, emergency repairs, clean ups and risk related costs like insurances [1, 6]. Unfortunately, pipe operators appear to have inadequate industrial technology to manage real-time monitoring of flanges. The definition and corresponding requirements on“real-time” monitoring are depending on the application context; real-time in this paper is defined as continous monitoring to be able to detect a leakage in a adequate time interval before seroius consequences will take place. Most of the existing methods can not deal with the complex situation of optimizing transportation and production and minimizing costs associated with the operation while maximizing reliability and real-time monitoring at the same time [2, 6, 12].

Based on these challenges, new data-based maintenance solutions offer the possibility to optimize the overall system of leakage management. With the help of condition monitoring it is possible, to find the optimum between early leak detection on the one hand and costly repairs, production losses and unplanned downtime on the other hand [5]. The widespread use of data-based maintenance concepts for real-time monitoring of critical flanges has not yet become established. This is mainly due to the formerly complex integration requirements and high costs for sensor systems and data analysis. As the costs of sensors providing valuable data and tools to analyze the data became tremendously cheaper in the last years, the trend is now also reaching smaller and less process critical assets. In parallel the rise of cloud computing in combination with edge processing enables installing sensors without the need for building up expensive local infrastructure or complex software integration requirements [10]. New sensor systems can now be retrofitted without the need to stop the plant or integration into legacy control systems. Thus, enabling data-based maintenance approaches to apply for assets, in this case piping systems and here especially flanges, that have been offline in the past. This technological shift allows to go from the reactive (run-to-failure) strategy in favor of a data-based predictive maintenance, whereby predictive in the meaning of this document means the possibilty to predict further, increased damage after occurrence of the leak, if no countermeasures will be taken [5, 10]. Predictive maintenance is a data-driven maintenance strategy that uses sensors to continuously monitor asset health and performance and allows a early detection of potential failures. Predictive maintenance is also a key enabler for new service-based business models.

This paper takes up precisely this development and describes a technology-based procedure of a real-time and continuous hydrocarbon leak detection for critical flanges for piping systems.

2. Review of potential leak detection methods

There are several methods and techniques for the detection of hydrocarbon leaks. Table 1 summarizes the main classes based on the principle of operation. The techniques include both exterior and interior or computational methods and as well as biological based detection methods [1]. The exterior approach uses different kinds of sensing systems to detect leakage outside a pipeline or a piping system [1, 4]. Moreover, the biological approach is based on visual, acoustic or olfactory senses of trained dogs or high qualified personnel to detect a leakage in a piping system. The interior approach utilises software-based methods like computational algorithms which receive data from sensors monitoring the internal pipeline parameters for detection task [1, 4, 13]. These different methods have been identified to be useful in the area of identification of available leaks. The

Method	*System*	*Examples*
Acoustic	Exterior approach	Acoustic Leak detector, hydrophones, Electromagnetic Acoustic Transducers (EMAT), piezoelectric meter etc.
Fibre Optics	Exterior approach	Optical sensors (for leak, strain, fatigue and ground movement detection), etc.
Infrared Thermography	Exterior approach	Infrared thermography camera
Magnetic Field Methods	Exterior approach	Eddy current, Magnetic Flux Leakage, Magnetic particle inspection, “Smart pigging” etc.
Electromechanical impedance technique	Exterior approach	Piezoelectrical patches in Electro-Mechanical Impedance (EMI)
Visual Inspection	Biological approach	Use of human eye, Satellite based Imaging, Inspection light, Trained dog etc.
Inventory accounting	Interior approach	Negative pressure wave (NPV) detectors, Pressure Point Analysis, Balancing Models, Real Time Transient Modeling, Digital Signal Analysis

Table 1: Selection of hydrocarbon leak detection methods [1, 4]

methods are irrespective of the class of the causal damage and potential leak identification due to metal loss. In the following, the different approaches are described and evaluated with respect to their suitability in the context of real-time monitoring of piping systems and resulting data-driven maintenance strategies. In the end there is a summary of pro and cons of each technology.

Acoustic leak detection utilizes noise emission or vibration caused by an unexpected fall in pressure to detect the existence of a leakage in a pipe [2, 7]. Due the high-pressure in the pipe elastic waves were generated by fluid escaping from the perforated point. There are serval installed sensors and the time lag between an acoustic signal detected by two sensors helps to identify the leakage position [12, 14]. However, especially for piping systems on the ground of a refinery with a high level of background noise critical leakage may not be detected reliably, because the noise hides the acoustic signal of leakage at a high flow rate. Also, it is not suitable for small leaks. [1, 11, 13]

Fibre Optic Methods uses sensors installed along the exterior of the pipe. When a leakage in a pipeline or piping system takes place and hydrocarbons engross into a coating cable, the temperature of this cable will change [2]. This leads to a temperature variation in the fibre optic cable which can be measured and anomalies along a pipeline or piping system can be detected [11]. The implementation cost of this method is high and will not work for systems protected by a cathodic protection system. [1, 11, 12]

A Leakage detection system using the *infrared thermography (IRT)* mechanism is also relevant for the detection of hydrocarbon leakages. The infrared cameras show an infrared range of 900–1400 nm, which allows this technique to detect temperature changes in the pipe environment. The result is a thermogram, which captures all images from the IRT camera. IRT can be used for different condition monitoring applications like heat transfer or tensile failure as it is a contactless and non-invasive. However, the cost of a high-resolution infrared camera is very high, while only covering the visible field for a mounted system. Moreover, quantifying a very small leak using this method is challenging.

There is a range of common methods utilizing *Magnetic Fields* to monitor piping systems and equipment regarding cracks, corrosion and reduced wall thickness. The common element of those methods is a magnetic field, which is generated by permanent magnets or electromagnets. The flow of either the magnetic resp. the induced electrical field in the base structure is observed, which will be influenced by structural flaws in the material. This is either carried out with sensors or visually with the help of magnetic powders or dyes. Magnetic Flux Leakage and Eddy Current Technology can also be applied in larger sensor arrays via Smart Pigging, where the carrier device (smart pig) is inserted into the pipe and scans continuously as it passes through. Due to magnetism based principles, these methods are only applicable for metal resp. magnetizable pipelines and piping systems [15, 16, 17].

Electromechanical impedance (EMI)-based techniques utilize piezoelectric transducers and the analysis of electromechanical impedance to detect structural flaws. EMI transducers are made up of small surface-bonded piezoelectric ceramic patches, as actuators and sensors. They emits high-frequency structure excitation to the host structure [18], at the same time, they also measure the overall dynamic impedance, in order to assess the structural integrity and thus, causes for leaks. In the situation of mechanical pipe defects, the EMI senses the variations in structural point impedance. The method shows operational limitations in high temperature environments. Furthermore the method is a high-cost factor and has high requirements on equipment. [1, 18]

Visual inspection methods of detecting leakages uses traditional processes of detecting leakages in a pipeline or a piping system using trained dogs, qualified personnel or air vehicles [1, 2]. These methods are most of the time based on experienced personnel who inspect the pipes and search for anomalous and unusual situations in the pipe's environment with or without measurement equipment. High experienced personnel i.e. recognise leakages through visual inspection or smelling the aroma coming from the hydrocarbon emission [1]. Also, the vibration and noise coming from a leakage point could be recognized by experienced personnel. Trained dogs work in a similar way focusing on smelling leakages. In all of the cases mentioned above the detection time is dependent on the frequency of inspections which varies from weekly up to even annual or less frequent inspections, so there is no real-time monitoring. [1, 13]

Inventory accounting methods are based on monitoring parameters connected to the fluid flow in a pipeline or piping system by using internal fluid measurement instruments [1, 12]. The systems operate continuously to monitor critical parameters in a piping system such as pressure, flow rate, temperature, density, volume and other parameters which quantitatively describe the products inside [4, 6, 14]. The difference between to segments of a piping system regarding pressure, temperature etc. can be used to detect a leakage based on various computational methods, for example mass-volume balance, negative pressure waves (NPV), pressure point analysis, digital signal processing and dynamic modelling [6, 14]. These methods allow a permanent monitoring of the condition of the piping system. However, some of the methods have disadvantages, for example mass-balances approaches depend very much on the size of a leakage and cannot be used for leak localisation. Digital signal processing is highly dependent on background noise and circumstances like corrosion, bending or blockage can lead to false alarms. The NPV method has a fast response time and is suitable for leak localisation but however, it is only effective for larger leaks. [1, 6, 12]. As a related analytical approach, it has been shown that also base data from Smart Pigging can be used to detect leaks. Although those tools are mainly used for wall thickness measurement and crack detection, by advanced signal processing of velocity and pressure data unique signatures of leaks as well as their location can be determined [19].

Based on the various reviewed pipeline and piping systems leak detection methods, the performance regarding a detection of small leakages, real-time and low-effort hydrocarbon leak detection varies depending on the approaches, operational conditions and pipeline networks [1, 6]. Real-time leak localisation and estimation of the leakage rate are important, as they will facilitate spillage containment and allow predictive maintenance strategies at an early stage to avoid serious damage to the environment. One pragmatic way to achieve this goal is through implementation of a certain number of leak detection sensors in a sensor network between the upstream and downstream of the piping system. By doing so, it will be easy to identify the position of a leakage and thus improve the ability to see and track information when a sensor acquires anomalous data. Remote monitoring of piping systems using wireless communications technology may have benefits of lower costs and effort, real-time response and the ability to identify the locations where leakages take place.

3. Real Time Monitoring of Critical Flanges

Based on the review, it can be concluded that each technique has some merits and drawbacks especially with a focus on real-time and reliable hydrocarbon leak detection [6]. LOCTITE® Pulse Smart Flange is one solution addressing these points. The core element of the system is an innovative carbon nanotube-based hydrocarbon sensor technology. The retrofit sensors are placed non-intrusively within the flange gap in combination with a secondary containment (see Figure 1). A secondary containment helps to prevent the medium from leaking into the

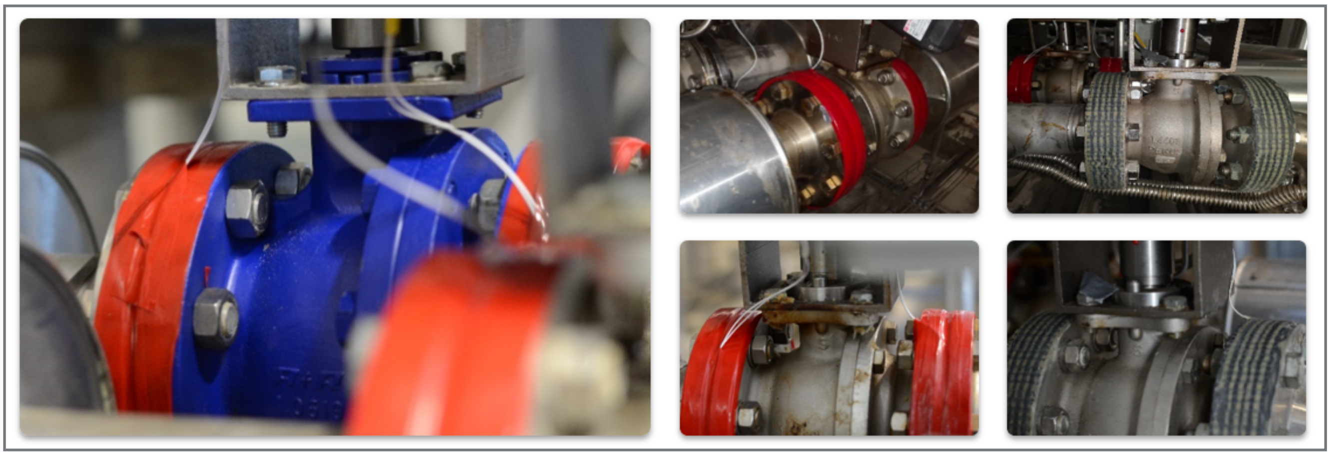

Figure 1: LOCTITE® Pulse Smart Flange installation examples

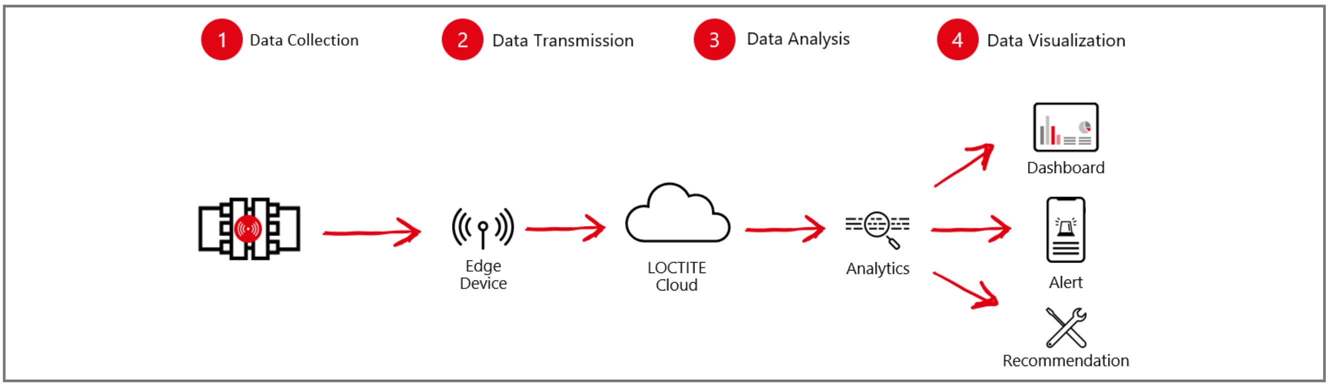

Figure 2: Schematic solution overview

environment for a certain period. The sensor can detect leakages in almost real-time and can be leveraged to monitor critical sections of pipes notifying the operator through an app and email notifications. Continuous digital documentation of the asset status and its accessibility increase transparency and reveal potential for improvement. Therefore, the integrity of every leak critical asset can be monitored continuously. Leakages can be repaired when they have not yet developed into more severe leakages. This helps operators to prevent costly unplanned downtimes and risky consequences that might develop from a leak. On the other hand, the solution may reduce the required efforts for manual inspection, while increasing the inspection quality. The carbon nanotube-based sensors detect even small hydrocarbon amounts and allows the operator to undertake countermeasures before they escape into the environment. These sensors collect data in almost real-time (Step 1) and transfer the information through dedicated IoT networks (Step 2), to a centralized database for analysis. Through an edge device the sensor data will be transmitted to a cloud (Step 3) and will be analysed (Step 4). The edge device is independent of local network thanks to cellular communication. The cloud runs that data through a set of prebuilt predictive algorithms to detect small leaks. A web-based platform independent of end device or operating system provide the information about leakages in real-time. Figure 2 shows a schematic solution overview.

4. Real Time Monitoring as Enabler for Predictive Maintenance

The advantages of predictive maintenance may be immense from a cost-savings perspective and include minimizing planned and unplanned downtime, maximizing the lifetime of a piping system, optimizing maintenance strategies including productivity of employees and increasing revenue [5]. The advantage of predictive maintenance is its ability to transform both a maintenance team and an organization, as implementing predictive maintenance allows asset managers to improve outcomes, continuously monitoring equipment and better balance different priorities such as profitability and reliability [5, 10]. Predictive maintenance cannot exist without real-time monitoring. There are two facets of real-time monitoring: online and remote. Online real-time monitoring is defined as the continuous monitoring, with data collected on critical parameters in an adequate time interval. Remote monitoring, as its name suggests, means equipment in this case piping systems can be monitored from a remote location, with data transmitted for analysis of critical parameters. The described LOCTITE® Pulse Smart Flange is one solution meet these requirements. This enables to go from the reactive (run-to-failure) strategy to a data-based predictive maintenance strategy (see Figure 3). Thus, continuous, real-time monitoring of critical flanges results in five key value drivers for plant operators described in the following.

1) Contribution to increased safety:

The greatest added value of continuous monitoring of critical flanges is certainly the contribution to increasing plant safety. Continuous monitoring in real-time enables early detection of leaks even before they can progress significantly and thus, pose a considerable safety risk. Consequently, it provides an additional level of safety in addition to existing systems and processes. In addition to the obvious added value in terms of health and safety risks, this can also result in an economic advantage, as the cost of insuring against safety-related incidents may be reduced.

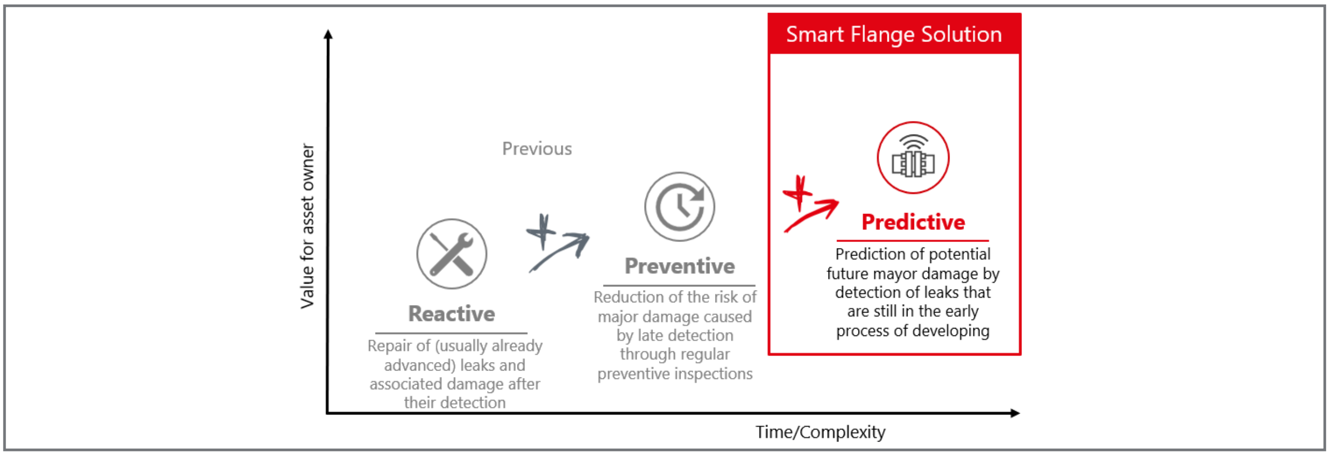

Figure 3: From 'reactive' to 'predictive' maintenance

2) Contribution to the reduction of environmental risks:

In addition to health and safety risks, another key added value of continuous and real-time monitoring of critical flanges is its contribution to reduce environmental risks. By preventing major leaks, damage caused by the release of critical substances into the environment can be reduced. This helps the environment and reduces the risk of reputational damage.

3) Contribution to the reduction of production losses:

In addition to the positive contribution to plant safety, the greatest economic added value of continuous monitoring of critical flanges for most plant operators is the contribution to reducing production losses. By detecting leaks in progress at an early stage, repairs can be planned in advance, thus reducing downtime and/or quality losses in production. With hourly opportunity costs in the four- to five-figure range, significant costs can be reduced by shrinking downtime in general and converting unplanned downtime to planned downtime. For a mid-size refinery, this can mean cost savings up to high six to mid seven-figure EUR amount per annum.

4) Contribution to the reduction of inspection, documentation and repair efforts:

Another positive economic added value of continuous monitoring is the contribution to the reduction of inspection, documentation and repair efforts. Even though existing processes and systems for monitoring critical flanges should not be completely replaced by a continuous monitoring solution such as the Smart Flange - the solution offers the possibility of reducing previous efforts. For example, inspection intervals can possibly be extended. In addition, the costs for repairs may be significantly reduced by early detection. Last but not least, efforts for manual documentation can be reduced by digital and automated data collection. For a medium-sized refinery, this in turn can result in cost savings of up to a mid-six to low seven-figure EUR amount per annum.

5) Contribution to increased transparency:

An often overlooked and underestimated added value of continuous monitoring of critical flanges and other assets lies in their contribution to increased transparency. The continuous collection and analysis of data makes it easier to identify weak points and uncover possible correlations. This makes it easier to learn from failures and to contribute conclusions for avoiding future errors – in this case, especially leakages.

5. Conclusion

Especially for critical flanges, as they often occur in several hundred even in small to medium-sized refineries, continuous monitoring is recommended to create not just an additional level of safety, but also to save costs. In the overall view, it is crucial that the operators do not only compare the costs of the solutions directly, but look at the whole picture and, for example, also include opportunity costs, downtimes, etc. in the calculation. Besides this, an increase in transparency and a reduction of environmental risks are key value drivers. In the future, it is to be expected that real-time monitoring solutions will continue to drive the shift from reactive to proactive maintenance. Especially in relation to falling costs for sensor systems, future solutions will not only be available or profitable for the most critical flanges and pipes, but for a wide range of equipment.

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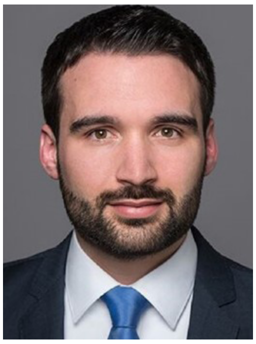
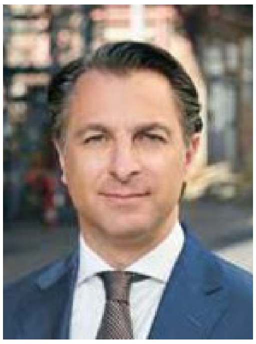
AUTHORS

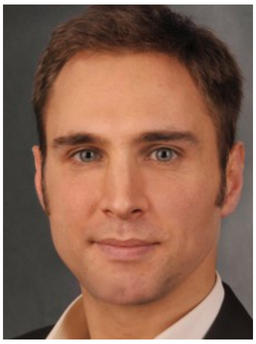
Jana Frank
Henkel AG & Co. KGaA
Country Business Head Singapore & Malaysia
Jana.Frank@henkel.com



Michael Honné
Henkel AG & Co. KGaA
Head of MRO 4.0
Michael.Honne@henkel.com



Kourosh Bahrami
Henkel AG & Co. KGaA
Corporate Vice President Henkel – Adhesive Technologies
Kourosh.Bahrami@henkel.com



Jens Schoene
Henkel AG & Co. KGaA
Global Technical Customer Service Management
Jens.Schoene@henkel.com

Tackling corrosion and leakage by retrofitting pipelines with fiber optic sensors

T. LANCKRIET, T. VAN HOESTENBERGE, T. VAN CAELENBERGHE > FLUVES NV

Abstract

Corrosion Under Insulation (CUI) of insulated pipelines and leakage or intrusion detection on underground utility pipelines are two applications where Distributed Fiber Optic Sensing (DFOS) provides a promising alternative to existing monitoring techniques. In this paper, we present case studies for both domains.

When Distributed Acoustic Sensing (DAS) is used in combination with Distributed Temperature Sensing (DTS) to monitor corrosion under insulation (CUI) risk in the chemical industry, a fiber optic cable is attached to the outer cladding of the insulated pipeline. This offers the big advantage that the insulation or cladding does not need to be dismantled to install the monitoring system. The monitoring system CUI-CONTROL was specifically developed this way.

On the other hand, detecting leaks and third-party intrusions (TPIs) in underground pipelines can be done by placing a fiber optic cable inside the pipe. This allows existing pipelines to be retrofitted without new trenching, and leak sounds are detected without concerns about the relative positioning between fiber and leak. With that in mind, DALI (Distributed Acoustics for Leakage and Intrusions) was developed, which is highly suited for retrofitting utility, steam, oil and gas pipelines.

1. Widening the application range of fiber optic sensing

Distributed Fiber Optic Sensing (DFOS) has been successfully applied for in the oil and gas industry for many years, first with Distributed Temperature Sensing (DTS), then Distributed Strain Sensing (DSS) and, most recently, Distributed Acoustic Sensing (DAS). Over the last years, the performance of DFOS systems and the related knowhow have increased while DFOS hardware prices have dropped, broadening the application range of fiber optic-based pipeline monitoring to new markets such as the chemical and manufacturing industry to monitor the risk at corrosion under insulation on pipelines, tanks, and cryogenic facilities, as well as the utility sector (drinking water, sewage water, district heating, ...).

For the utility sector, and especially the drinking water sector, additional challenges arise compared to oil & gas pipelines. These include:

- Pipelines can be of a very old age (up to 100 years), with the pipeline condition and even the route not fully known at the start of a project.
- A very wide variety of pipeline materials are used (concrete, steel, cast iron, asbestos cement, PVC, polyethylene, and several others).
- Pipelines are buried in heavily urbanized areas, under roads, railways, canals, and other infrastructure.

Both in the chemical sector and in the utility market, there is a vast volume of existing, ageing pipeline assets that are much more prone to leakage or corrosion than newly constructed pipelines. To minimize the maintenance (opex) and replacement (capex) expenditures, inspection methods should therefore focus on retrofitting existing water pipelines with fiber optic monitoring.

2. DAS and DTS working principles

Distributed Acoustic Sensing systems (DAS) and Distributed Temperature Sensing systems (DTS) are optoelectronic instruments that record acoustic vibrations and temperature along the length of a fiber optic cable. DAS and DTS are distinguished from (industrial) IoT sensors by the fact that they give a continuous and distributed acoustic or temperature profile down the length of the sensing wire rather than at discrete sensing locations. The physical principle behind DAS and DTS is as follows [1]:

1. The interrogator fires light pulses into the fiber using a highly coherent laser.
2. Photons reflect on small inhomogeneities in the glass matrix due to Rayleigh (for DAS), Raman or Brillouin (for DTS) scattering. These reflections are dependent on thermal and acoustic vibrations on the fiber and return to the interrogator where they are recorded and analyzed.
3. Since a pulsed light source illuminates only a piece of the fiber at a time, this allows for a distributed measurement of the scattering on the fiber that is highly spatially accurate, a principle known as OTDR (Optical Time Domain Reflectometry).

As a result, a DAS or DTS system essentially converts a single fiber into a string of thousands of highly sensitive acoustic vibration or temperature sensors. Due to the optical nature of the measurements, a single DAS or DTS device has a range of up to 90 km, is not vulnerable to electric interference, and is fundamentally ATEX-proof.

Due to the huge amounts of data produced by distributed sensing systems, a data management, processing, and visualization approach is essential. The interrogation devices are usually connected to a processing unit (such as an industrial PC or a server) that handles data storage and processing.

3. Detecting early stages of corrosion

The CUI-CONTROL system was developed by Fluves, an engineering company specialized in fiber optic monitoring. It consists of several components:

1. A fiber optic cable is attached to the outer cladding of the insulated pipeline, tank, or cryogenic facility. There is no need to dismantle or rupture the cladding, insulation, or pipe.

2. A DAS and DTS system that record acoustic vibrations and temperature along the fiber, with a spatial resolution of 1 m.

3. Advanced signal processing and machine learning software, which scan the raw acoustic and temperature measurements for increased risks of corrosion. The CUI-CONTROL software runs on an edge server that is co-located with the DAS and DTS system and transmits its results to the cloud or the operator intranet.

4. An online dashboard that visualizes the asset (pipeline, tank or ice box) status in real time, shows the location and history of any anomalies, and sends alarm notifications via e-mail or SMS.

3.1 BASF pilot test

A pilot test of CUI-CONTROL was executed at BASF Antwerp (Belgium) on a 300 m insulated MDI pipeline section. To monitor the pipeline, a fiber optic cable was attached to the outer cladding of the pipeline with weatherproof tape (Figure 1).

The pipeline has been continuously monitored since August 2021, and several successful proof of concept tests have been performed by BASF. The CUI-CONTROL software detected several potential corrosion spots along the pipeline. Besides pinpointing the spots with a 1 m accuracy, the detection system also provided an estimate of the severity of the corrosion risk (small – medium – large risk), meaning that Fluves could prioritize the spots according to corrosion risk for BASF. A visual external inspection is always part of the maintenance strategy at BASF. In this specific section of the pipeline the inspection team found no visible holes, dents, or other abnormalities on the outside of the cladding, even at the spots that were identified as high-risk.

In April 2022, a BASF team removed the cladding and insulation on the monitored section and inspected the locations that were identified by Fluves' CUI-CONTROL system in detail. At all identified points, the corrosion risk matched perfectly with the CUI-CONTROL predictions (figure 2). Also, the spatial coverage as forecasted by Fluves' CUI-CONTROL system matched 100% with the reality, so the locations were pinpointed very accurately (1m accuracy). This also means that the CUI-CONTROL system is able to locate corrosion risk hotspot that could not be detected by external visual inspections.

Figure 1: The Fluves engineers installing the sensing system on the MDI pipeline at BASF.


Figure 2: Corrosion was detected on the exact points that the CUI-CONTROL system pointed out.

In response to the pilot test results, Robin Guldentops, the Asset Manager ESP/IL at BASF, said that "CUI-CONTROL was able to find the exact locations of potential corrosion sites. The system is able to measure the degree of risk at corrosion with great precision, and the system has the added advantage that it can be applied on the outer layer of the jacketing, without having to dismantle anything".

3.2 CUI-CONTROL return on investment

The installation of a fiber-based CUI monitoring system provides direct financial gains to the pipeline by reducing inspection costs, reducing asset damage and downtime due to CUI, prolonging the asset lifetime, and reducing energy losses. Additional benefits that happen are reduction in downtime and welding costs, reduction of urgent leak repair, improvement in inspection planning, the gain of an active leak detection and fire detection system in place. Not to forget: the positive publicity because innovation steps are being made, and on the other side avoiding negative publicity on environmental risks. The fiber that is placed on the pipes also opens the door to add-on applications such as steam trap monitoring and pipeline vibration

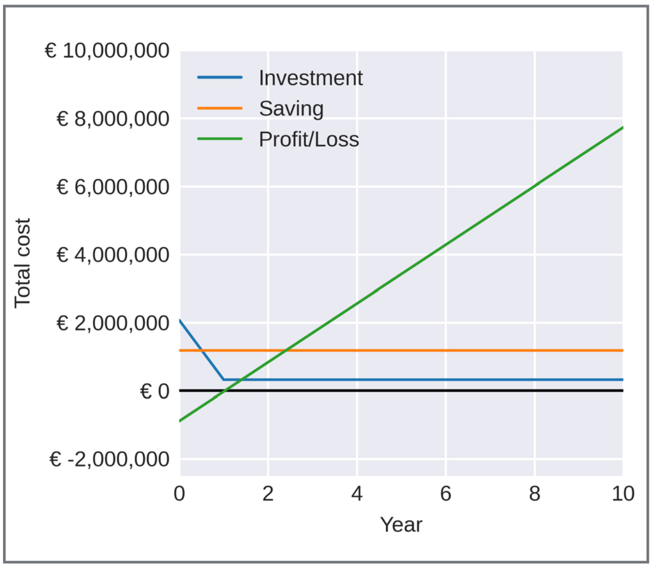


Figure 3 The return on investment of installing CUI-CONTROL is less than two years.

monitoring.

The overall return on investment of a CUI-CONTROL monitoring installation was calculated for a fictitious plant with 155 km in insulated pipelines, which is representative for a large chemical production facility. In this example, the return on investment of installing the CUI-CONTROL system is less than two years Figure 3).

4. Locating leaks in water pipelines

For underground utility pipelines, such as trunk mains for drinking water, retrofitting by trenching an external fiber is uneconomical due to the presence of other infrastructure above the pipeline. For this reason, a pipeline monitoring system that uses a fiber optic cable installed inside the pipeline was developed: the DALI (Distributed Acoustics for Leakage and Intrusion) system. It was jointly developed by Fluves, an engineering company specialized in fiber optic monitoring, and Vigotec, a manufacturer and distributor of pipe systems and engineered plastics. The components are similar to CUI-CONTROL although there are some differences:

1. A fiber optic cable is installed inside the pipeline. The cable housed in a durable cable mantle that is certified for safe use in drinking water. An innovative installation system was developed that allows to install the cable in the pipeline while it is pressurized and in operation.

2. A DAS system, which records acoustic vibrations along the fiber, with a spatial resolution of 10 m.

3. Advanced signal processing and machine learning software, which scan the raw acoustic measurements for notable incidents such as leaks or third-party intrusions (TPIs). The DALI software runs on an edge server that is co-located with the DAS system and transmits its results to the cloud or the operator intranet.

4. An online dashboard that visualizes the pipeline status in real time, showing the location and history of any alarms, and sending alarm notifications via e-mail or SMS.

4.1 FARYS pilot installation

A pilot test of DALI was executed on a 6 km pipeline section near Brussels, Belgium, operated by the drinking water utility FARYS. The pipeline has a 1000 mm diameter and a three-layer structure known as sidero-cement: an inner cement lining, a steel core tube, and an outer layer composed of reinforced concrete.

To monitor the pipeline, a fiber optic cable housed in a polyethylene microduct (a hollow tube) was installed inside the pipeline. The installation of the cable was done in 5 sections of 200-1900 m length, with the cable exiting and re-entering the pipeline in between each section (Figure 4). This was done in order to bypass shut-off valves along the pipeline route (which cannot be closed if the cable passes the valve directly) and to allow for maintenance access to the fiber. Electrofusion fittings were used to provide a reliable, pressure-proof seal around the microduct where the cable enters or exits the pipeline.

The pilot installation, executed in February 2020, was performed manually by specialized staff entering the pipeline, while the line was empty due to unrelated maintenance work. Since the pilot, a new system was developed that allows to install the cable inside the pipeline while the pipeline is operational and pressurized.

After a period of initial testing, the pipeline has been continuously monitored since October 2020, and several successful blind tests have been performed by the

Figure 4 Fiber optic cable entering and exiting the pipeline to bypass a shut-off valve.

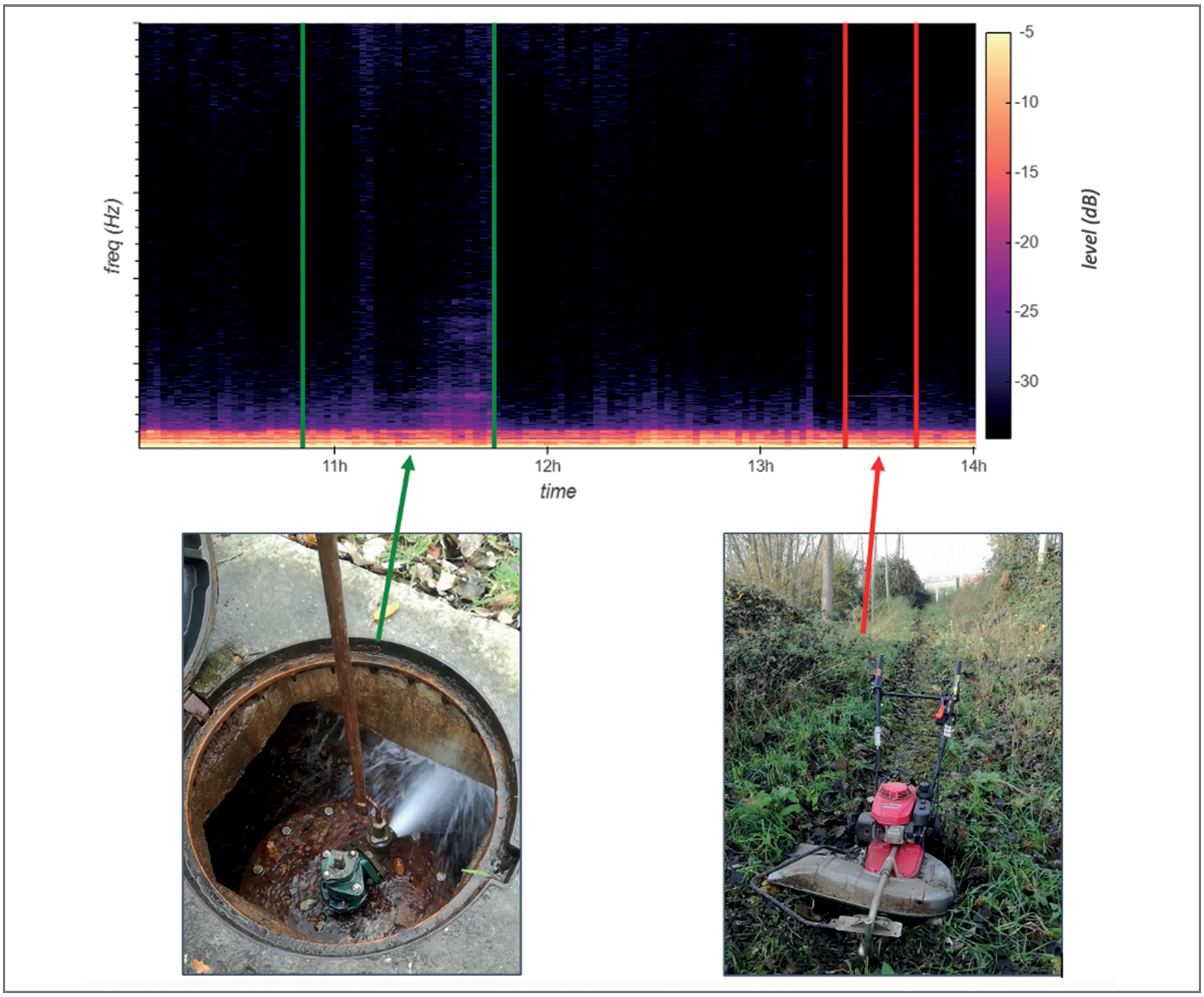


Figure 5 Results from blind tests. Top: frequency spectrogram. Bottom left: view during synthetic leak test. Bottom right: view of lawnmower used for intrusion detection test

pipeline owner. Figure 5 shows results of two blind tests in which a synthetic leak was created by opening an air release valve on the pipeline (Figure 5, bottom left) and by driving over the pipeline with a lawn mower (Figure 5, bottom right) The two events have a clearly distinct acoustic signature, as seen in the spectrogram (Figure 5, top). Numerous synthetic leak tests were performed varying valve types, valve openings, and leak flow rate, and were used to develop a classification system using machine learning, in order to correctly identify different types of events such as leaks, vehicles, and intrusions.

After the machine learning system was set up and successfully validated during the blind tests, the monitoring system was implemented in an operational dashboard that provides the pipeline operator a 24/7 overview of the pipeline status. The online dashboard displays the overall sound level, the timing and location of any incident alerts (e.g. leaks) along the pipeline, and sends e-mail alerts to the pipeline operator when an incident occurs.

4.2 Deployment types

Having been successfully validated, DALI can now be installed on existing infrastructure with a novel system that allows to insert the cable without taking the pipeline out of operation. Several use types are possible:

- Permanent monitoring, in which the fiber and the DAS sensor are permanently installed on the pipeline, allowing for permanent, 24/7 tracking of the pipeline status. This is most applicable for large, critical pipelines.

- Semi-permanent monitoring, in which the fiber remains permanently in the pipeline, while the DAS sensor (the costliest component) is connected periodically (e.g., every quarter) or needs-based (when there is a suspicion of a leak) to assess the pipeline condition.

- Mobile monitoring, in which a short cable (up to approx. 500 m) is inserted in a pipeline and connected to a DAS. Measurements are performed for a few hours to localize leaks, after which the cable is retracted from the pipeline. This is especially applicable for small (residential) water pipes.

4.3 DALI return on investment

The installation of a fiber-based pipeline monitoring system provides financial gains to the pipeline owner by reducing the cost of lost product and by reducing the risk of damage to the surrounding environment when a leak occurs, and these are the two main benefits for oil and gas pipeline monitoring. For drinking water pipelines, however, the main financial gain is by prolonging the operating lifetime of existing pipeline assets. Many large water pipelines in Europe and around the world have an age of more than 50 years and are prone to leaks and ruptures. Replacing the entire pipeline is very costly (a.o. due to the infrastructure built on top of the pipeline), and there is a large financial gain in installing a fiber optic monitoring system that prolongs the asset lifetime while keeping the risk of leaks and ruptures at an acceptable level.

To illustrate this, Figure 6 shows an example return on investment calculation for a fictitious 50 km pipeline, under the assumptions that renewing the entire pipeline costs € 2000 per meter and that the pipeline lifetime can be extended from 50 to 70 years due to the installation of a monitoring system. DALI has an initial installation cost that is less than 1% of the cost of replacing the entire pipeline, as well as an annual recurring cost for leak detection software licenses and maintaining the fiber system. In this example, the return on investment of installing the DALI system is less than two years. Besides the extension of the pipeline lifetime, installing a fiber optic monitoring system offers several additional benefits for drinking water utilities:

- Reduction of Non-Revenue Water (NRW) losses due to leaks

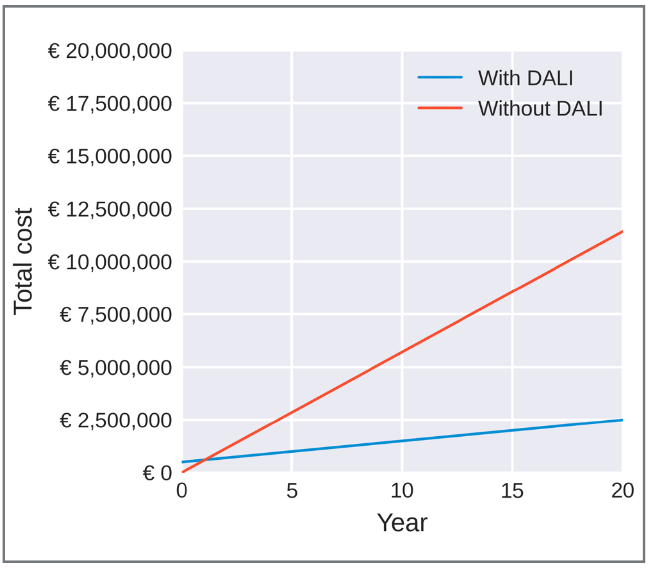


Figure 6 Return on investment calculation for monitoring of a drinking water pipeline.

- Reduced risk of third-party damage due to large pipeline ruptures

- More informed maintenance and long-term asset management planning

- In addition to pipeline monitoring, the installed fiber bundle may also be used as a fiber backbone, e.g. for communicating with other instruments and equipment along the pipeline (pumps, valves), or for leasing out to telecom companies.

5. Conclusions and outlook

The increasing age of utility (water, steam, gas) and industrial (e.g. chemical) pipelines and the associated risk of leaks and ruptures underlines the growing need for pipeline leak detection and monitoring. The current energy crisis only exacerbates this need, especially for heated (insulated) pipelines. In general, inspection and monitoring should focus on existing pipelines, since these are more prone to problems than newly constructed assets, meaning that the ability to retrofit is crucial. In addition, leak-finding tools should bridge the gap between monitoring (which is permanent but only detects the problem, and does not localize it) and inspections (which can pinpoint the location of a problem but is one-off). Distributed fiber optic sensing is a new technology that can fulfill these requirements. As demonstrated in the two use cases, applications that are already fully mature include CUI detection in insulated pipelines, as well as leak detection in drinking water pipelines.

6. Acknowledgements

We gratefully acknowledge FARYS for their support in the development of DALI and the pilot deployment. We gratefully acknowledge BASF for their enthusiasm during the whole pilot process and the further roll out of the CUI-CONTROL system.

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AUTHORS

Thijs Lanckriet
Fluves nv
Project Manager
thijs@fluves.com

Thomas Van Hoestenberge
Fluves nv
CEO
thomas@fluves.com

Timothy Van Caelenberghe
Fluves nv
Sales Advisor
timothy@fluves.com

An increasing concern: Third Party Interference Damage on buried pipelines - A European case study

Y. JOUBEAUX > OVERPIPE

Abstract

Encroachments on buried HP Gas pipelines represent 50% of accidents on pipelines world-wide. The consequences for pipeline owners can be critical, resulting in fatalities and injuries, but also economic cost: shutdown of refineries, damage to the environment and more. This is a huge issue for both types of pipelines. For older existing pipelines because of a change in class location and therefore need of compensatory measures. For new projects, as it is not always possible to install them far from built up areas or because they service industrial areas.

1. THE POSSIBLE SOLUTIONS

Solutions differ depending on the type of pipe. To protect existing lines, the only reliable solution for years was reinforced concrete slabs installed above the existing pipelines. For new projects, extra depth, thicker walls, detours of the pipeline, visible warning, may be used and even combined following the QRA results. Cost and maintenance needs will be key factors.

2. A CASE STUDY OF A CATASTROPHIC ACCIDENT IN EUROPE & THE CONSEQUENCES

- In 2009 the French Government, in response to an earlier 3rd party strike accident, required pipeline owners to conduct QRA on all their existing lines and to retro fit protection of several hundred kilometers of hazardous sections
- How the idea to use HDPE plates was formulated and validated
- HDPE versus concrete
- Issues with HDPE plates: slippery surface, continuity of the protection, consequences for CP testing
- Applications: when on existing lines and when on new projects?
- The risk reduction factor: the French example
- Brief summary and reflection on HDPE plate use

1. An increasing and worldwide concern

For sure, 30 or 40 years ago, when this HP gas pipe was installed, it was in an empty land, with no specific safety issue. But today, close to various sections of this pipe, there are residential buildings, schools, shopping areas and factories. Moreover, there is a plan to build a new mall at less than 1000 m from the gas line and it is just impossible to shut off the gas during the works. This is exactly the kind of concern that every gas company (or oil, chemicals, etc…) meets in any country. It is a worldwide issue.

Considerable progress has been made in recent years, especially regarding pipeline location accuracy (warning & GIS systems) and prior notification before starting any works (one Call, Dial Before You Dig).

However, third party interference – mainly excavation damage – is still the first cause of accidents on gas pipes.

Data reinforces this is the case globally. Some examples:

- US Department of Transportation 2014 report establishes that during 1993-2012 there were 1630 incidents caused by third party damage on gas lines in the USA, with 141 deaths and 440 injuries (Table 1).
- European Gas Pipeline Incident Data Group (EGIG) reports in 2015, 1309 incidents for the period 1970-2013 on 143 000 km of transportation lines, with 35% due to external interference (Figure 1).
- In Japan, Keijo Gas Co 2009 reports 37.7% of incidents (2003-2007) due to third party construction (Figure 2).

Today, most end-users are conducting QRA studies to determine the sections of their pipelines impacted by this risk and to identify the appropriate solutions, for both new projects and existing lines.

Pipeline Type	Third-party Damage Incidents	Fatalities	Injuries	Property Damage
Gas Distribution	924	118	376	20
Gas Transmission	290	14	38	20
Gas Gathering	14	0	0	40
Hazardous Liquid	402	9	26	80
Total	1630	141	440	160

Table 1: Comparison of Consequences of Third-party Excavation Damage incidents Over 20 Years

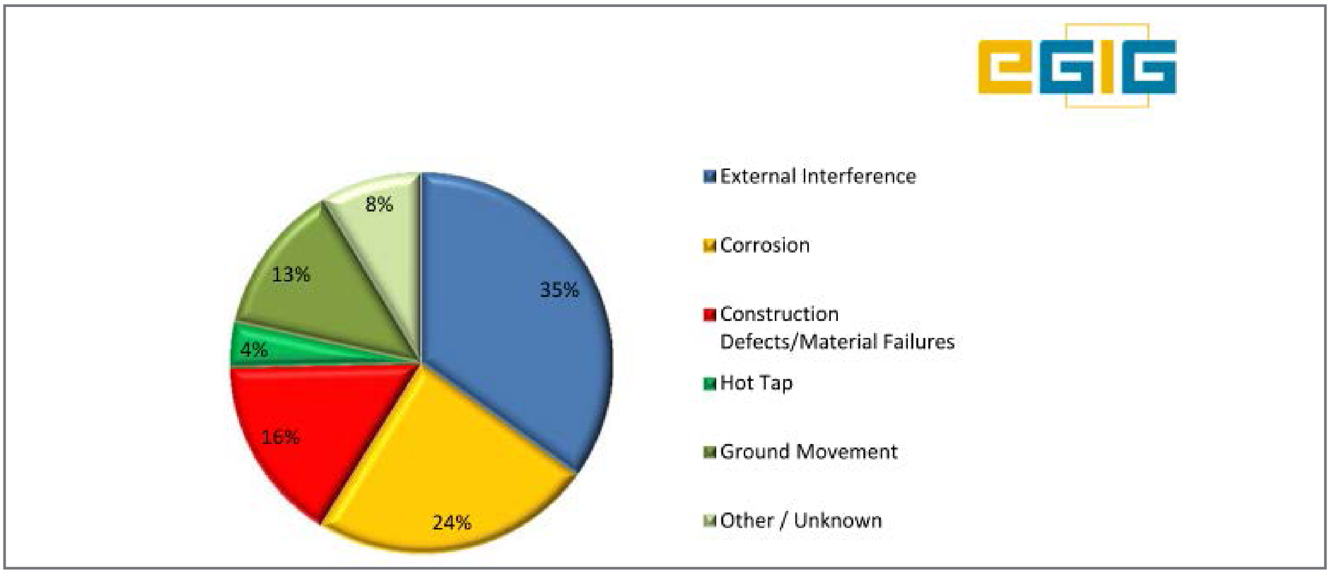

Figure 1: Distribution of incidents (2004 - 2013)

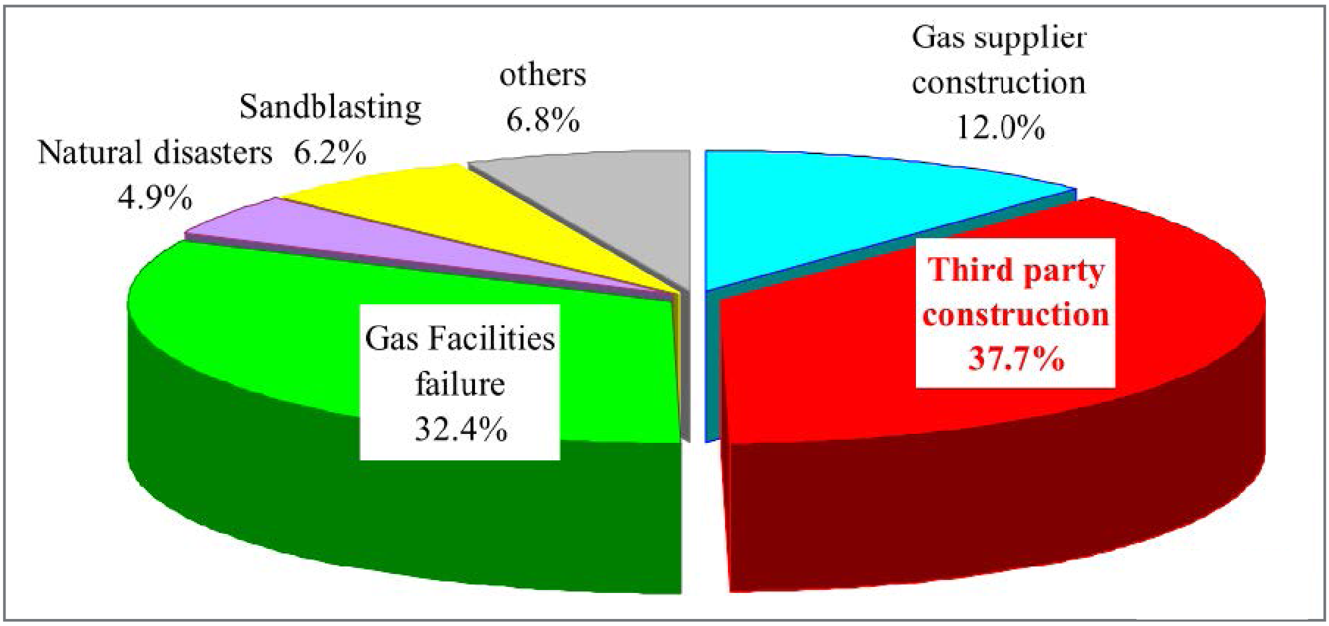

Figure 2: The status of occurence of accidents that the supply/distribution phase

2. Possible solutions

Solutions exist to protect buried pipelines from third party interference.

These vary between new projects or existing pipelines.

For new projects, this concern will be included in the design process and a wide range of solutions are available:

- Optimizing the pipeline route to avoid populated areas. However, it could be economically or technically impossible to make large detours.
- Warning devices, for example surface signage or sub surface warning tapes & meshes
- Increased pipe wall thickness to resist penetration or increasing the depth at which the pipeline is buried (both of which can have large cost implications)
- Installation of mechanical protection on some sections.

A different issue arises with the protection of existing pipelines. A change in class location or protection needs due to a new building project for example, limits the solutions for the pipeline owner. In these cases, installation of mechanical protection above the existing pipeline is the primary solution. This requires the re-opening of trenches, careful excavation above the pipe, installing the protection and backfilling. The main mechanical protection device until recently was to use reinforced concrete slabs, which are costly to install, inefficient as a warning device and cumbersome to deal with for future inspection or repair of the pipeline.

3. A case history: the Ghislenghien accident and its consequences in France

2004, July 30th, 8.56 AM. (adapted from Wikipedia)

A few weeks before the date of the explosion, during the construction of a factory in the industrial park of Ghislenghien, (Belgium) an excavator hit a HP pipe of natural gas (maximal pressure 80 bars) belonging to the company Fluxys. It was neither noticed or reported.On July 30th, following a normal increase of gas pressure in the pipe, the gas main ruptured and began to leak. As fire brigades arrived, responding to the leak, the main exploded.A column of flames, almost 100 meters high, rose into the sky. It was seen from more than 15 kilometers away. A section of the gas main, 11 meters long and weighing several tons, is thrown 200 meters.Electric circuits in buildings located several hundred meters from the explosion, melted due to the intensity of the heat. This heat was felt within two kilometers of the site. Pieces of building were thrown up to six kilometers away. The noise of the explosion was heard by numerous witnesses up to the southeast of Brussels (50 km).

Figure 3: The Ghislenghien accident

The disaster caused 23 deaths and 132 injured. Some bodies were found up to 100 m from the explosion.

The shock at the magnitude of the disaster was felt not only in Belgium, but across Europe and in France in particular.

4. The French reaction to Ghislenghien

There are on the French territory 50,200 km of pipelines carrying hazardous products (36,500 km of which for HP gas transmission) with an average age of 26 years (2009).

After the Ghislenghien accident, the risks posed by the age of the network, growing urbanization encroaching on pipeline reserves and the lack of recent, reliable Quantitative Risk Assessment (QRA) were deemed as no longer acceptable.

The French government made an "order" (which does not require a parliamentary vote) published on 2006 August 4th. It is called "arrêté multifluides".

This order stated new rules for the design, construction and operation of transmission pipes. New values for danger thresholds and calculation of lethal effects were adopted, leading to important changes in class locations and protection measures. Regulations for prior notifications, declarations and authorizations were substantially reinforced. Generally speaking, all actions to be taken were aimed to enhance security of buried lines.

Regarding specifically the risk of third-party interference, this "order" led to several legally binding guides, established by a committee composed of all companies involved in transport of hazardous products by buried pipelines (called "GESIP). One of those guides sets the rules for QRA as seen in Figure 4.

These new obligations required the operators to dramatically change their practices to manage third-party damage prevention. Due to the level of measures to be implemented in such a short time frame, operators had to be innovative. Examples of this innovation were early use of drone surveying and the use of optical fibers for pipeline monitoring. The" SIG" (geographic information system) was also strengthened, a system of ONE CALL was established (eg Dial Before You Dig) and training was made mandatory for excavator operators.

But the most substantial changes may have been the ones brought to mechanical protection, due to the challenging nature of the issue.

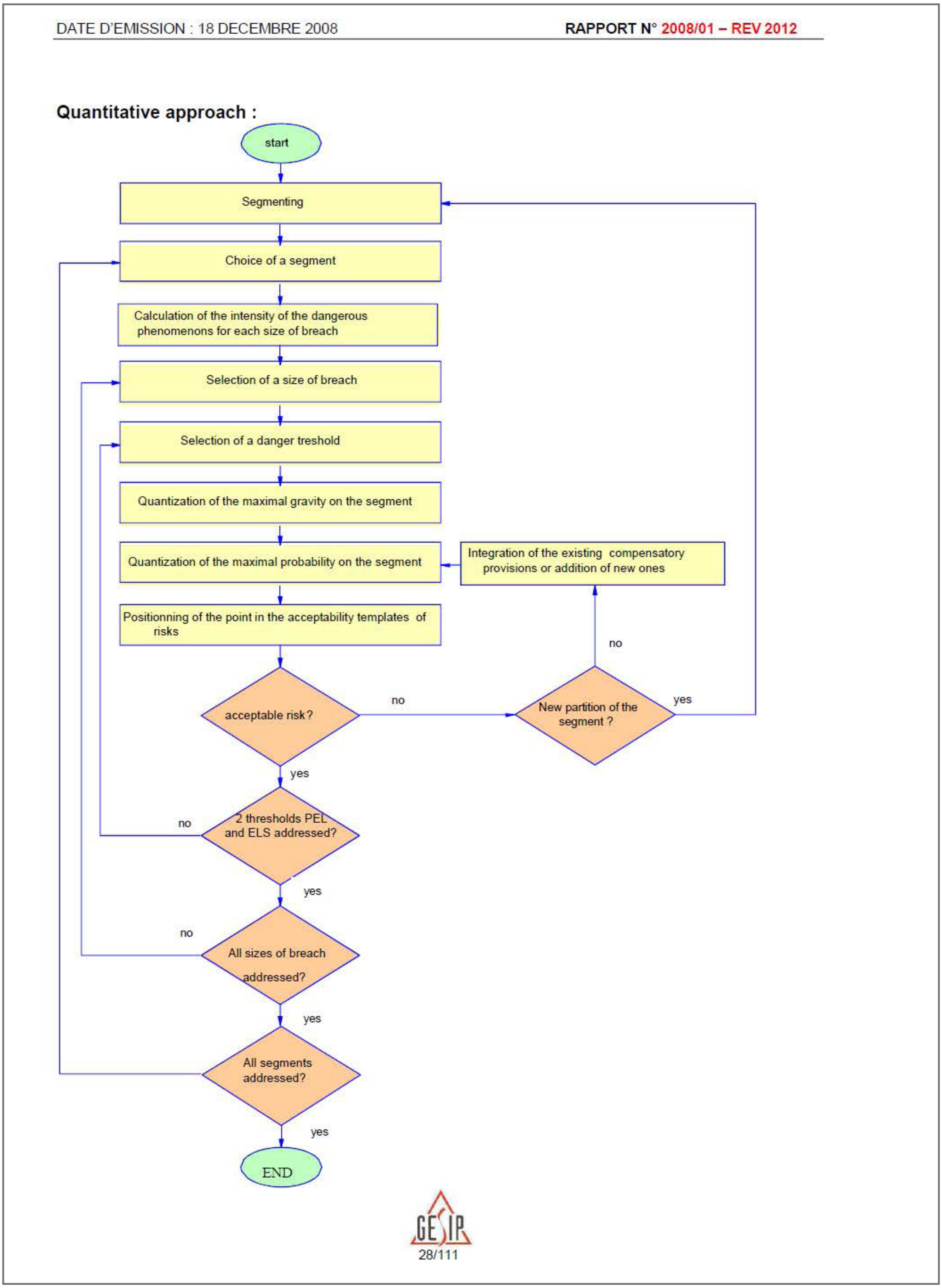

Figure 4: Quantitative risk assasements

5. Mechanical protections: a pressing need for innovation

When the studies were conducted, several hundred kilometers of existing transmission pipelines were revealed to need a mechanical protection to comply with the new security regulations. All to be completed by the end of 2012.

At the time the only possibility was to install reinforced concrete slabs above the pipelines. Although theoretically possible, this was practically inconceivable. Such works would need to manufacture and transport hundreds of km of concrete slabs and considerable resources (both personnel and equipment). As an example one full truck will transport about only 100 m of concrete protection slabs. Pipeline owners, primarily Gaz de France (now named ENGIE), were also concerned with the practicality of removing concrete slabs in cases of inspection or repair.

The R&D Department of Gaz de France took the initiative to create a working group with the goal to suggest innovative solutions. As a regular contractor for GdF, Yannick Joubeaux was invited to join this group in 2005.

6. The idea: replace concrete with plastic!

The terms of reference for mechanical protection were to find an easier, lighter and cheaper solution to concrete. Yannick suggested designing a plastic plate to protect the pipes. Proposing to replace 150 mm of reinforced concrete by 15 mm of plastic was not at first regarded as the magic bullet. However, after an extensive program of testing various raw materials and processes (with GdF its own tests in their laboratory), HDPE plates were recognised as a reliable solution. GdF R&D department reported the following at the IGRC conference in 2008 (Figure 6)

IGRC International Gas Union Research Conference PARIS 2008

Figure 5: The logo of the IGRC 2008

6. PE SLABS : A VERY EFFICIENT WAY TO PROTECT PIPELINES, WITH GREAT ADVANTAGES.

Polyethylene (PE) slabs have been felt as a good alternative to protect buried pipelines against earthmoving equipment. Compared to concrete slabs, PE slabs would offer some great advantages :

- A light solution : handling is much easier; there is no need for lift apparatus and installation is much faster,
- A thin solution : less cluttering in the ground,
- A warning solution : PE is more unusual in the ground than concrete, and it may be tinted yellow and printed ("high pressure gas" for example).

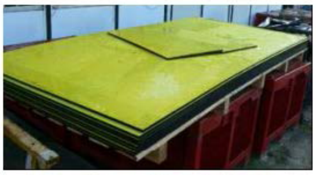

Figure 6 : Some of the tested PE slabs

Furthermore, operation of networks would become easier : this solution is easy to cut if we need an access to the pipeline.
PE slabs (from 10 mm to 20 mm thick) have been tested under controlled conditions : a 1 m high vertical bucket impact given by a 32 t mechanical excavator. Results show that PE slabs are at least as efficient as concrete slabs :

- depending of the sharpness of the teeth, from 1 to 10 knocks of bucket are necessary to go through the slab,
- the slab is not broken by the impacts : the teeth punch it... and are then blocked. When trying to remove its bucket, the operator generally also removes the slab (if not, the slab is still in place and keeps its mechanical barrier role).

Figure 6: Extract from the IGRC report 2008

7. PE plates: yes but ...

Of course, to deserve this recognition, the HDPE plates have to meet many specifications. Some of those were adopted into a GESIP report dedicated to safety compensatory measures on transmission lines , other added in the end-users standards. Hereunder the main requirements:

7.1 Mechanical resistance

Obviously the first target!

Despite shortcomings, concrete slabs do offer very high mechanical resistance to external impacts. They therefore set the standard for mechanical resistance. So any new solution would need to resist the assault by a shovel of a 32 tons excavator using its full power at 1M height.

Why excavators? Because they are used in 70% of the construction sites in urban zones and 80% in rural zones (IGRC report 2008).

Why 32 tons? Because more than 80% of the excavators used in urban sites have a mass lower than 32 tons… and 100% in urban zones. (IGRC report 2008)

What does "resist" mean in this context? The goal is: the pipe protected by the plate MUST NOT BE HIT by the teeth of an excavator shovel, whatever its direction and power (up to 32 tons, which covers nearly all the uses). In order to guarantee this, it was specified that the plate should preserve its "integrity" after an assault. In this case, "integrity" means that the teeth of the bucket must not destroy the plate and moreover that there must not be any crack growth between the points of impact although the plate may be punctured by the teeth (depending on the kind of soil).

7.2 Colour Identification

Resisting an excavator assault is the main purpose of pipe protection. But the security will be much higher if any assault can be avoided. This goal requires an efficient warning that will stop the driver in his digging work.

One of the disadvantages of concrete slabs is that they have the colour of…. concrete. When installed in inhabited areas they can be easily mistaken for old buildings foundations. Trials conducted by Gaz de France with excavator's drivers showed that a majority did not understand that a pipe was under the slab when they hit it! They just wanted to remove it to go on with the digging and sometimes deployed their hydraulic hammer to break up the slab.

This is why a yellow full body coloured plate was proposed. When an operator sees not only one yellow plate but realizes that the plate encountered is connected with others to form a continuous yellow line – as the plates protect a significant part of the pipe – there is a very little chance that he doesn't imagine that all this has a meaning…Of course he will stop digging.

7.3 Warning message

In addition to the colour warning, a warning message was added – fully customizable – on the plate, such as "DANGER GAS PIPELINE BELOW".

The warning message is embossed during the production molding process. Printed messages will never have multiple decades life needed.

7.4 Security of workers

Plastic plates are obviously slippery and therefore represent a danger for workers during installation. This is why end users such as ENGIE require a non-slip surface that can be achieved by pins pattern embossed during the molding process.

7.5 Durability

HDPE which will last decades underground without significant degradation. A SABIC report (2008) on reliability of HDPE pipes in water distribution: 40-year-old pipes were tested and continued to perform well. Concrete slabs cannot offer any comparable guarantee as the concrete but also the reinforcing steel will be dramatically affected by the soil components.

7.6 Chemical resistance

HDPE offers a very high and wide resistance to chemicals as stated in SABIC's report on chemical resistance of PE.

7.7 CP Readings

Concrete slabs are indeed a very efficient screen above the pipe they protect which has a potentially harmful side-effect.

Groupe d'Étude de Sécurité
des Industries Pétrolières et Chimiques (*Oil and Chemical Industry Safety Study Group*)

Appendix 16 Table of risk reduction or aggravation factors

1 Subject

This appendix gives effectiveness values of the compensation measures identified and coefficients of reduction or aggravation of the historical frequency of leakage from the network. These values have been determined by experts on the basis of the information available at the time of writing of this guide.

2 Table of risk reduction or aggravation factors

	Third-party work	Fault in construction / material	Corrosion	Natural causes	Reduction factors	Sources
Placement of piping						
o Rural zone (non-urbanised)	X				0,80	Ineris report
o Suburban zone	X				3	Ineris report
o Parking	X				1	expert opinion
o City	X				3	expert opinion: data based on suburban environment
o Parcel allotted and closed off	X				0,50	expert opinion: factor better than in rural environment
o Zone with no ground movement				X	1	
Design/construction						
o Depth	X				2 to 0.01 – see table below	expert opinion
o Thickness	X				if pipe thickness > or = 12mm: 0.01	justification: study by *Gaz de France*, expert opinion by equivalence with factor of concrete slabbing
					if pipe thickness > 8mm: not known at present	
Physical (mechanical) protection of piping						
o No protection	X				1	
o Concrete slabs	X				0.01 with in-built warning or signalling grid	study by HSE
	X				0.05 reinforced but without warning grid	
	X				0.2 not reinforced and without warning grid	study by HSE
o Steel plates	X				0.01 with warning grid	
	X				0.02 without warning grid	
o PE plates >12 mm	X				0.01 with in-built warning or signalling grid	experimental study by GRTGaz

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Figure 7: Table of risk reduction or aggravation factors

The protection installed must allow water to go through. This is very important to avoid discrepancies in measurements of cathodic protection by maintaining a same resistivity above and under the plate. This is why HDPE plates have drainage holes. So, as not to compromise the structural integrity of the sheet, their number and surface must be limited: a ratio of 0.6% of the total surface has been decided by GRT Gaz, ENGIE's subsidiary for gas transmission. Holes drilled post production can weaken the sheet, therefore it is important to have them integrated in an injection molding process.

7.8 Transport/Installation

Use of plastic protection plates will eliminate the requirement for lifting gear and dramatically reduce transport costs. No more cranes and 30 sheets to a double pallet for transport. A full truck will allow to transport more than 800 m protection. The light weight also means the heaviest plastic plates are still only a two-man lift.

7.9 Continuous Connection

It was specified that the plates have a connection system. A removable clip was proposed, as easy to install as to remove for further inspection or repair. Other systems can be implemented to ensure an overlap between the plates or an end to end installation.

7.10 Pricing

At the draft stage it was pointed out that the economic record of the new products must be clearly competitive compared to concrete slabs. Considering costs of transport, machinery (as cranes) and manpower, this was probably the easiest goal to reach.

7.11 Ris reduction factor

Considering the order of 2006, it was decisive that the plates were granted with the same risk reduction coefficient as the concrete slabs. Based on the numerous tests made by GdF, the GESIP group adopted the following matrix: HDPE plates have the same reduction factor as concrete slabs, i.e.0.01. That means that the plate divides the risk of accident by 100

8. Conclusion

The accident in Ghislenghein caused an unexpected awareness in France of the importance of 3rd party strike prevention and of the danger due to the urbanization close to pipelines. The subsequent actions taken by the authorities made it necessary to imagine new solutions. Development and use of plastic mechanical protection for buried pipelines became one of these new solutions. The same issues in other countries are leading to the same conclusions and since they are aware of this solution, HDPE plates are recognised in countries such as Saudi Arabia, Malaysia, Australia and New Zealand. One can be sure that this kind of solution will spread worldwide as it presents many advantages for all stakeholder.

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AUTHOR

Yannick Joubeaux
OVERPIPE
CEO
y.joubeaux@overpipe.com

Considering the challenges of optimizing aging pipelines

H. SMITH > ATMOS INTERNATIONAL

Abstract

External factors such as global supply chain challenges, the push for Net Zero and an ongoing introduction of new pipeline regulations have raised concerns about the integrity of aging pipelines. Aging pipelines carry their own risks which can lead to product leakage, ruptures and explosions if left unaddressed.

This article takes a look at the process of optimizing aging pipelines and what some of the challenges are.

In response to global supply chain challenges, the push for Net Zero and an ongoing introduction of new pipeline regulations, the integrity and security of aging pipelines have become a prominent topic, with many pipeline operators already being exposed to the challenges that come with an aging or legacy pipeline network. While current advancements in leak detection can help with reducing consequences, they do not negate the inherent risks that accompany an aging or legacy infrastructure.

1. Defining aging pipelines and their risks

There is no universal definition for an aging pipeline, but regulatory organizations make an effort to at least provide some criteria. In response to a series of gas pipeline incidents in 2011, the US Department of Transportation (DOT) and the Pipeline and Hazardous Materials Safety Administration (PHMSA) enforced a call to action on the repair, rehabilitation and replacement of the highest risk pipelines and it is worth noting that pipeline age is among the high risk indicators.[3]

Since 2005, PHMSA has also began conducting an annual inventory report which charts the reduction of pre-1970 gas and hazardous liquid pipelines, suggesting pipelines 35 years or older may be considered within the "aging" category.4 Age alone may not be the only criteria for defining aging pipelines though. The ability to categorize a pipeline as "aging" is also made possible by charting a pipeline's periods of failure over a period of time and conducting a reliability analysis.

A reliability analysis can be applied to most pipeline lifetimes and projects and they typically discover three periods of failure rate in the project lifecycle:

- Early failure period
- Intrinsic failure period
- Wear out failure period

If we apply this model to the installation of a pipeline, the early failure period can be recognized within the expected incidents that arise when a new pipeline is installed or introduced within an existing pipeline's infrastructure and could be caused by installation error and poor handling.

Incidents then rapidly decrease to a minimum as the pipeline transitions into an intrinsic failure period, when the pipeline is at a point where it is successfully used at an operational level and has a low failure rate.

Data as of October 24, 2022
Data source: US DOT Pipeline and Hazardous Materials Safety Administration

Pipeline type	% Reduction pre 70 miles from 2005 to 2021	% Total installed pre 1970 in 2021
Gas distribution main miles	20.4	31.1
Gas distribution service count	38.3	21.7
Gas transmission miles	15.9	54.5
Hazardous liquid miles	6.2	40.5

Figure 1: Table showing the reduction in miles of pre-1970 pipelines since 2005 (accurate on the date shown)[4]

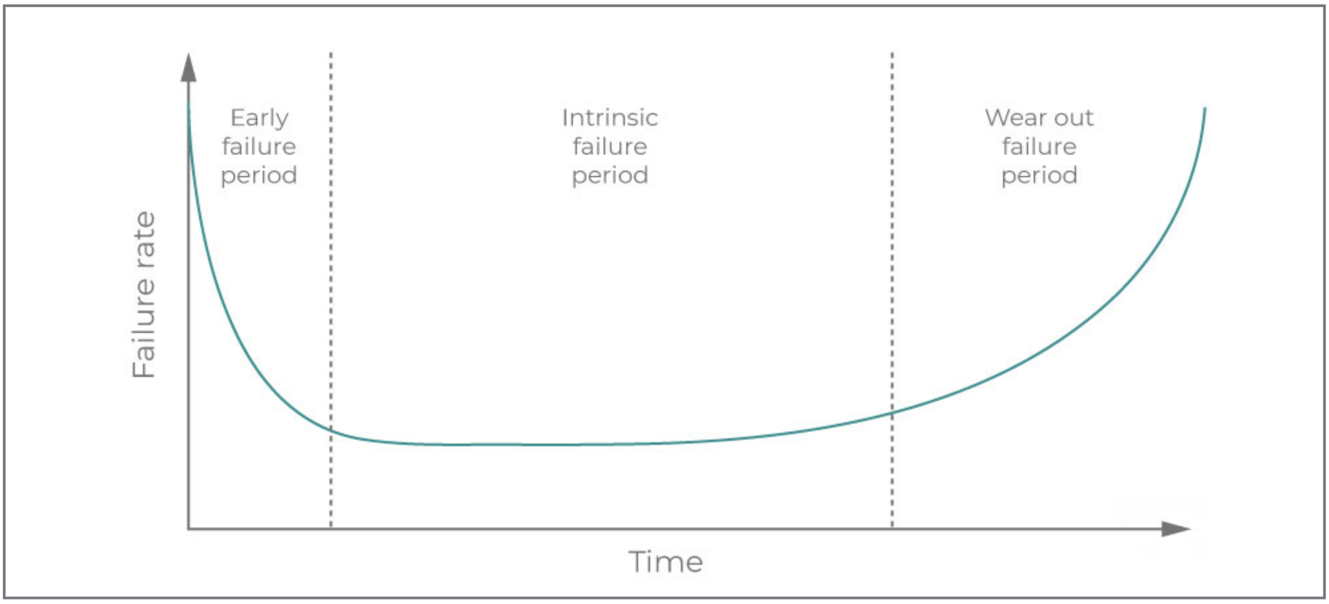

Figure 2: A visualization of the bathtub curve, as used to define the reliability of a product

As with any product, the pipeline will ultimately reach a point in its lifecycle when it deteriorates and the number of incidents begin to rapidly increase again. This is a signal of the wear out failure period as shown in the bathtub curve in Figure 2. It's worth noting that a product's age is highly variable when it reaches its wear out period, which is why Figure 2 doesn't represent a specific time span on its X axis. A poorly installed pipeline with continued poor handling by pipeline operators could reach its wear out period in 5-10 years, for example.

Effectively defining a pipeline as "aging" is as much a case of determining how smoothly it operates over time, and when it has reached its wear out period, as it is a case of defining an aging pipeline by its age alone. There is a range of risks to an aging pipeline which can signal to operators that the pipeline is approaching its wear out failure period.

2. The risks of an aging pipeline

Corrosion is one of the leading causes of pipeline incidents and due to aging pipelines often having outdated infrastructure they are more prone to external factors like the soil, air and water which can cause corrosion. If corrosion is left unaddressed it can lead to leaks and even explosions in natural gas pipelines. For water pipelines, the particles created by corrosion can settle inside the pipeline distribution network, impacting the quality of water supply.[5]

Another risk of aging pipelines is the potential damage they can cause if they run through a high consequence area (HCA), such as densely populated areas, sensitive ecosystems and drinking water areas. If a leak progresses into a spill, the consequences can vary greatly depending on where the release occurs and the commodity involved in the release, but as an aging pipeline deteriorates there is a heightened risk of potential damage to HCAs. If left unaddressed, an aging pipeline which leaks an excessive amount of product can cause an explosion or environmental disaster which could result in a far greater financial cost than the loss of product. Fines and clean-up costs can amount to millions of dollars if leak detection solutions are not implemented in advance. The crime of pipeline theft also exposes aging pipelines to risks.

Enough information is made publicly available on the state of current pipeline networks to present an opportunity for pipeline thefts. More than half of the oil and gas pipeline infrastructure in the USA is at least 50 years old,[6] for example, and much of Mexico's pipeline network is over 30 years old, with many illegal tapping points already being detected on its gas and petroleum lines.[7]

3. Repair or replace

Because the costs incurred by replacing a pipeline are expensive, many pipeline operators look to make repairs to the pipeline's existing infrastructure to prolong its life, but short-term fixes like leak mitigation fail to accomplish much in the way of leak detection.

4. Optimizing aging pipelines against leaks: the challenges

To mitigate corrosion, for example, coating systems are often applied to aging pipelines with a view to recoating when required, but this requires extensive knowledge to identify the most appropriate coating system and an experienced coating contractor to complete the task.[8] If the pipeline section in need of coating is in a HCA, such as a densely populated urban location, this can raise the costs by a substantial amount. Another challenge faced by coating systems is that although they accomplish a short-term solution for leak mitigation, they fail to consider the future problem of leak detection. Applying leak detection to aging pipelines can be a challenge due to the infrastructure often being built long before the modern hardware and software that are used to detect leaks today.

One customer based in the UK has a pipeline network with one of the largest storage capacities in the world and recently required the installation of leak and theft detection technologies on its network. Elements of the pipeline infrastructure dated back to the Second World War (WWII). The challenge was to provide support for a pipeline which was aging and had varying standards of wall thickness or different coating finishes. Fortunately, the non-intrusive hardware we provide can be retrofitted to aging liquid pipelines. Atmos Eclipse, for example, provides instrumentation as part of an effective leak detection system that gathers flow,

Figure 3: Atmos Eclipse non-intrusive instrumentation

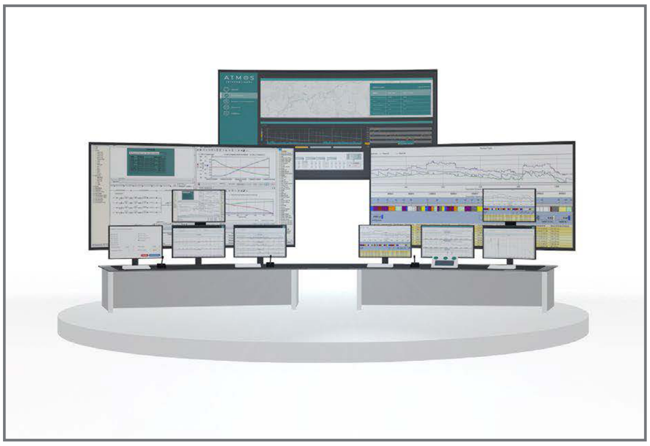

Figure 4: Atmos Simulation suite (SIM)

pressure and temperature data without needing to penetrate an aging pipeline's infrastructure.[9] A combination of Atmos Eclipse and Atmos Wave Flow was used to provide a leak and theft detection system, allowing a solution to be installed with reduced hardware and project costs.

Another challenge of optimizing aging/legacy pipelines can be seen in incidents like ruptures and explosions, an example of what can happen when aging infrastructure struggles to meet the demand for cleaner burning fuels.[1] The transition to carbon neutral energy will present further challenges for the aging pipeline infrastructure due to concerns that the fuel can cause hydrogen embrittlement, when the metal degrades, resulting in a leak or rupture.[10] Simulation software like Atmos SIM can calculate and forecast pipeline pressure and flow thus helping pipeline operators run aging pipelines safely and cost effectively. In addition, it uses model-based leak detection to detect and locate leaks in gas pipeline networks effectively, minimizing the consequence of leaks .[11]

Some aging pipelines are restricted in terms of their audit trail too. For example, some pipeline operators still refer to physical maps of their pipeline network. Again, simulation software like Atmos SIM is effective by using real-time modeling offering more visibility of the actual pipeline operating conditions than a hand-drawn map. With external factors presenting new challenges to aging pipelines every day, new pipelines are being increasingly considered. But for pipeline operators who have no choice but to repair and maintain their existing infrastructure, leak detection systems such as Atmos Wave Flow and hardware such as Atmos Eclipse can be retrofitted to an aging pipeline and are a tried and tested method of effective leak and theft detection, mitigating the risk of leaks if the pipeline fails.

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AUTHOR

Harry Smith
Atmos International
Sales and Senior Research Engineer
harry.smith@atmosi.com

Illegal Hot Tappings – Qualification Stages of an innovative Inline Inspection Tool

S. BENICHOU, A. LEVY, J. DE MOREL, J. L. BONNEVILLE, B. MARQUIS> TRAPIL

Abstract

Product theft has been a major issue for many pipeline operators around the world. We all have in mind the terrible explosion of a gasoline pipeline in the town of Tlahuelilpan, in the Mexican state of Hidalgo. The blast killed at least 137 people and injured dozens more. This story made its mark, but illegal tappings is not an isolated fact. Europe is not spared by this threat. The CONCAWE organization which gathers figures about leakages reported a boom of leakages due to illegal tappings in 2015 in Western Europe with more than 140 cases. Even if this number is now decreasing, the majority of the spills are still due to syphoning even if at the same time criminals, getting more and more sophisticated, are more difficult to catch.

These are reasons why operators still rely on innovation which has led them to use different or redundant technologies in order to detect every mischief. However, the perfect mix of technologies still doesn't exist and this is TRAPIL decided to get its R&D team involved in the design of new effective solutions. One of them is the T3. The T3 for "Trapil Theft Tracker" is an inline inspection tool based on the long experience of Trapil in ultrasonic aiming at detecting, identifying and locating taps up to the smallest ones. The tool has been designed to be compact, easy to handle in order to reduce downtime, and launched as often as necessary in order to provide a very fast report and counteraction in case of suspicion. This paper describes the customer-oriented design approach based on feedbacks from the field and the technical qualification process adopted by TRAPIL in order to build an innovative tool whose design is patented.

1. Description of the device

This article concerns a device for the examination of the interior of pipelines using ultrasound technology. Such a device is designed to inspect pipelines transporting fluids, in particular liquids of homogeneous type. It may be, for example, water, refined hydrocarbons or certain crude oils.

Operators of transmission pipelines must regularly implement means of controlling and monitoring the integrity of these pipelines within a regulatory framework. Over time, with changes in the environment and operating methods, anomalies appear in these pipelines. With improving tehcnologies, transportation pipeline operators have to implement a large number of control means or devices called intelligent pigs that are able to detect geometric anomalies, corrosion, cracks or metallurgical type anomalies. These defects can affect the base metal, welds, straight or bended parts. They can evolve and, if not treated, can lead to the loss of containment of the pipeline and seriously impact people, property and the environment. Today these operators are also facing new threats defined as illegal tappings. These defects are caused by the intervention of an association of organized criminals who drill the pipe, install a tap or a valve connected to a hose at the end of which a tank or other storage capacity is connected. These losses of products can represent up to nearly 40% of the volumes lost by European refined hydrocarbon carriers (cf Concawe Report No. 12/20). The restof these losses is caused by problems of mechanical origins, third-party activity, corrosion or operation. The means currently available for detecting and identifying illegal tapping can be devided into three parts:

- Human resources for land and/or air surveillance
- Systems of monitoring and recording on the pipeline with a monitoring and remote monitoring device
- Acoustic or magnetic intelligent pig

The second means requires a rather heavy infrastructure and substantial investments and more if the pipeline is already laid and in service (for example laying of optical fiber, strain gauge, composite piezo sensor and other cables and relay remote transmission stations, particularly complex data processing software and maintenance of all these means).

The third means which includes the two types of Intelligent pigs already mentioned:

- The acoustic pig; it needs to encounter illegal tapping and therefore sufficient noise when the pig passes to be able to be detected, it is not able to detect illegal tapping without active tapping.

- For the magnetic intelligent pig ; these are high resolution MFL (Magnetic Flux Leakage) type intelligent pig, these pigs are designed to detect generalized corrosion or pitting. In the context of tapping detection, they are used in a particular way by adapting the hardware and software configurations. They require rather heavy means of implementation (length of tools, specific handling means and associated risks and present analysis difficulties). They involve significant operating costs and cannot be used regularly and independently by pipeline operators.

To offer operators of hydrocarbon transport pipelines a reliable and economically viable solution, TRAPIL has developed and manufactured an instrumented inline inspection tool which, through the combination of various components and computer processing, detects, identifies and locates clandestine derivations and other types of faults which could appear on these pipes. This device is called T3 (TRAPIL THEFT TRACKER).

This tool is based on the implementation of an ultrasonic control method. The ultrasonic control module is made up of several dozen piezo-composite transducers, half of which are dedicated to acoustic wave emissions and the other half dedicated to the reception of these waves. Thus, to cover the complete circumference of the pipe, several tens of pairs (transmitter/receiver) are staggered. To be able to discriminate between illegal tappings and other defects that may be present in the pipe (cracks, laminations, dents, etc.), two other rings of about ten couples are placed on the device knowing that a phase shift angle is applied between each of the three rings. Thus, when the pig passes, the wall of the pipeline is locally and uniformly traversed by ultrasonic waves.

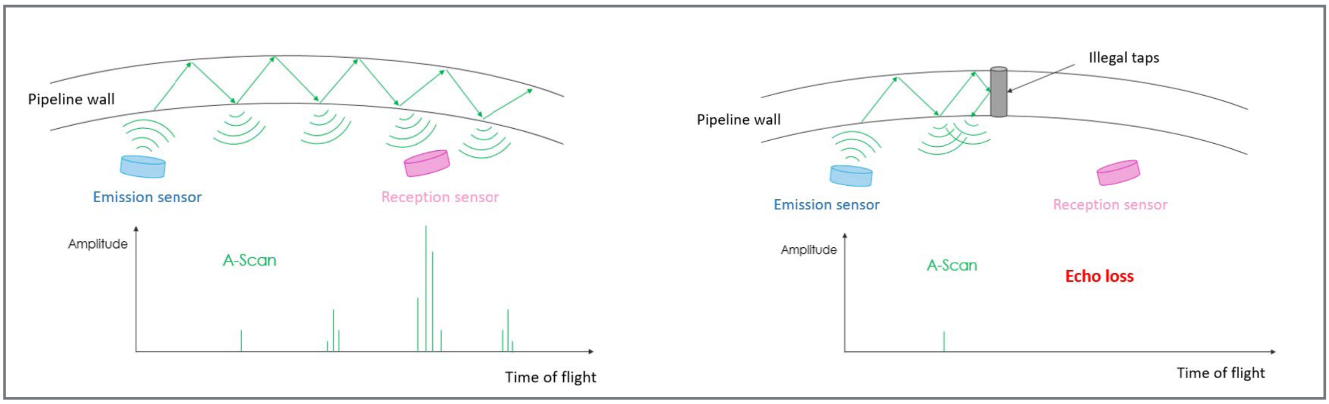


Figure 1: Principle of controlling and detecting illegal taps

The principle of detection and identification of illegal taps is based on the detection of a loss of the transmission wave. When tapping occurs in a control zone, that is to say on the ultrasonic path located between a transmitting transducer and a receiving transducer, the ultrasonic beam which travels through the zone concerned is more or less prevented (depending on the size and nature of the taps) to continue its course in the wall of the pipe and therefore to be received by the piezo-composite transducer called receiver.

In addition to the analysis of the amplitude of the transmission signal, the time of flight or ultrasonic path is also scrutinized, in particular its evolution along the longitudinal axis of the pipe. The length of the suspected indication is also analyzed as well as its angular position in the pipe. The longitudinal distances from the upstream and downstream welds are also notified. Different ultrasonic responses have been characterized and demonstrate a close link between the size, the nature of the tappings and the loss of the transmission signal.

The design and assembly of the pig aims to make it easy to operate, just like a cleaning pig, the objective being to be able to be adopted and used by transport line operators.

This should allow these same operators to schedule as many passages as possible and thus have knowledge and continuous monitoring of the pipeline. Spare items such as cups, wheels are indicated in the user manual and maintenance parts are made available to users in order to carry out preventive and/or corrective maintenance throughout the life of the device. The data preparation and extraction process is documented in the user manual allowing the operator to transmit the recorded data to an analysis centre for a prompt report. The weight and dimensions of the scraper are optimized, so as to make it easy to handle. Hence, in most cases one or two operators are enough to operate it (this depends on the diameter of the pipe to be inspected). However, it is recommended to use personal protective equipment as well as appropriate means of handling and transport.

Once the inspection is completed, the recorded data is extracted and transmitted to the analysis centre. An automatic analysis software is used to analyse the data generated during the inspection. This analysis is composed of several steps:

- Detection of girth welds: these have a unique signature. The first step is to detect these welds and record their position.

- Creation of a pipe tally: by exploiting the mechanics of the ultrasonic carrier and the data recorded by the tool, coupled with information on the acquisition frequency, an instantaneous speed of the pig when passing welds is calculated. Then a calculation of the length of each tube between two consecutive welds is carried out and recorded.

- Detection of illegal tappings: an automatic analysis of the data, tube per tube, will look for the elements having the signature of illegal taps. If necessary, it will then be identified and recorded. A list of localized anomalies is set up (kilometric position, tube number, and position on the circumference of the tube).

As presented above, the T3 pig allows regular monitoring of transport pipes, enabling the comparison of several passages by the software. This tool makes it possible to compare the results of the automatic detection of two inspections of the same pipeline, in order to highlight the differences and target changes in the pipeline condition like the presence of new elements.

Once the automatic analysis has been performed, a final step is to analyse the most notable signals and anomalies using a data visualization software. This operation is carried out by trained and qualified personnel with the necessary experience. This software makes it possible to view and navigate among the different data generated by the T3 (pressure, temperature, battery voltage, navigation angles, etc.) in particular the ultrasonic data, presented under several conventional views for this type of information (A -Scan, B-Scan, C-Scan, D-Scan). It also allows the end-user to notify events that will be displayed and saved in a database. In addition, the software integrates a module for the simultaneous display of two inspections of the same pipeline in order to be able to perform a visual comparison. Certain information or illustrations produced by this tool can be extracted and attached to the inspection report.

To be able to locate illegal taps or any other anomaly, the T3 pig produces a certain amount of data and process it in order to target a place and landmarks in the surroundings which aim to guide the operator to the anomaly to be investigated. Thus, the weld log, the longitudinal position between the consecutive girth welds, the angular position of the anomaly in the pipe, coupled with pressure information, navigation angles and external data, are all means which make it possible to make the location of the detected elements more reliable.

The speed range of passage of the T3 in the pipe allows easy programming for the operator, and this by guaranteeing the same performances of detection, identification and localization of illegal taps. The speed of propagation of the ultrasonic waves and their path in the liquid medium and in the steel of the pipe wall on the one hand, and the sampling and storage capacities of the on-board electronics on the other hand, offer a great tolerance to the variations in the speed of displacement while maintaining the detection and identification capacities.

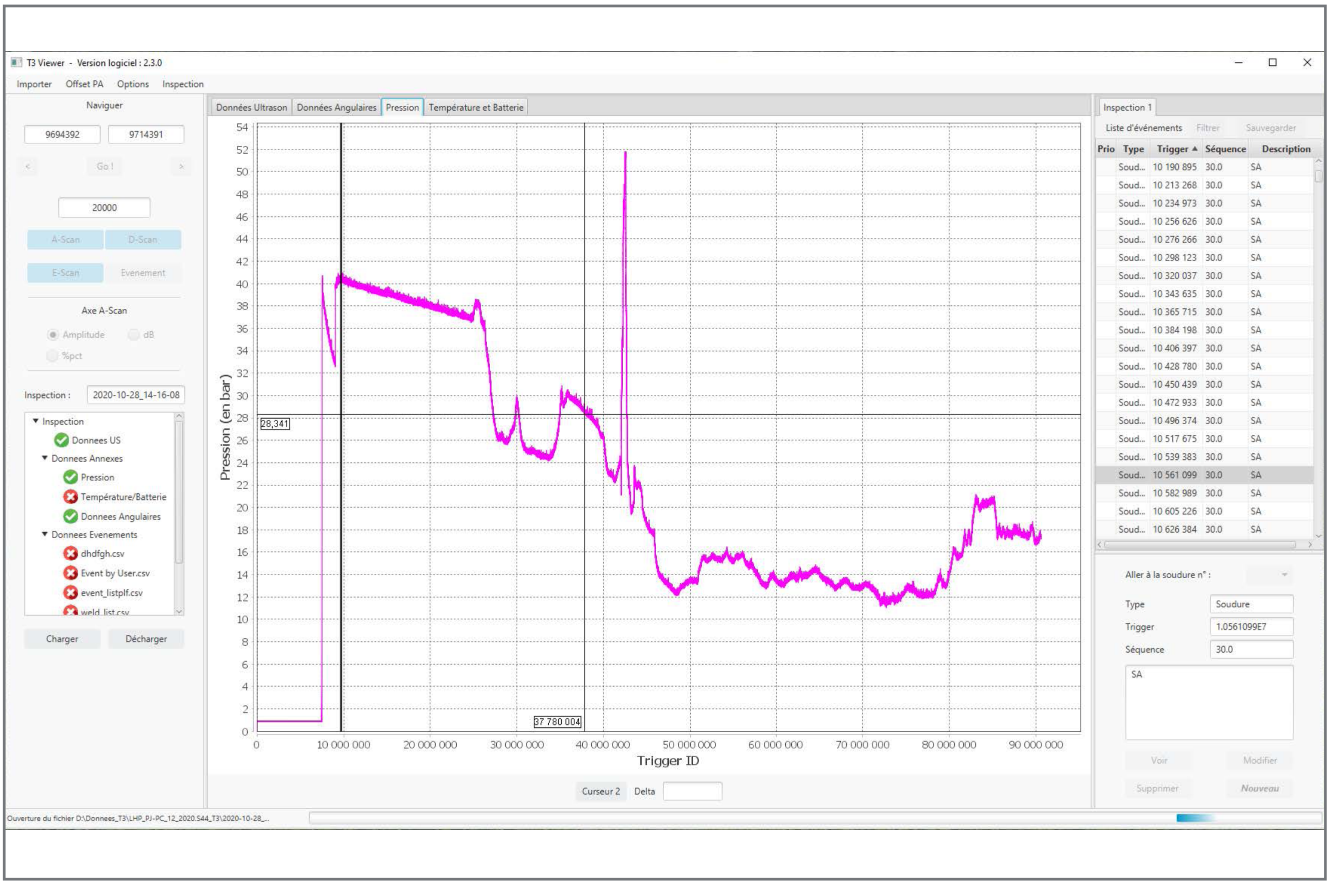


Figure 2: Pressure recorded during an inspection

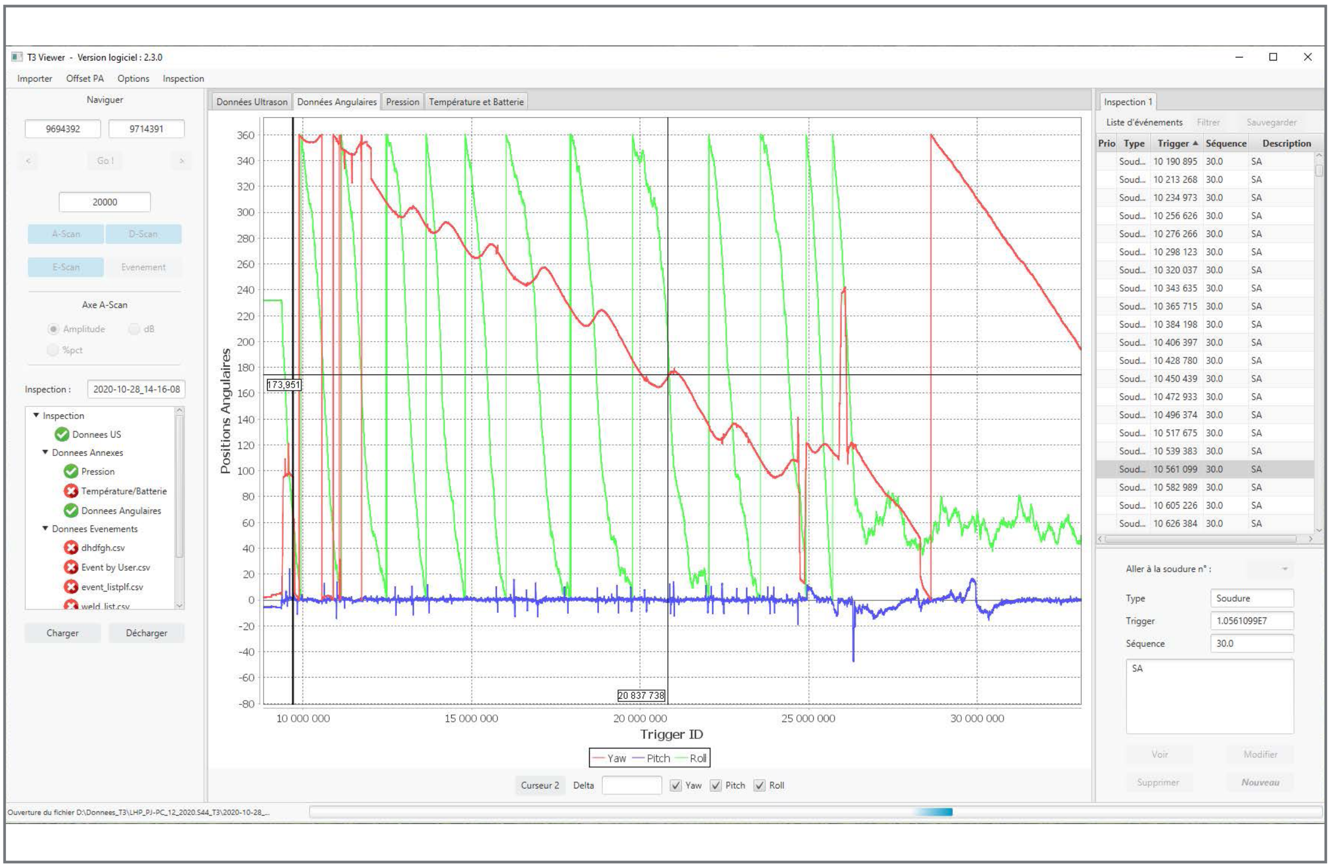


Figure 3: Navigation angles recorded during inspection (Rolls, Pitch, Yaw)

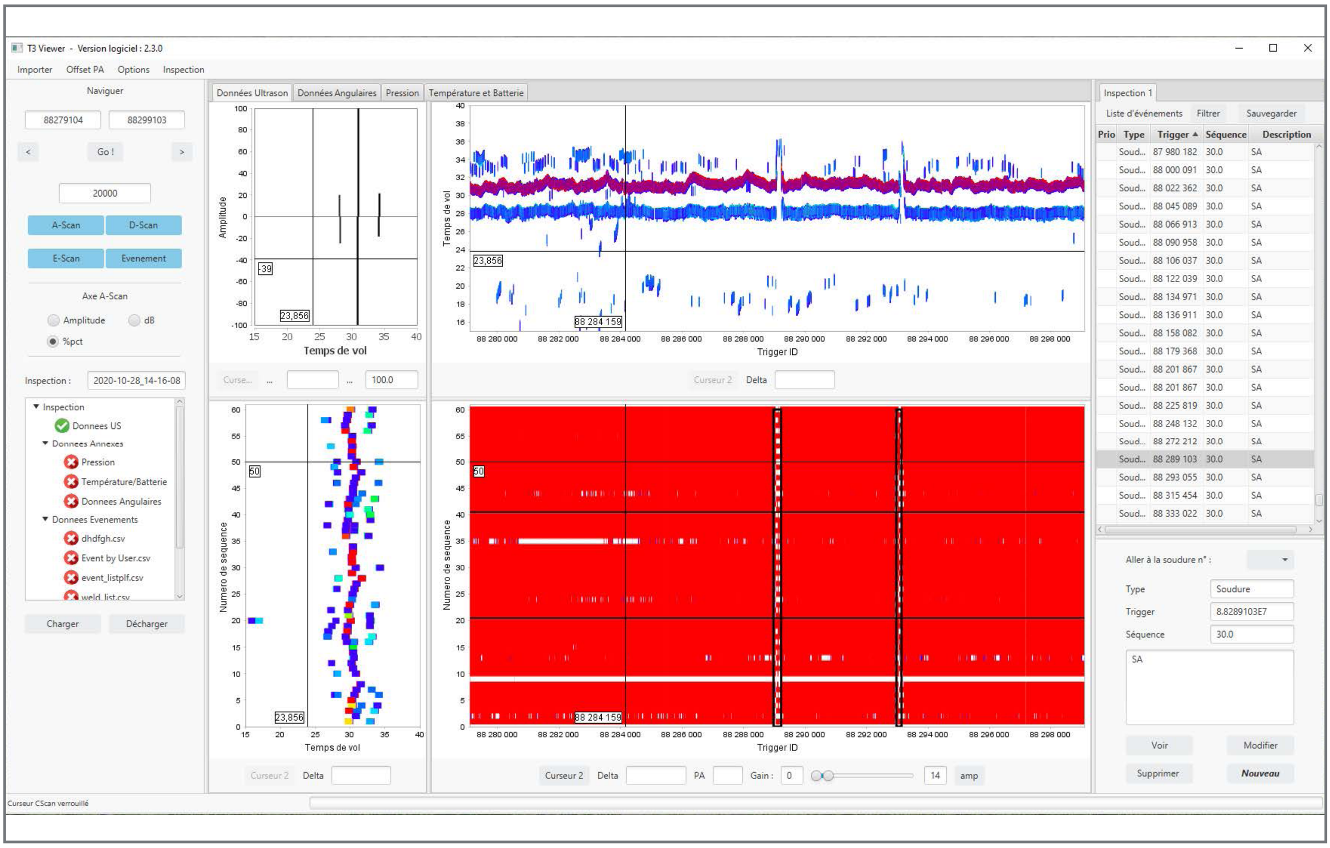


Figure 4: Views A –B – C – DSCAN used to validate the identified information

The design of on-board electronics, particularly in the choice of its architecture, active and passive components and their associations, makes it possible to limit electrical consumption. The definition of the battery which provides electrical power to the on-board electronics is based on the integration of lithium cells. These cells have a high energy density and a capacity that guarantees an autonomy of more than 60 hours. The T3 pig is equipped with a low frequency electromagnetic transmitter (22 Hz), which enables its detection by above ground marker within a radius of one meter above the pipe. The information is updated by the recording by the above ground marker of the signals produced by the transmitter present on the T3 pig and the synchronization of the internal clocks of the T3 and the above ground markers. This instrumentation makes it possible to carry out readjustment points on the route of the pipeline which aims to help the operator to locate the anomalies detected.

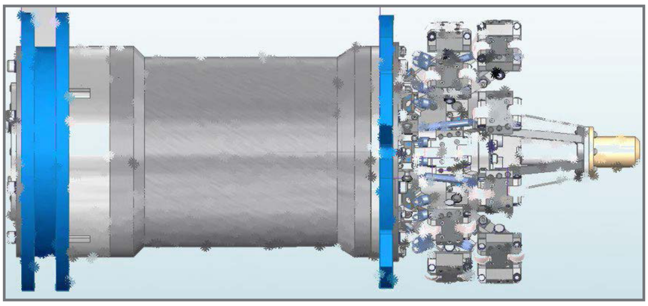


Figure 5: Side view of the assembled T3 scraper before an inspection

2. Bench performance validation

To verify, validate and produce technical performance specifications for the T3 tool, a test bench was built. It has several nozzles of different manufacturing methods and size. These taps are representative replicas of what has been discovered on various pipes in Europe. This test bench has been a key instrument to qualify the capacity of detection of the tool on the different typical illegal tappings presented, to characterize the acoustic responses of each of them and to develop the processing algorithms embedded in the automatic analysis software. It also qualified the data visualization software.

Device diameter available	12'', 14 and 16''
Illegal taps diameter	>1mm
Dent detection, identification and localization (POI ≤ 90%)	Deflection >2% OD
Detection of vertical and horizontal bends and definition of radii of curvature	yes
Length (mm)	760
Weight (kg)	45
Min bend radius	5D
Minimum crossing diameter (mm)	260
Autonomy (h)	60
Battery charging time (h)	12
Operating and storage temperature (°C)	-10 à 55
Max working pressure (bar)	120
Inspection speed (m/s)	0.5 up to 2
Tube length accuracy (%)	<1*

*At constant speed

Table 1: Specifications of the T3 Scraper

Figure 6: Tube comprising the typical Illegal tappings

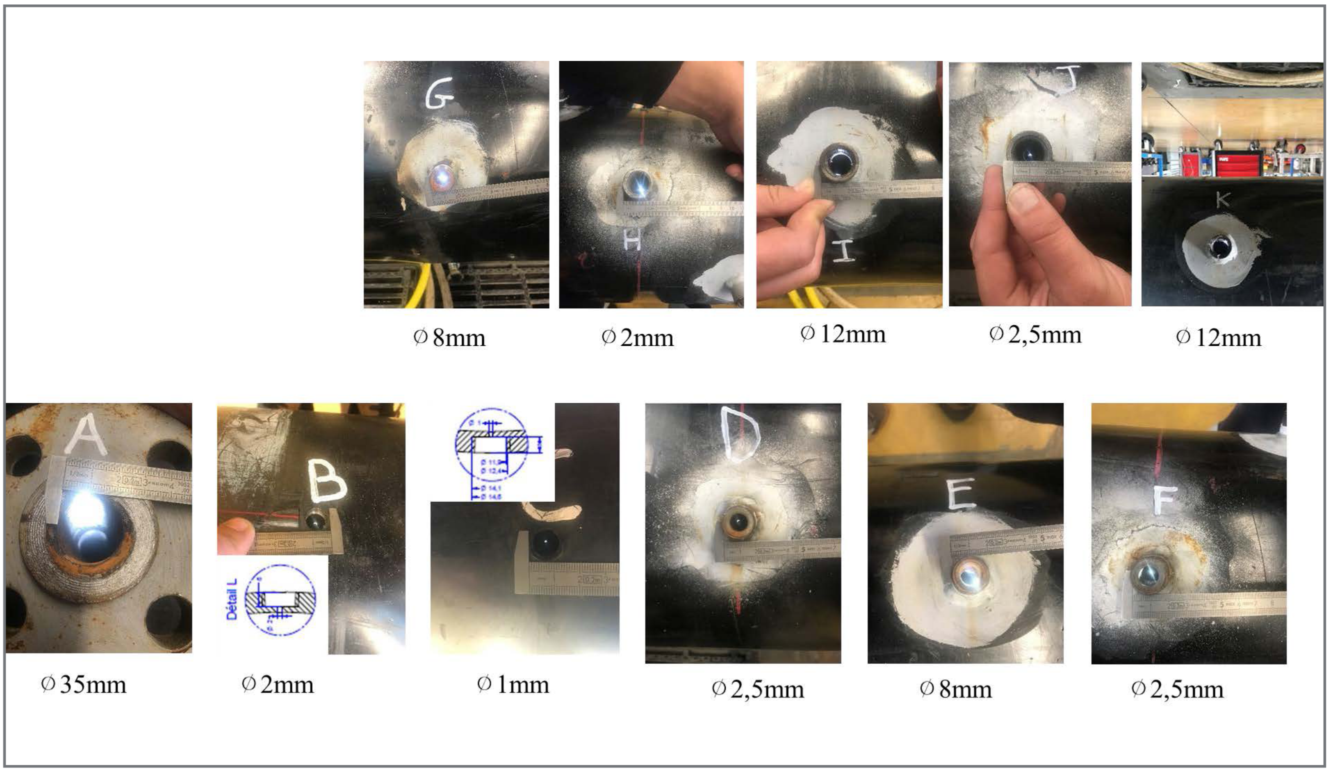


Figure 7: Various Illegal tappings studied

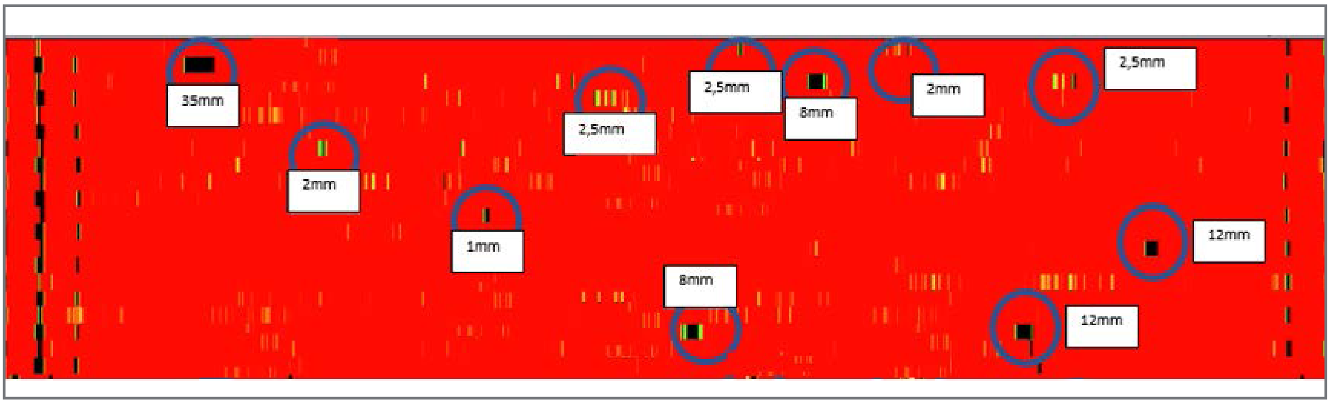


Figure 8: CSCAN of the amplitudes of the signals recorded with the detection of taps present in the test bench

3. Results obtained in real situation

Once the validation of the method and the integration has been carried out on the test bench, several inspections in real conditions were performed. Two pipelines located in the Normandy region (north-west of France), were inspected on several occasions.

Pipeline #1: 12.75'' x 25.3km, average thickness 7.92mm

Pipeline #2: 12.75'' x 43.7km, average thickness 7.14mm

3.1 Reproducibility of the measure

Given the nature of the faults to be detected and the monitoring strategy, one of the essential points to be validated is the reproducibility of the measurement. Knowing that the information recorded is the amplitude of the analogic signal and the time of flight of the echoes, it was necessary to check the level of reproducibility obtained. Thus, the average max amplitudes, the average number of echoes and the average flight time per tube have been compared, it can be observed on the graphs below that the results obtained are particularly close and therefore make it possible to easily compare several successive inspections (the orange and blue curves on each graph correspond to the two rows of probes mounted on the T3 pig).

3.2 Analysis process

Once the inspection has been carried out, the recorded data is extracted and formatted, then transmitted to the analysis center. The automatic analysis developed in-house by the TRAPIL teams makes it possible to detect, identify and locate defects such as illegal taps and to quickly submit an analysis report. The automatic analysis software allows analysis of the data generated by the T3 pig. This analysis takes place in several steps:

- Automatic detection of girth welds,
- Creation of pipe tally,
- Illegal Taps detection: automatic data analysis, tube per tube, looking for elements with the typical signature of illegal taps.

For each illegal tappings type indication a probability of identification is associated. This probability is established according to several criteria such as:

- The signal-to-noise ratio in the area surrounding the suspect indication,
- The variation in the number of echoes,
- The slope of the amplitude drop,

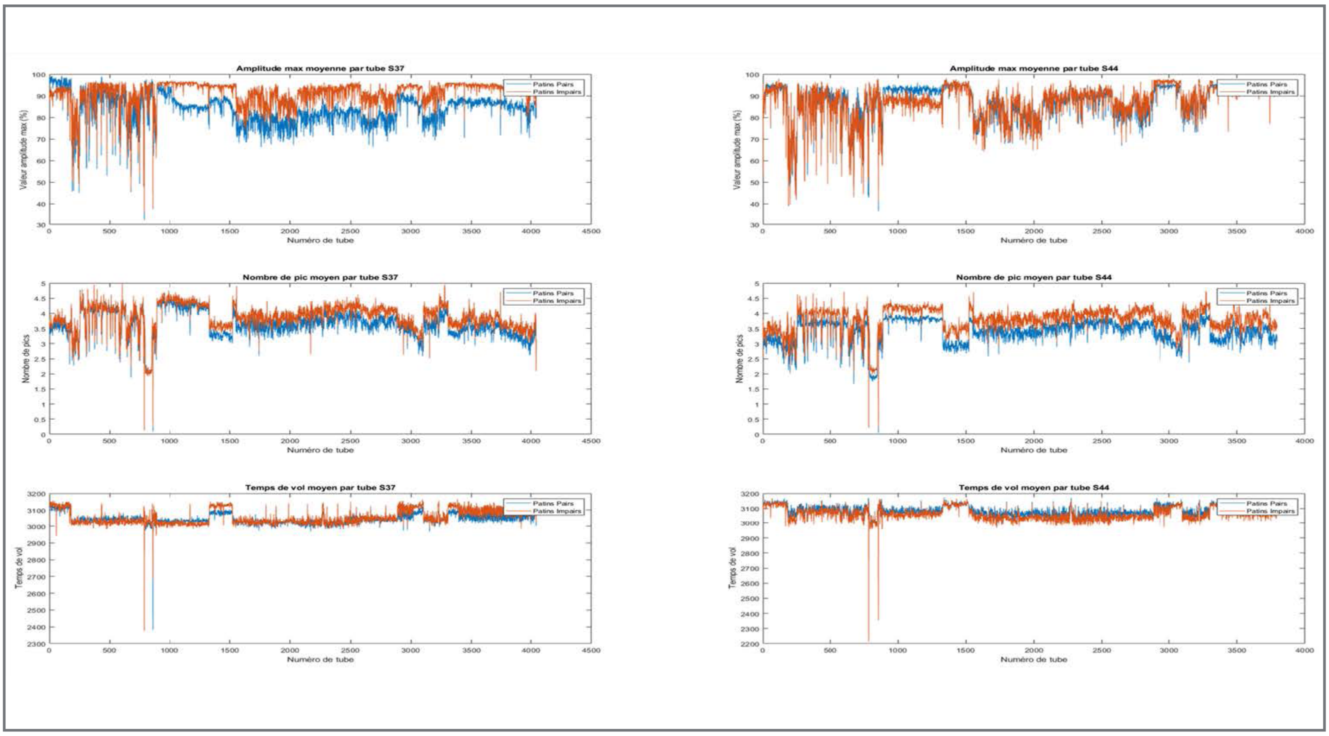


Figure 9: Statistics obtained during two successive inspections of pipeline # 1 Right and left (amplitude/number of echoes and time of flight)

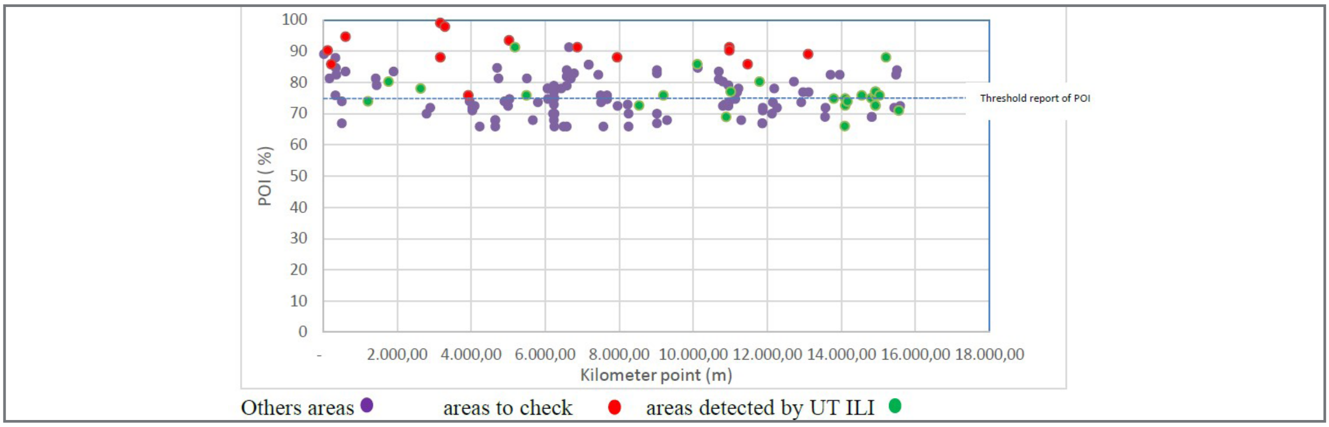


Figure 10: Distribution of selected areas in relation to their POI (Pipeline #1)

- A comparison in size (longitudinal and circumferential) with the reference illegal taps of the test bench,
- The presence of the indication in the preceding passage and a comparison of these characteristics.

This processing cycle can be completed in less than 72 hours after receiving the recorded data. The data produced by the device can also give rise to an automatic comparison of successive passages on the same pipeline in the case where previous reports are available. The analysis is based on the monitoring of new elements, enabling new reports to be submitted quickly. For the two pipelines inspected in Normandy, the results indicated in the inspection report are presented in Figure 9.

3.3 Analysis report

Pipeline #1:

As a result of the illegal tapping detection, 146 indications, whose POI is higher than 65%, are identified. Figure 10 is the repartition of these 146 indications according to their Kilometer point (shifted on the conventional UT passage) and their respective POI. Among the 146 indications, 25 where detected with the previous standard UT inline inspection; this includes several defects types as shown in Table 2 & 3.

Pipeline #2:

As a result of the illegal tapping detection, 78 indications, whose POI is higher than 65%, are identified. Below (Figue 11) is the repartition of these 78 indications according to their pK (shifted on the conventional UT passage) and their respective POI. Among the 146 indications, 2 where detected with the previous standard UT inline inspection; This includes several defects types as shown in Tables 4 & 5

4. Return of field investigation

Based on the information provided by the T3 inspections of the two pipelines concerned, investigations

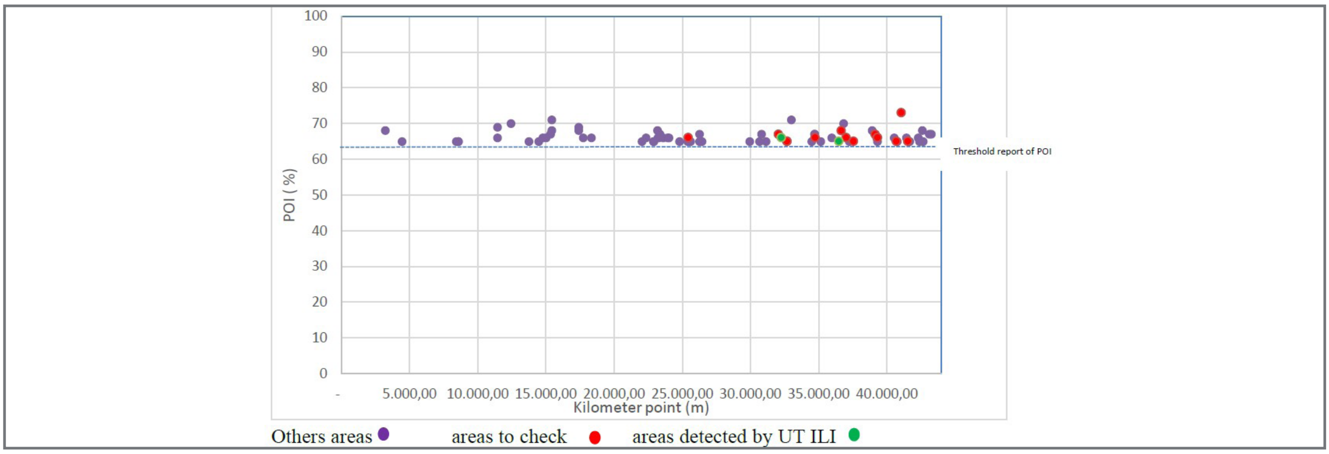


Figure 11: Distribution of selected areas in relation to their POI (Pipeline #2)

	T3	UT ILI
Metal loss	11	206
Lamination	4	193
Dent	10	114

Trigger T3	Area N°	Angular Position (°)	Pipeline N°	POI (%)	Length of feature (mm)	UT ILI Comparison	Presence in previous inspection
6 421 424	2	348,2	21	90	14,9	Suspicious signature	Yes
6 591 717	4	8,9	34	86	18,1	nothing to report	Yes
7 261 728	12	4,9	66	95	44,8	nothing to report	Yes
11 595 796	21	13,5	298	88	22,7	nothing to report - Bend	Yes
11 596 276	22	355,7	298	99	71,4	nothing to report - Bend	Yes
11 797 801	23	357,3	309	98	19,1	Suspicious signature	Yes
12 871 813	24	350,0	365	76	25,3	Suspicious signature	Yes
14 711 690	38	6,5	459	94	81,8	nothing to report	Yes
17 796 911	67	10,1	619	91	17,1	nothing to report	Yes
19 586 410	78	351,5	723	88	51,2	nothing to report - Bend	Yes
24 618 999	100	9,1	998	91	33,7	nothing to report	Yes
24 620 262	101	10,0	998	90	20,3	nothing to report	Yes
25 444 666	107	337,2	1042	86	19,7	nothing to report	Yes
28 168 405	120	343 ,1	1184	89	15,2	RAS	Yes

Tables 2 & 3: Defect types found on Pipeline #1

	T3	UT ILI
Metal loss	1	351
Lamination	1	299
Dent	0	211

Trigger T3	Area N°	Angular Position (°)	Pipeline N°	POI (%)	Length of feature (mm)	UT ILI Comparison	Presence in previous inspection
61 918 301	33	0	2360	66	14,81	nothing to report	Yes
75 116 777	43	333	2921	67	14,65	nothing to report	Yes
76 365 029	45	26	2981	65	18,13	nothing to report	Yes
76 365 229	46	26	2981	65	16,66	nothing to report	Yes
80 556 448	51	319	3170	66	14,18	nothing to report	Yes
84 425 687	55	21	3348	68	19,11	nothing to report	Yes
85 746 906	57	358	3385	66	12,74	nothing to report	Yes
86 865 385	59	40	3438	65	13,52	nothing to report	Yes
90 082 259	61	42	3589	67	19,87	nothing to report	Yes
90 428 352	64	33	3605	66	24,75	nothing to report	Yes
93 204 346	66	32	3737	65	12,65	nothing to report	Yes
93 940 800	69	28	3772	73	15,57	nothing to report	Yes
94 912 577	71	331	3815	65	13,72	nothing to report	Yes

Tables 4 & 5: Defect types found on Pipeline #2

are planned. Thus, the returns of ten controls are being compiled on pipeline #1 and five on pipeline #2. Surface checks are carried out in particular with an electromagnetic pipe detector. An excavation is also scheduled on one of these points in connection with an electrical disturbance, even if the risk of an illegal tapping has been lifted.

5. Conclusions

The primary objective of the T3 "TRAPIL Theft Tracker" is to meet the particular need to detection of illegal taps, whether the sampling is active or not during inspection. Only the defects that may be related to this type of indications are therefore identified during the inspection performed with the T3.

From an operational point of view, the compact design of the T3 makes it possible to avoid additional operating costs due, for example, to facility modifications and the handling and lifting operations required with heavy conventional intelligent pigs. The results obtained in real conditions, described in this article, show the robustness of the control method and the selectivity of the detection system. Thus, the first results show a high reproducibility of the measurement accompanied by a very weak interaction of the signals with commonly encountered defects such as laminations, metal loss, and dents. For dents, a detection and identification software module is being developed, which will provide special monitoring, particularly with regard to the appearance of dents on the upper position of the pipeline which are generated by third-party works.

6. Note

The T3 intelligent pig or device for inspecting a pipe, in particular with regard to Illegal tappings, has been the subject of a patent application filed with the National Institute of Industrial Property, it bears number 2109200.

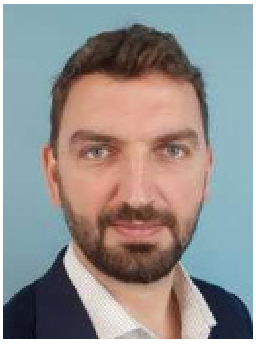
AUTHORS

Stéphane Benichou
Trapil
Head of Study and Production ILI Depatment
sbenichou@trapil.com

Allan Lévy
Trapil
Computer Engineer
alevy@trapil.com

Jérôme De Morel
Trapil
International Business Manager
jdemorel@trapil.com

Jean Luc Bonneville
Trapil
Technical Director
jlbonneville@trapil.com



Bertrand Marquis
Trapil
Head Of Measurement and Quality Department
bmarquis@trapil.com

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Ask the Experts

Leak Detection & Monitoring

Q1) What technology is available for leak monitoring on dense-phase CO2 pipelines?

Chris Davison: API 1130 provides a recommended practice for Computational Pipeline Monitoring (CPM) for liquids. SCADA mass balance calculations based only on measured flow meter data can be unreliable and produce false alarms. By coupling measured data with a hydraulic simulation that can also account for fluid properties and thermodynamic effects while compensating for metering errors, it is possible to identify the signature of a leak with more reliable results. A Real-Time Transient Model (RTTM) approach can be retrofitted using existing metering and telemetry. For sub-sea pipelines or existing buried pipelines, installing specialist equipment, such as fibre, is challenging and costly.

Q2) How is leak detection conducted on short flow lines with limited instrumentation?

David Stobb: To detect a leak event on short-flow lines carrying non-compressible fluids, we need to measure the flow in at one end of the short-flow line and then the flow out on the other end. Monitoring these two measurements' differences can help identify a leak event. For short flow lines, say for lines in the range of half a kilometre to two kilometres, operators often don't invest in instrumentation such as pressure measurements, temperature measurements, etc. or spend time on extensive monitoring. Thus, there isn't enough data to do Computational Pipeline Monitoring (CPM) or run Real-time transient models in such situations, and it would probably also be unwarranted for such pipelines. Hence, if flow measurements exist on both ends of the pipeline, it is sufficient to monitor the difference and detect leak events in cases of non-compressible fluids. For compressible fluids, however, the approach isn't as simplistic. Factors such as line-pack calculations need to be considered, which calls for a more comprehensive approach.

Q3) Leak detection, prevention and monitoring are critical challenges for the hydrogen economy. What should we watch out for?

David Stobb: In a recent survey conducted by DNV, 82% of the Pipeline Operators said that their organisations are actively entering the hydrogen market. Unmistakably, the pace of the energy transition is accelerating, and oil & gas operators are gearing up to adapt to the energy transition. Hydrogen is a novel fluid with unique characteristics. Organisations should carefully evaluate the readiness of their existing infrastructure to handle hydrogen, whether it is pure hydrogen, blended with natural gas or transported as liquid ammonia. Beyond testing the feasibility of their existing infrastructure – in terms of composition and design, organisations must invest in a sound leak detection system that leverages Computational Pipeline Monitoring (CPM) and RTTM. Another critical challenge our clients often face is the lack of internal know-how and experience regarding the operational differences of a pipeline transporting hydrogen. For a safer, more secure transition, these companies can rely on a high-fidelity model-based trainer, such as Synergi Pipeline Simulator's Trainer, to train their engineers on a simulation model of their new system. The pipeline operators can use these models to gain relevant insights and hands-on knowledge and ensure that the operational teams are geared up to manage hydrogen pipelines in the real world.

Q4) How do we maintain our leak detection systems?

David Stobb: The secret to effectively and optimally maintaining a leak detection system is a well-trained staff and a communication environment that promotes the relay of key operational details. Regardless of the leak detection system you invest in, to truly unlock its potential, pipeline control room and support or planning staff must stay up to speed on regulations, abnormal field operations, measurement infrastructure status and capabilities, facility changes, and understand how that influences day-to-day operations while having a good overview of the network and the internal and external factors impacting it. An operating company benefits greatly from having dedicated leak detection staff to stay abreast of all this important information. Unfortunately, in a recent industry survey of pipeline operators, skills shortage and an ageing workforce were cited as the second most significant barrier to growth after political risk and instability. This reiterates the need for regular training to ensure your leak detection support staff and controllers are fully trained. Realistic simulation environments to train pipeline controllers will help them recognise and respond to abnormal pipeline behaviours or emergencies while ensuring that your leak detection systems are up-to-date and compliant with legislation.

Q5) How can I change my instrumentation to improve leak detection?

David Stobb: For optimal leak detection, it is vital to secure high-quality, high-accuracy flow and pressure measurements along the pipeline. If you are transporting a fluid highly dependent on temperature, it is also essential to have frequent temperature measurements along the pipeline. For Real-Time Transient Model (RTTM) based leak detection systems, those measurements should be provided on a 1 to 20-second scan period.

Q6) What do I look out for when investing in a leak detection software system?

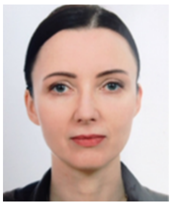
David Stobb: A sound leak detection system is robust, not just in what the software offers but also in how effectively it performs under all operating conditions. It is also essential to consider how comprehensive and flexible the solution is. As the industry evolves, you need a solution that can handle variations.

Victoria Monsma: Always opt for a fast, robust, reliable solution based on proven technology. Also, I recommend using a combination of different techniques.

Find more of your questions answered here: www.pipeline-journal.net/news/ask-experts

THE EXPERTS

David Stobb, Principal Pipeline Engineer, DNV
David Stobb has been with DNV for over 26 years and has been involved with the deployment of real-time transient model-based leak detection systems for transmission pipelines. In addition to leak detection systems implementations, he provides technical oversight to a team of engineers and consultants as they deliver various solutions involving transient hydraulic models.



Victoria Monsma, Senior Pipeline Integrity Specialist, DNV
Victoria is a Senior Integrity Specialist at DNV. She provides expert technical advisory services for oil and gas companies, including design and post-construction verification of oil/gas transmission pipelines, safety and integrity assessments, asset integrity management programs, and many other aspects of pipeline technology.
Victoria is a Subject Matter Expert in the field of reuse of existing natural gas networks for the transport of hydrogen. She is also involved in the development of hydrogen service portfolios, methodologies, guidelines, and service specifications. With a broad range of expertise, Victoria supports DNV's customers in making informed decisions when converting their existing assets to hydrogen. Victoria is a member of a working group developing Dutch standards for pipelines NEN 3650/3651-Requirements for pipeline systems.

Chris Davison, Product Manager, DNV
Chris has 25 years of experience deploying, maintaining & supporting real-time transient model-based leak detection systems. He spent the last 13 years with DNV as a Principal Consultant and subject matter expert. Chris recently assumed the role of Product Manager for Synergi Pipeline Simulator, DNV's transient flow simulation software, and drives the future strategy, roadmap, and QA for this internationally recognised tool. He is based in the UK and has overseen several leak detection projects in the EMEA & APAC regions.

With each issue of the journal, the "Ask the Experts" section focuses on a new topic of particular relevance to the pipeline industry. People from the international pipeline community are invited to send in their questions which will afterwards be answered publicly by selected experts from the respective field.

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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

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

PETRONAS
Malaysia
www.petronas.com

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

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