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ptj - moving forward with new services and a new design

Admir Celovic
Director Publications
EITEP Institute

You have certainly noticed it already: the ptj now looks different than before. This is the result of an extensive improvement process to which we have committed ourselves in order to provide the international pipeline community with even better content. Of course, the appearance plays only the smallest part, even if it is the most conspicuous at first glance.

The ptj has received a new website which offers more extensive added value. All important pipeline news around the world are clearly and appealingly presented on our homepage. You, the reader, can filter according to your own criteria. Whether industry news or political developments: With just a few mouse clicks, you receive the reports that are really relevant to you.

This also applies to our extensive collection of articles with which we provide pipeline experts from all over the world with details on the latest technical innovations. The abstracts are now all digitized and tagged, enabling you to quickly and accurately retrieve the content that is of particular interest to you as a pipeline professional.

We are also constantly improving our newsletter: With the help of a series of international partnerships, we will be able to process the most important business events from the pipeline world even better and more purposefully for you. With ptj, you have an information hub that you should keep an eye on regularly in order to stay up to date.

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Also, do not forget to register for the upcoming Pipeline Technology Conference (ptc) in Berlin, Germany, taking place from 30th March to 2nd April 2020. As Europe's leading pipeline conference and exhibition, the ptc provides you with the attractive opportunity to inform yourself about state of the art pipeline technologies. More than 80 pipeline operators from around the world will be present, making ptc to a central hub for business opportunities.

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Yours,

A. Celovic

> Admir Celovic, Director Publications, EITEP Institute

THIS ISSUE'S COMPLETE CONTENT

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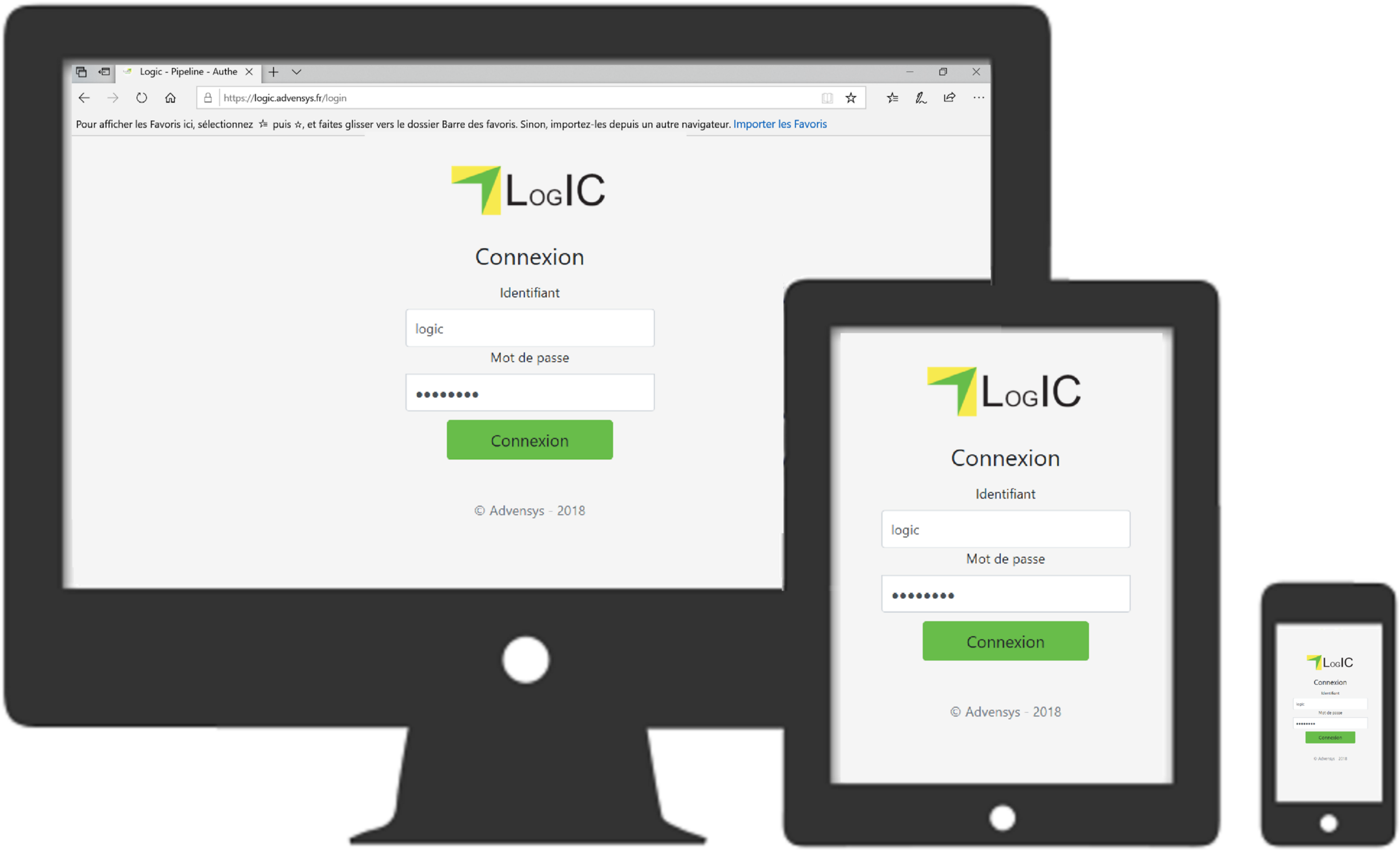
Quality Process, Digitalization of Pipeline Construction



Léna Muscillo > LogIC

Abstract

Pressurized fluid transport structures are subject to regulatory obligations for which the system operators must ensure compliance with the administration. In order to meet the obligations and ensure safety of the networks, in addition to the regulatory documents, the managers demand from the holders of laying contracts, the provision of documents allows attesting that the pipelines were made in accordance with professional standards and contractual requirements (plans, operating modes, self-checks, trial)..

As a quality service provider for the managers and the holders of laying markets on the main gas works built since 2013 in France, LogIC experience feedback has allowed us to note that management and quality assurance processes implemented on these worksites could be optimized. As a result, we decided to digitalize and dematerialize building quality management by developing a connected mobile application. This application installed on PDAs and Touch Pad (Honeywell) allows access to the field, to all the data of a pipe or a welding thanks to the individual identification by bar code labels (examples: ready welding for coating, bending pipe). The use of this application also makes it possible to integrate all the construction data into the database from the site (no more paper, no more document repositories at the end of the day).

From a quality management point of view, the self-checks and trials activity reports are automatically generated, the production monitoring is instantaneous, the welding logs are fed automatically and instantaneously. These developments make it possible to ensure the compliance of site activities, to access all construction data directly from the field, to make the feedback of information reliable, to secure sensitive data, to reduce worksite / office trips, to reduce paper in this air of technological mutation, this application is obvious! It's LogIC

1. CONTEXT

Nowadays, in pipeline construction, important human resources are set in place to provide the necessary elements in order to guarantee works conformity.

However, the management remains handwritten for the construction site part, followed by quality control and computer transcription. This current quality-process organization is not efficient, that's why we developed a quality management turnkey tool, Q.C.M.

Our experience permits us to know that the key of success, for this kind of project, is based on people. In addition to knowledge of networks managers requirements, we developed this tool with a human point of view to improve working conditions and performances. Each is actor of the success, using the best, everybody can give their best.

Q.C.M. permit our customers to guarantee the conformity of their construction improving team work conditions, optimizing quality control tasks efficiency and reducing papers and car rides.

2. Q.C.M. TOOL – THE EFFICIENT WAY TO BE EFFECTIVE

It's composed of a mobile application associated with label readers and bar code labels, glued to the pipes and welds.

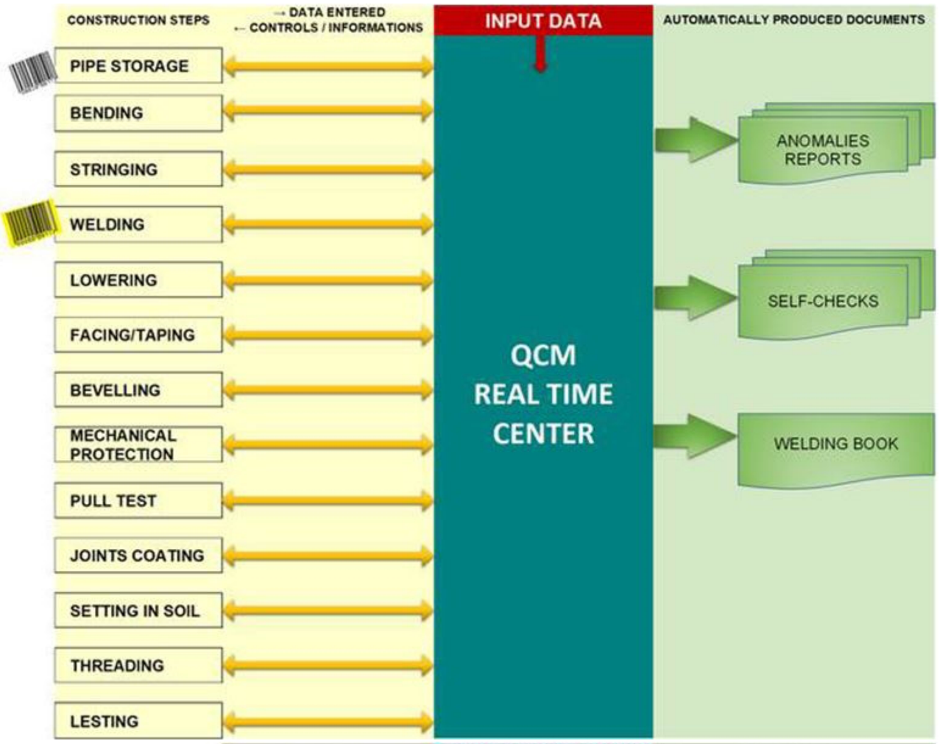
This tool is used from pipe's reception (or manufacturing) to the pressure test, by construction team, quality control center and project management, on the construction site and at the office.

3. THE APPLICATION

This application is set on PDAs and Touch Pad (Honeywell) and allows an access to the field, to data pipe or a welding thanks to the individual identification by a bar code label (examples: ready welding for coating, bending pipe).

- Fits all regulations
- Fits all fluids
- Fits all languages

HOW Q.C.M. WORKS?



	FIELD ACTIONS	SIMULTANEOUS ACTIONS BY Q.C.M.	OUTPUT DATA
PIPE STORAGE	- Pipes labeling - Entering delivery and storage control data	- Control of data entered	- Project pipe list completed - Welding book completed
BENDING	- Pipe scan - Entering the realization data	- Control of the conformity of the realization - Reclassification if not conform and if possible	- Self-check - Welding book completed
STRINGING	- Pipe scan	- Recording the pipe geolocation	- Self chek - Welding book completed
WELDING	- Scan both pipes - Weld labeling	- Control conformity of the assembly - Recording the weld geolocation	- Welding book completed
LOWERING	- Scan of the first and the last pipe of the section	- List of the pipes that make up the section	- Self check

Figure 1: How Q.C.M. works

REQUIRED INPUT DATA

- Pipe packing list from supplier – Excel file
- Pre-bending book – Excel file
- Machines used on the project – Hand grabbing in the app
- Authorization and access of the responsible
- Project technical data (tolerance value, compliance rules, specific requirements) – Hand grabbing in the app

THE SELF-CHECK

The self-checks need to be provided to the customer within 24 hours after operations. They were all digitalized and, thanks to the Q.C.M. quality system management, are automatically generated by the data entered by the operators on the field.

Application adaptabilities allows us to create, digitalize and integrate other documents in addition to those currently developed.

This automatic data transfer allows the yard team leaders to provide, in real time, the daily advancements toward the quality cell without going back to the project office. Sensitive to safety, we wanted to reduce the number of car trips which are an important cause of accident.

By eliminating hand notes, retranscription on computer, impressions and scans, managers can focus on their core business and specialities.

THE WELDING BOO

It's the pipeline construction's reference document.
It lists all elements that constitute the structure (pipes N°, welds N°, welders' identification, materials used, non-destructive test reports, etc).

This document is essential for the success of pressure tests before the pipeline is put into service.

Our app allows to secure the completeness of this document by integrating in real time the necessary information identified on the field.

ANOMALIES REPORT

The application compares the data received with those expected or imposed by the regulations.

If an anomaly is detected, a report is automatically sent, by email, to the concerned managers. The app got an area dedicated to anomalies where managers can learn more about the non-conformity and treat it easily, in real time.

Here is all the benefit to introduce Q.C.M. on a pipeline construction site, saving time. An important stream of data is generated at the same time but from different place and specific activities. Having a general point of view, in real time, on activities progress allows an efficient management of the anomalies and time in general.

4. BARCODES & LABELS

Two kind of barcodes are used:

- White ones for pipes
- Yellow ones for welds

Each barcode is unique and printed in 3 copies, or more, depending on the project we are working on.

Yellow labels are glued near to the weld, the white ones are glued on, or inside, the pipe.

Labels are made in Polypropylene material. It provides excellent reading and adhesive performance on a wide variety of surfaces including non-polar, slightly rough and curved substrates. It also resists against all climatic conditions (Sun, rain, snow, cold/hot, etc.).

5. SCANNERS & PRINTERS

Figure 2: Honeywell scanner with the LogIC application

We use two kinds of scanners, CT50 and EDA70, and one printer, PC43T.

This professional equipment offers a great autonomy, is resistant and very efficient in a hard environment such as on a construction yard (rain, cold/hot, fall, etc).

Our partnership with HONEYWELL guarantees reactivity, professionalism and availability across the world.

6. BENEFITS

- Use an efficient quality management system
- Optimize construction times and costs
- Allows production tracking
- Remove most of the possible mistakes
- Edit automatically reports and self-checks
- Fill automatically the welding book
- Follow in real time the progress of the project
- Allow the actors of the yard to focus on their core business
- Anticipate and secure pressure tests
- Secure and stock all project data
- Increase the safety level of the yard

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Advanced Onshore Pipeline Anchoring Alternatives

Adham Ghali, Elie Dib > INTECSEA UK Ltd.

Abstract

Pipelines may observe significant axial displacement or force at the ends that tie-in with connected equipment and/or facilities. These axial forces are mainly driven by pipe size, temperature, pressure, length and surrounding soils or supports, and can have devastating effects on connecting facilities if not properly accommodated in the design.

The most common approach to address this issue is deployment of concrete anchor blocks just before tie-in locations to achieve full isolation between pipelines and other connected systems. This leads to an increased cost of construction as well as handling and installation of massive concrete tonnage on a soil foundation of potentially high uncertainty, therefore proving to be economically unattractive. With the expansion of fields and processing facilities, including an anchor may also be physically challenging due to space restrictions.

This paper covers assessments of several pipeline case studies that range from 6" to 18" Nominal Pipe Size (NPS) interacting with the major soil categories clay and sand for design temperatures up to 250°C. The assessments show that for a significant number of cases the presence of an anchor is an over-design of the pipeline system, leading to unnecessary costs and potentially more complicated logistics.

Studied cases were analysed using the non-linear Finite Element Analysis (FEA) algorithm of the Abaqus software suite with controlled end displacements.

The work also establishes a case envelope to which the outcomes of this study will be applicable where pipeline conditions lie within the boundaries of the studied cases.

1. INTRODUCTION

Pipelines, particularly steel ones, can observe significant axial displacement or force at straight ends that tie-in with connected equipment and facilities. This is mainly driven by temperature, pipe size, straight length, surrounding soils, supports, and pressure.

Depending on the pipeline configuration, the axial effect is conventionally quantified by either calculating the fully restrained theoretical force at the pipeline end, or fully converting the force to end movements in a theoretically unrestrained pipe.

Depending on functional requirements and operator specifications, the generated axial forces and movements need to be within the allowable limits of connecting utilities, such as piping, or isolated using an engineered solution.

Recent advances in seismic imaging and reservoir mapping technologies (Halsey, 2016) have enabled production from deeper reservoirs at higher pressures and temperatures. This poses new challenges to production and transport infrastructure design, which are sometimes technically prohibitive using conventional engineering.

This paper discusses the current issues facing pipeline end interface design under elevated operating conditions and presents a Finite Element (FE) based approach to optimize, or eliminate, pipeline anchoring requirements.

2. TECHNICAL CHALLENGE

The search for new, production feasible, hydrocarbon reservoirs is driving drilling deeper wells (DeBruijn, et al., 2008), and with temperatures increasing proportionately with depth in the order of 15 to 30 degC per 1km of depth (Satter & Iqbal, 2016) this translates to more challenging design conditions.

Concurrently, pipeline technologies have developed and enabled an increase in operating pressures from 2 to 120 bar between the years 1910 and 2000 (Hopkins, 2007). More recently, the use of thermal recovery techniques, even in shallower layers, has dramatically increased production temperatures (Belani & Orr, 2008).

It follows that requests for pipelines designed to temperatures in the order of 70 to 100 degC for production from high-temperature wells (Mahmoud, 2017), are becoming more common. Pipelines designed to such conditions could generate sufficient axial force to cause damage to connecting infrastructure if left unrestrained or not considered in the design.

The conventional approach to resist axial forces is by utilizing anchors at the interface (Bahadori, 2017). Some Engineering Standards for designing concrete blocks also define the allowable limits for pipeline end displacements (Saudi Aramco, 2005).

For lower flowing temperatures the required anchor capacities are in the order of 2000 to 3000 kN, typically yielding an anchorage footprint of 5x5m, with typical depths of between 4 and 5 m. However, anchor capacities for larger pipes with challenging design conditions can reach 5000 to 9000 kN, with much larger footprints (16x16m) (SA_Water, 2007), which is demonstrated in Section 4.

The construction of such anchors, particularly in mature fields with safety and access complexities, leads to excessive soil resistance requirements and becomes near prohibitive. Moreover, supporting sheet piles may be required if many anchors are required within a congested field (Thorley & Atkinson, 1994).

Notably, (Ghdaib, et al., 2011) conducted a field monitoring study on a pipeline anchor block system indicated that the installed anchor block sizes could be reduced based on the obtained strain and stress response data.

3. AVAILABLE SOLUTIONS

An investigation of available alternatives to mitigate the large expansions and forces encountered at pipeline ends was driven by the challenges outlined in Section 2 with the aim of reducing anchor size or eliminating the anchor requirement.
One of the options to reduce the end forces and the anchor block footprint is combining gravity based anchors with a form of piling, such as sheet piling as shown in Figure 1.

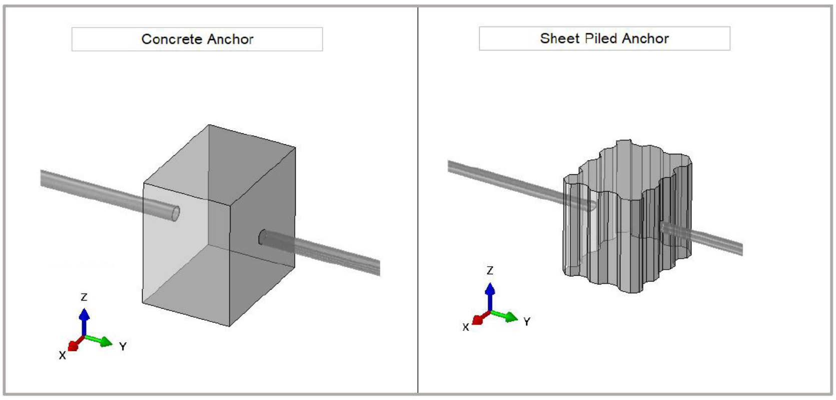

Figure 1: Pipeline Ends - Anchor Blocks

Route optimization is also a common option, and although primarily utilizing in-line bends to minimize route obstructions and rough terrain, it is sometimes aimed at minimizing straight pipe lengths to reduce high load and stress concentration areas as indicated in Figure 2.

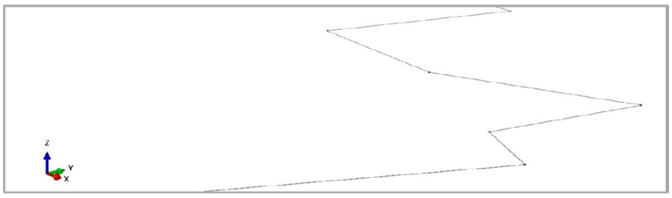

Figure 2: Pipeline Route - Minimizing Straights

Another alternative is introducing L, Z or U bends at the pipeline end to accommodate the incoming forces and expansions as shown in Figure 3.

4. CONVENTIONAL APPROACH

The typical approach to designing tie-in interfaces is obtaining analytical estimates for end forces and displacements using principal equations. This is widely considered a quick method providing conservative results.

This was performed for the investigated cases and ASME B31.8 (ASME, 2016) equations for calculating restrained pipe axial forces were consulted.

End displacements were calculated using the difference between the driving pipeline strain due to temperature and pressure in the face of resisting soil friction to arrive at the resulting pipeline end expansion.

That formed the basis for concrete block sizing based on lateral earth pressure theory (Das, 2014), which covers stability, sliding, overturning and base load checks on anchor design. Below is a summary of the concrete block sizes required.

Concrete Block Requirements

Diameter-to-thickness ratio	Pipe Size [NPS]	Concrete Block Footprint [m^2]	Concrete Volume Requirement [m^3]
25	6	36	111
	8	59	228
	10	84	328
	12	130	507
	14	160	624
	16	245	956
	18	336	1310
10	6	68	263
	8	146	570
	10	261	1018
	12	392	1529
	14	490	1911
	16	680	2652
	18	897	3498

Figure 4: Concrete Block Requirements

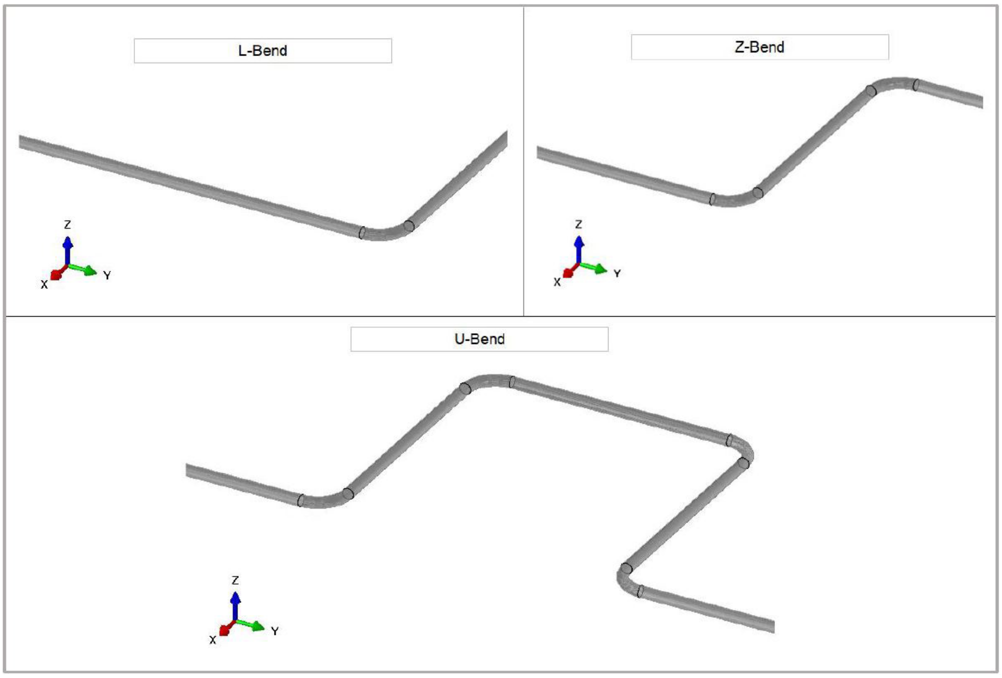

Figure 3: Pipeline Ends - Bend Configurations

5. ADVANCED APPROACH

In recent years the increased availability and efficiency of FE based Analysis and computational power have enabled detailed capture of previously over-estimated loads by considering geometrical, soil and material non-linearities.

The advanced approach is based on utilizing FE tools to capture the property and geometry variations not captured in the conventional approach presented in Section 5.

Additionally, incremental FE analysis is useful in defining the workable limits of a proposed configuration, including the maximum acceptable temperature or pressure.

5.1. NON-LINEAR SOLUTION

The FE based Abaqus solver efficiently estimates forces and displacements of buried pipelines approaching above ground tie-ins and simulates pipe and soil 3D behaviour.

Contrary to the conventional single system linear solution, the non-linear Abaqus solver is based on incremental loading and equilibrium, this enables the simulation of true loading scenarios as they would occur in real-life.

5.2. COUPLED MODELLING

A key input for anchor block force balance is the incoming loads on both sides, the above ground and the buried side of the anchor location. Conventionally, this would be independently calculated for each side and conservatively approximated, resulting in over-estimated above ground displacements and exaggerated the interface loads.

This can be optimized through coupled modelling, which incorporates the stiffness of connected piping/utilities into the modelled system as indicated in Figure 5.
The established model continuity develops a global understanding of the integrated system during design and ultimately helps reduce, or eliminate, approximations at interfaces and achieve maximum design optimization with minimum construction spreads.

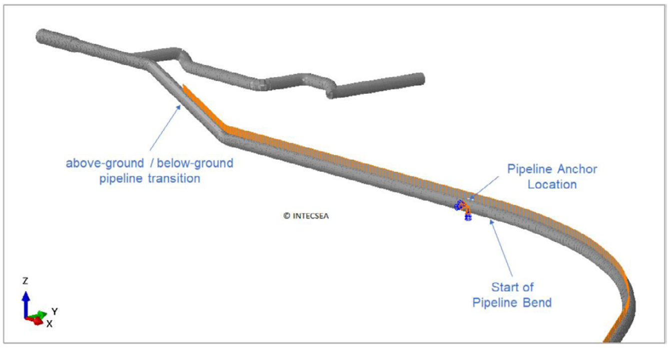

Figure 5: Coupled Pipeline/Piping Model

5.3. SAMPLE CASE STUDY

To demonstrate the benefits of advanced analysis capturing realistic interface loads when utilized alongside simple geometry, the simplified Z-bend pipeline end configuration Figure 6 was selected as a representative sample case. The analysed cases covered buried pipe sizes between 6" and 18" covering 2000m of straight length for diameter-to-thickness ratios 10 and 25.

Optimization outcomes were measured by comparing the resulting forces and displacements to the analytical estimates as detailed in Section 6.

For this study, soil springs used in the analysis represented cases of typical sand and typical clay to cover both cohesionless and cohesive soil types. On a typical assessment, soil properties are obtained from geotechnical survey interpretations transformed into workable analysis inputs

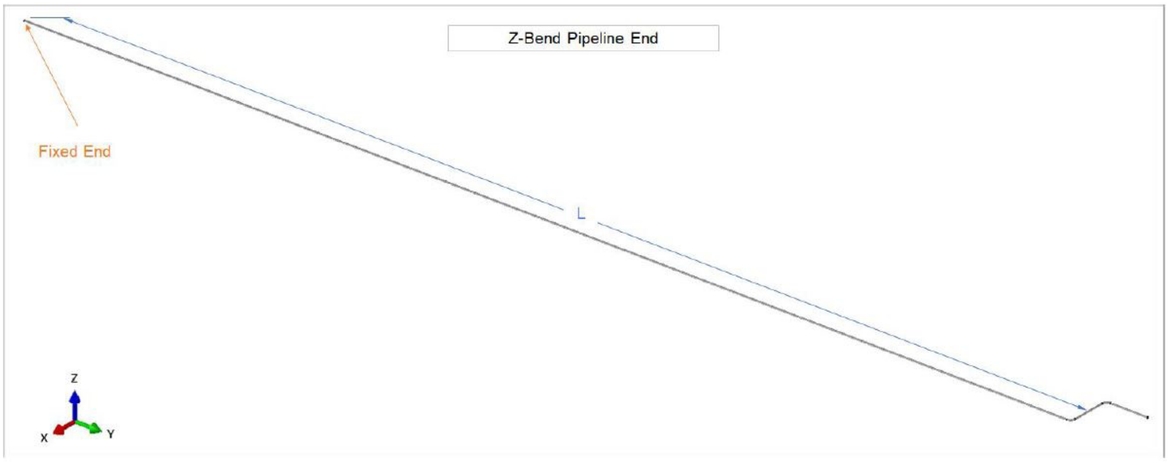

Figure 6: Selected Z-Bend Configuration

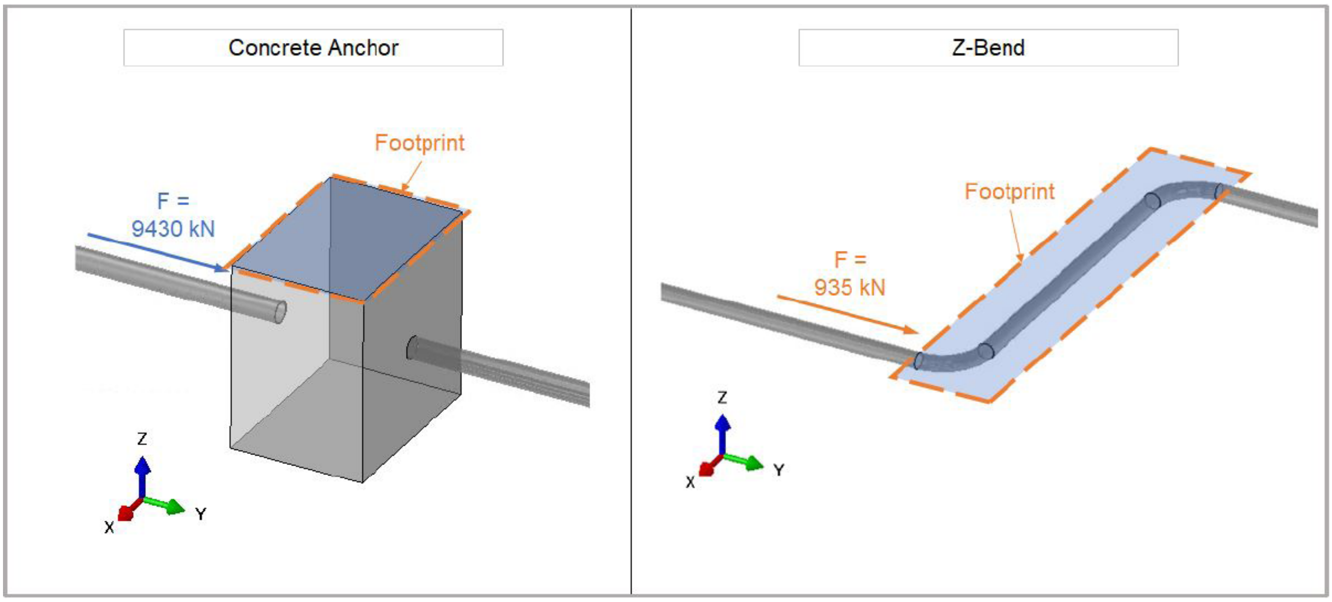

Figure 7: Sample End Force Comparison - 14" Pipe

based on PRCI (Douglas G. Honegger, 2004) soil models for axial, lateral, vertical bearing and vertical uplift resistances.

6. COMPARATIVE ASSESSMENT

6.1. RESULTS

The investigation included a comparative study of the resulting forces and displacements from the conventional approach and the advanced approach. The following outputs comprise the values used in the comparison for the studied load cases:

- Full force feed-in – This is the fully restrained axial force based on standard (ASME, 2016) calculations. It is the highest axial force possible for each considered case.
- Optimized force feed-in – This is the FE based axial force at the end of the straight pipeline segment, immediately before the Z-bend. This represents the axial force observed at the pipeline end with the introduced end optimization.
- Figure 7 indicates the forces when compared for a sample case.
- A sample force profile indicating the fully restrained force feed-in and the optimized force feed-in is shown in Figure 8.
- Full movement feed-in – This is the FE based displacement at the end of the straight pipeline segment, immediately before the Z-bend. It is the largest achieved end displacement for each modelled case
- Optimized movement feed-in – These are the conditions at the end of the Z- bend investigated in this study, they represent the partially restrained conditions only accurately captured using FE based analysis.

Figure 9 indicates the displacements when compared for a sample case. A summary of the results for non-cohesive soils indicating reduction is shown in Figure 10.

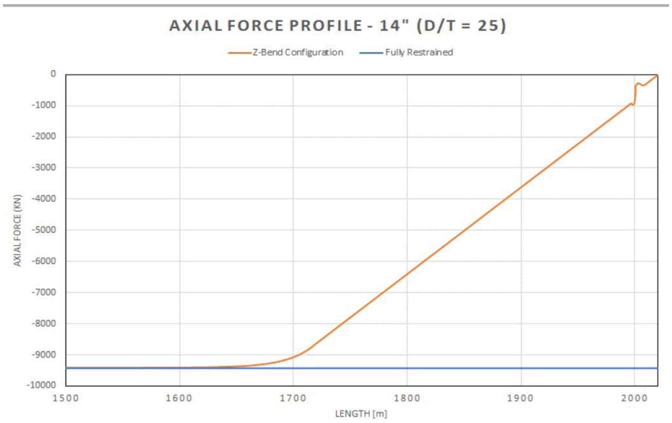

Figure 8: Sample Force Profile

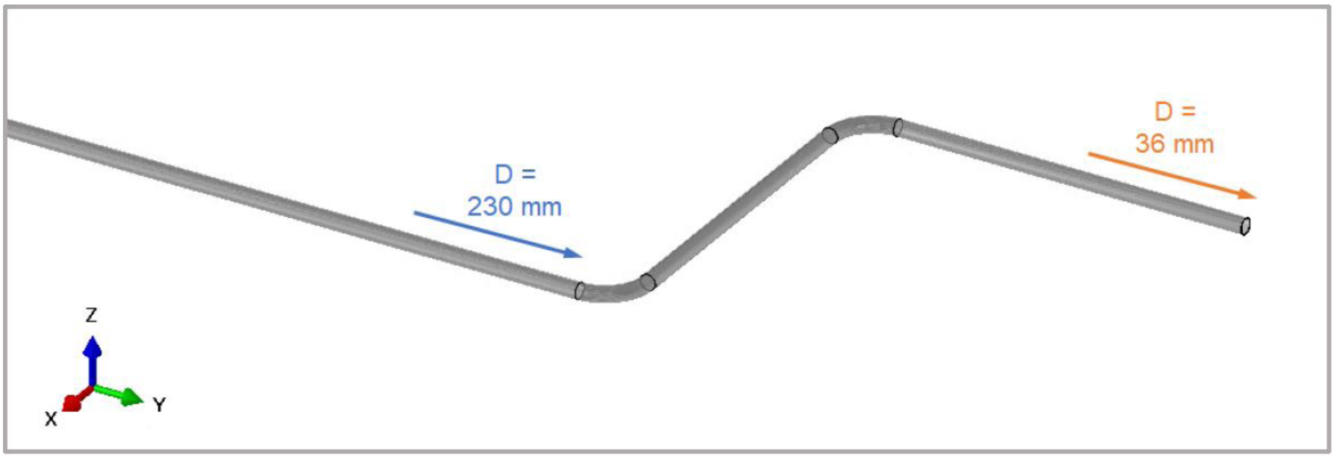

Figure 9: Sample End Movement Comparison - 14" Pipe

Force, Expansion and Footprint Reduction – Non-cohesive soils

Diameter-to-thickness ratio	Pipe Size [NPS]	Axial Force Reduction	End Expansion Reduction	Concrete Block Footprint [m²]	Spool Footprint [m²]
25	6	73%	60%	36	67
	8	77%	76%	59	67
	10	81%	84%	84	88
	12	87%	83%	130	88
	14	67%	90%	160	109
	16	86%	93%	245	109
	18	86%	95%	336	130
10	6	84%	84%	68	130
	8	87%	90%	146	142
	10	89%	94%	261	142
	12	90%	95%	392	163
	14	91%	96%	490	163
	16	91%	98%	680	183
	18	91%	98%	897	183

Figure 10: Force, Expansion and Footprint Reduction - Non-cohesive soils

6.2. DISCUSSION

6.2.1. END FORCE AND DISPLACEMENT

Upon reviewing the resulting forces and displacements, the assessment indicates effective axial force values of 30% or less of the conventional fully restrained axial force and 60% or more reduction in end displacements for the analysed cases.

It is clear from the results that the fully restrained axial loading is significantly higher than the partially restrained force at the anchor location. This is demonstrated in the presented force reduction in Figure 11.

The conventional approach of conservative analytical estimates of pipeline end force and displacement offers a clear split of scope between different engineering disciplines utilizing interface loads in their design, it also facilitates independent discipline variations and progress measurement.

However, based on the technical challenges presented in Section 2 and the results presented in this Section, this approach sometimes becomes uneconomic and unrealistic due to the pipeline anchoring occupying too much large real estate and sometimes introducing pipe misalignments.

The advanced approach, on the other hand, offers a versatile approach to addressing the loads at pipeline end connections, which depends on accurately capturing the interface loads and stiffnesses.

Although it does not offer complete isolation, advanced computation of interface loads enables the design to match the exact loading requirements.

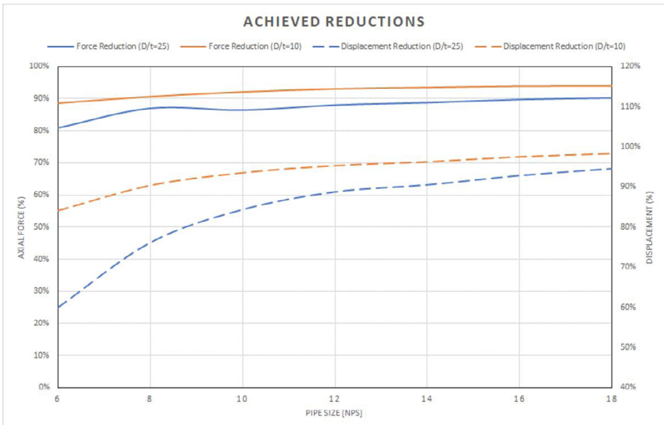

Figure 11: End Force and Displacement

6.2.2. SOLUTION FOOTPRINT

Using the conventional approach, isolation is achieved using the anchor footprint, explained in Figure 7, which incrementally increases with the increase in pipe size and diameter-to-thickness ratio.

Using the advanced approach shows the investigated Z-bend configuration offers minimal footprint increase with pipe size to achieve the desired reduction in forces and displacements. This results in optimized solution footprint for all investigated pipe sizes with diameter-to-thickness ratio of 10, and an optimized footprint for 12" and larger pipe sizes for diameter-to-thickness ratio of 25 as shown in Figure 12.

6.2.3. COUPLED MODELLING

The concept of coupled modelling discussed in Section 5.2 was applied by the author extensively on project specific configurations, using both linear and non-linear solvers.

A pilot comparison with the conventional independent approach showed that coupled modelling reduced the translated forces by more 90%. Moreover, the stress utilizations on the connected piping dropped by a full order of magnitude for thick wall pipes with diameter-to-thickness ratio of 9.5.

This indicates significant technical and economic advantages of utilizing model continuity for pipeline ends design.

7. CONCLUSIONS

This paper demonstrates a simple, technically feasible engineering approach to optimizing pipeline end configurations, end expansions and forces for the investigated cases.

A sample case of Z-bend at the pipeline end is shown to reduce the axial force by 85% on average when compared to complete fixation achieved using anchor blocks, while maintaining axial displacement at less than 20% of the unrestrained pipeline configuration on average.

The results show that the Z-bend can be an efficient and less environmentally invasive alternative than conventional anchor blocks for buried pipelines, with established reduction in footprint for thick pipe sizes between 6" and 18", and thin pipe sizes between 12" and 18".

Moreover, if anchoring is unavoidable, significant reductions can be achieved in anchor capacity requirements while still maintaining the purpose of the anchor by adopting the advanced modelling approach discussed in this paper.

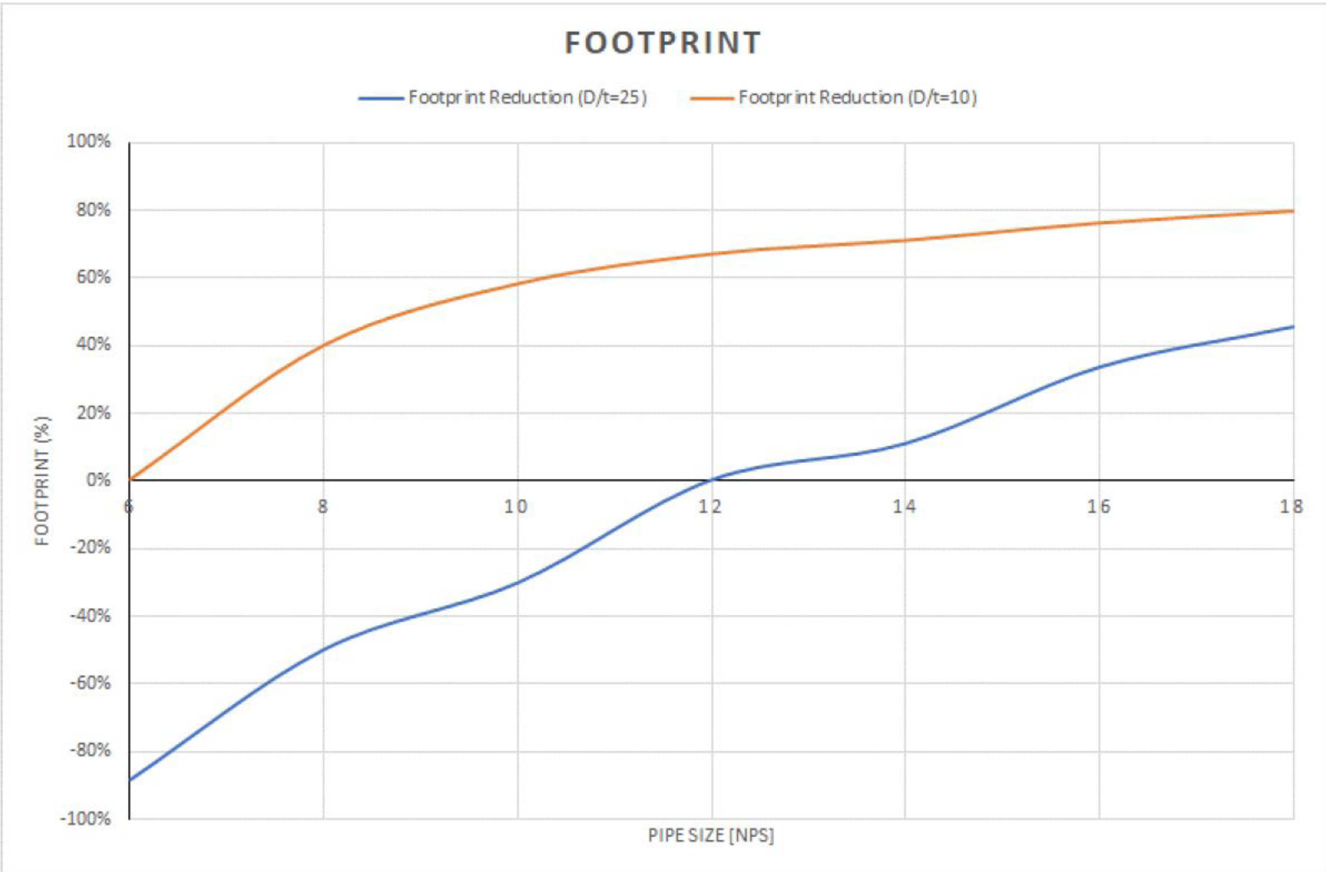

Figure 12: Solution Footprint

Introducing connected piping/utilities for project specific configurations further added to the presented optimization as discussed in Section 6.2.3. It is therefore also concluded that coupled modelling of pipelines and connected piping/utilities enables the design to accurately capture the forces and displacements from all system components.

This optimization of the interaction loads between underground pipelines and the connected above-ground facilities realizes significant technical and economic benefits.

8. RECOMMENDATIONS AND FUTURE WORK

Based on the results presented in this study, it is recommended that detailed investigation of engineered alternatives to concrete anchor blocks is adopted as common practice within the pipe size envelope of 6in to 18in, with diameters ranging 10 to 25 times the thickness.

Additionally, a risk assessment of the assumptions is also recommended to complement this work with quantifiable probabilities and scenarios of failure to drive further reduction in required sizes and, where feasible, eliminate the need for pipeline anchor blocks.

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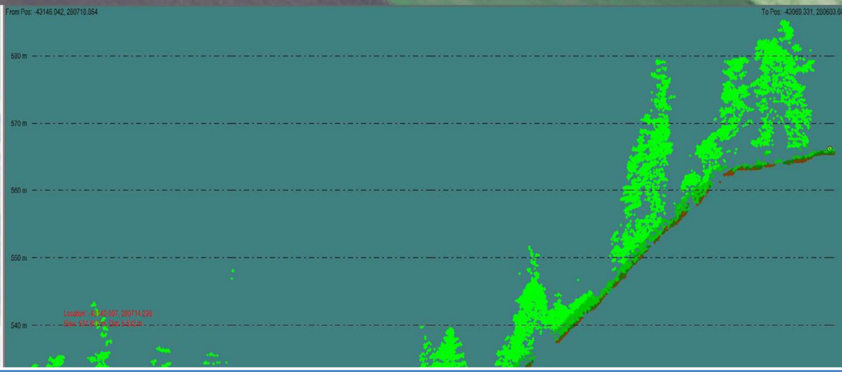
River crossing and water crossing survey by airborne bathymetric laser scanning - Case study TAG



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Abstract

Airborne bathymetric laser scanning delivers the same results as regular airborne laser scanning, but with one major difference, this technology is able to penetrate water. The technology has matured through the past years, meanwhile it is used for the bathymetric survey of lakes, harbors, coastal shore lines and rivers.

The Trans Austria Gasleitung (TAG) is a major part of the gas supply chain for central Europe, it consists of three and mostly parallel pipelines and five compressor stations, the diameters are from 36 to 42 inch and the operating pressure is up to 70 bar. The TAG leads from the Slovakian-Austrian border to the Austrian-Italian border and crosses Austria on a length of approx. 380 km, it is composed of approx. 1,140 km pipeline in total.

Trans Austria Gasleitung GmbH, as operating company, has performed a bathymetric survey of 23 selected river crossings by airborne bathymetric laser scanning in 2017. The survey was part of several remote sensing services performed to monitor the situation at site and to update the base map data along the entire route of TAG, the river crossings are spread along TAG´s 380 km.

The technology enables a totally new approach to perform bathymetric surveys for all kind of water crossings of pipelines, such as river crossings, landfalls and other kind of water crossings. It delivers more and better information in shorter time, compared to classical procedures like terrestrial survey or echo sounding. The right approach for the survey mission ensures the capturing of all required data.

1. TRANS AUSTRIA GASLEITUNG (TAG)

1.1 TAG PIPELINE SYSTEM

The TAG Pipeline System consists of three lines (TAG I, TAG II, TAG Loop II), five compressor stations, auxiliary equipment as well as two Entry Points and one Exit Point. The Pipeline leads from the Slovakian-Austrian border near Baumgarten an der March to the Austrian-Italian border near Arnoldstein covering a length of about 380 km and is composed of about 1,140 km pipelines with diameters ranging from 36 to 42 inches and a pressure of up to 70 bar. The total installed power of the compressor stations is approx. 480 MW.

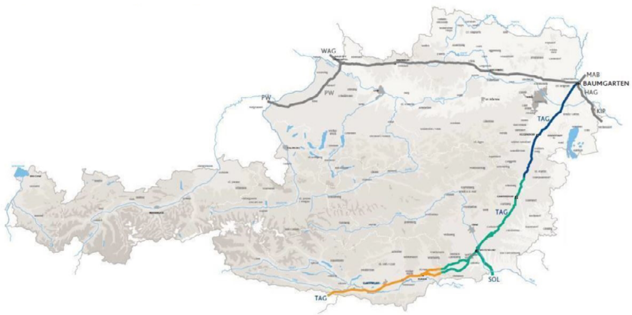

Figure 1: TAG Pipeline System

The TAG Pipeline System is used for supplying domestic customers in Austria as well as for the transit of natural gas to Italy. Via the SOL Pipeline System (Süd - Ost - Leitung) of Gas Connect Austria GmbH, which diverges at Weitendorf from the TAG Pipeline System, transit to Slovenia is also possible.

1.2 PIPELINE MONITORING SERVICES 2017

TAG performed pipeline monitoring services in 2017, the bathymetric survey of 23 river crossings was part of it. Prior to those services a pilot project on 60 km was performed in 2016, the goal was to tailor the services to the needs of TAG.

The applied technologies were airborne route videos, airborne laser scanning, photogrammetry (orthofotos, vectorisation) and airborne bathymetric laser scanning. Deliverables of those services were airborne videos of the route (HD/IR), 3D classified pointcloud, DSM, DTM, orthofotos, vectorisation (incl. polygons), raw data of the flights incl. aerotriangulation, flight strips, tiles, etc. and a report.

The results of the airborne bathymetric laser scanning were finally integrated into 3D pointcloud derived from the airborne laser scanning.

2. TECHNOLOGY & SETUP

2.1 TECHNOLOGY

Airborne laser scanning is when a laser scanner, while attached to an aircraft during flight, creates a 3-D point cloud model of the landscape. (Wikipedia/ https://en.wikipedia.org/wiki/Lidar)

Airborne bathymetric laser scanning is the same, more or less, with the difference that a green laser is applied and the laser beam is facing forward and backwards. These differences enable the laser beam to penetrate water.

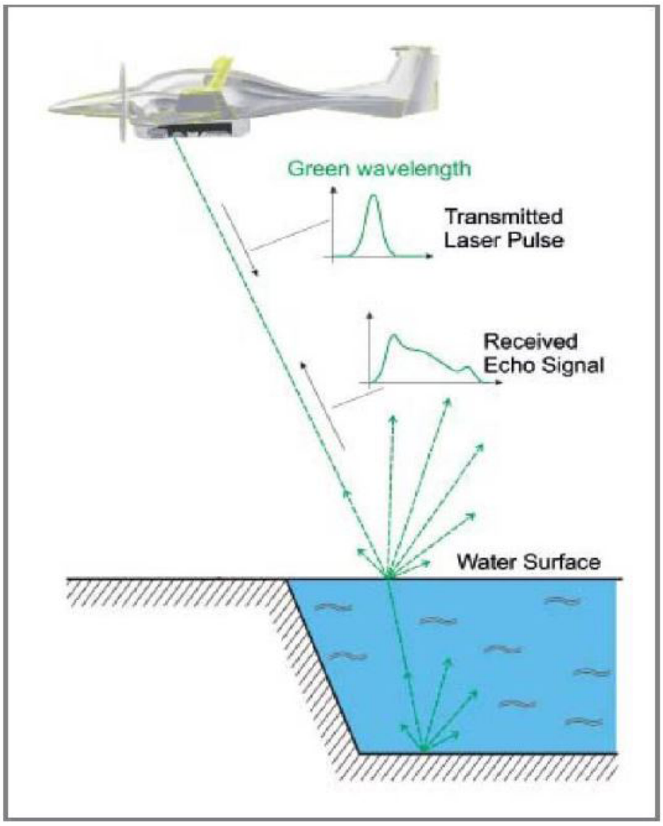

Figure 2: RIEGL, Scanner VQ-820-G

Limiting factors for the water penetration are the flow speed of the water and the water turbidity. The less the flow speed and the clearer the water, the better and deeper the measurement.

All on the market available sensors provide a parameter about their water penetration capability, that parameter is the Secchi depth. The Secchi depth is determined with a Secchi disk, which is a black and white, 20 cm diameter disk used for measuring the turbidity of water. The disk is lowered into the water until it just disappears from sight. The depth at which the disk disappears is called the Secchi depth. An assessment of the secci depth of rivers / waters to be crossed prior to a survey campaign is possible.

2.2 TAG – SETUP 2017

For the bathymetric survey of the 23 river crossings of TAG we selected a RIEGL VQ-820-G sensor with a Secchi depth of 1 and a given accuracy and precision of 25 mm under laboratory conditions. The sensor was mounted on a Cessna 182T, and it was operated on 400 m flight altitude above ground level.

3. CHALLENGE & IDEA

3.1 SPECIFICS OF RIVER CROSSINGS

Pipeline river crossings are difficult, expensive and time consuming during design, construction and operation/ maintenance. River crossings are permanently threatened by flooding and washout. They need a special survey, a special design, special protection measures and finally they need to be monitored throughout the whole lifecycle.

3.2 CLASSIC SURVEY OPTIONS

Bathymetry is the underwater equivalent to topography. The classic survey options for the bathymetry of pipeline river crossings are either by walk through or from a vessel. Walk through as long as river depth and flow speed allows to pass the river and from a vessel after walk through is not possible anymore.

Walk through means to survey either by classical terrestrial survey or GPS. From the boat means to survey either by classical terrestrial survey or GPS from the boat, or survey by echo sounding or radar. Echo sounding or radar is usually combined with GPS, these technologies can be applied for big water depths as well, which is their real strength.

The main challenge of the classic survey approach is the related logistics. River crossing are usually spread out along the route, which is often a few hundred kilometers, and to perform this approach surveyors need to mobilize on site with all required survey equipment, including vessel if required. After the finalization of a crossing the survey team needs to transfer to the next crossing.

Benefit of a classic survey approach is, surveyors are on site and see more location specific details. Disadvantage is the required longer time for mobilization, survey, transfer to the next site, demobilization and processing. Longer weather dependency is another disadvantage furthermore limitations by vegetation for good sights during the survey need to be overcome. Finally only profile lines at selected locations are delivered, instead of an array of survey points for the riverbed.

3.3 HISTORY & PROJECT IDEA

We received a sample data set of Riegl`s latest airborne bathymetric laser scanner in the beginning of 2016, and we were heavily impressed of that data set. Riegl is one of the world leading producers of laser scanners.

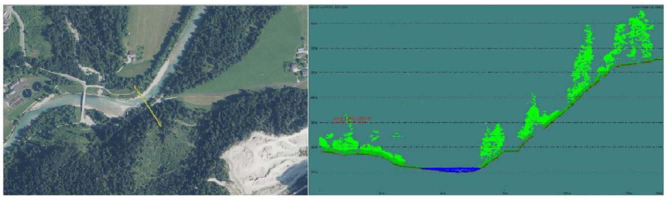

Figure 3: Test airborne bathymetric laser scanning Saalach, orthofoto and profile through the classified 3D pointcloud

To be sure on the quality and the real capabilities of such a sensor we decided to perform a test including a comparison with a classic terrestrial survey. The test was performed on the river Saalach at the stretch of the Austrian-German border.

After the successful test and based on the experiences gathered from the test, we developed the idea of an alternative solution for the survey of pipeline river crossings. We contacted TAG and presented the results, finally we were able to convince TAG to apply the technology for the bathymetric survey of the TAG river crossings.

4. SCOPE & RESULT

The specified scope was to survey 23 selected river crossings along 380 km route with airborne bathymetric laser scanning. We applied the setup as described above, see chapter 2.2 TAG – Setup 2017.

Two flights were required, one flight per day. The specified crossings were covered in both directions and we ended up with a point density of 14 pts/m². We captured 21 crossings and only for 2 crossings we got no results, due to water turbidity. The river width varied from 3 m to 191 m, and the captured water depth was up to 1.5 m.

The processing of the captured data required 15 days, as processing is more extensive than regular processing of airborne laser scanning, due to the large amount of signal noise on the one hand and on the other hand due to some special processing steps.

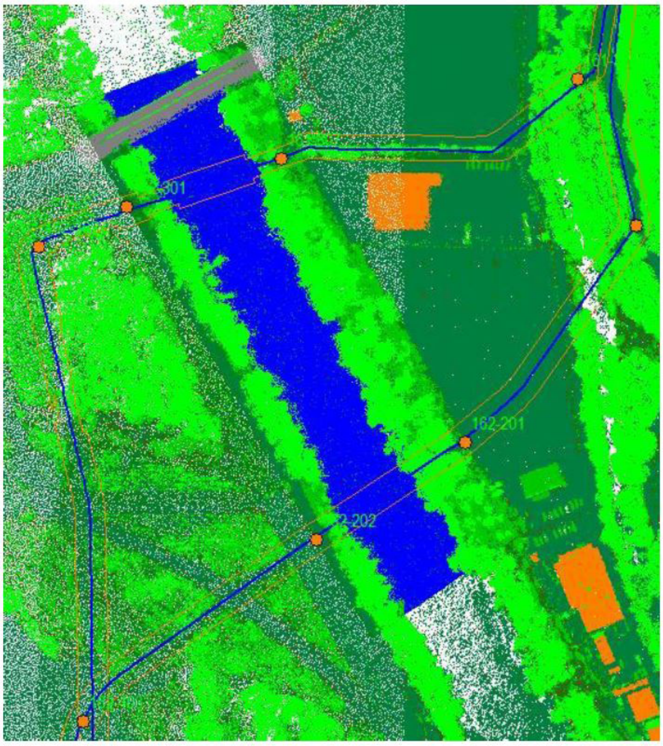

Figure 4: Classified 3D pointcloud with integrated river section, 300 m

The result is a classified 3D pointcloud including the waterbody, which is the basis for a digital surface model (DSM) and a digital terrain model (DTM). It was agreed with TAG to integrate the crossing section into the data that were captured with the regular airborne laser scanning for the entire route. The intention was to have one dataset with a combined result from both technologies along the entire route.

5. RIVER CROSSING MUR

This sample provides an overview about the results. The selected crossing of the river Mur is located westward of Weitendorf in Styria, the route splits up and TAG I crosses the Mur southeast of TAG II and TAG Loop II. The river width is about 54 m and the water depth at the crossings is about 1.2 m.

See the right image of figure 5, there is the biggest difference to classic survey visualized, the result of airborne bathymetric laser scanning is an array of survey points for the riverbed.

Figure 6 provides a profile of the Mur crossing of the TAG Loop II, it is composed of the points from the 3D pointcloud providing the vegetation in a corridor ± 2 m along the route, generated terrain from the classified ground points and the top of pipe received from intelligent pigging.

Due to the array of survey points for the riverbed such profiles can be taken at any location on demand. Therewith it is easily possible to check the situation up- and downstream of the crossing.

6. CONCLUSION

6.1 AIRBORNE BATHYMETRIC LASER SCANNING VS. CLASSIC SURVEY

The recommended surrounding conditions for both approaches are the same, both should be applied during low water and not during the vegetation phase.

Figure 5: Left: River crossing Mur, orthofoto and route Right: River crossing TAG II and TAG Loop II, 3D pointcloud waterbody switched off, intensity colored

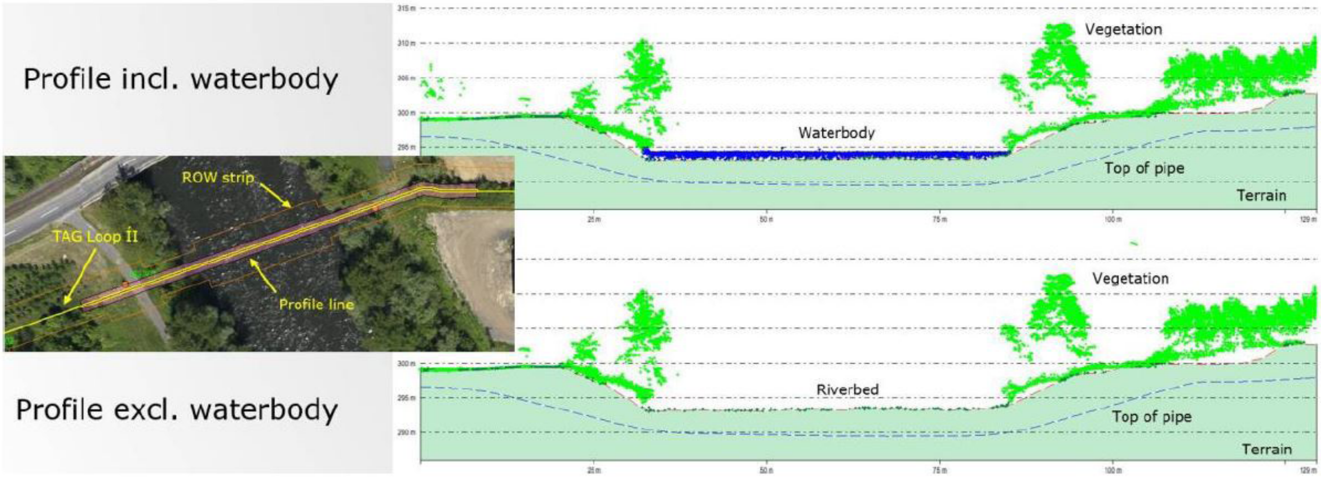

Figure 6: Mur crossing TAG Loop II, profile line & profiles with & without waterbody

The results of both approaches are very different in their nature. Airborne bathymetric laser scanning provide an array of survey points and an orthofoto, as usually a digital airborne camera is used parallel to the airborne bathymetric laser scanner. The deliverables are the classified 3D pointcloud, DSM / DTM and orthofotos covering the specified area. From those deliverables profiles can be extracted at any required location. Floodplains can be included and can be covered easily from the air.

The result of classic survey are measured points along specified profile lines only, those are used to generate the profiles, beside a multibeam echosounder would be used. Floodplains can be included, but require additional terrestrial survey which is laborious. DTM can be generated by interpolation, using all collected survey points, but available survey points will be way less as from a laser scanning approach.

In case of several river crossings along a route, the required time for the flights is way less than the required time for performing classical survey, after the flights there is no more dependency on climatic conditions or water level, as the following processing works are performed in the office. Required time for TAG was 17 working days, 2 days for the flights and 15 days for the processing. Estimated amount of time for a classic survey is 25-28 days at least. This is an optimistic estimation valid for following assumptions, 1 survey team, 1 day per crossing including transfer, 2-5 days in-house processing and stable climatic conditions during the survey campaign.

Logistics for the flights is much easier, than for a classic survey. The aircraft is mounted with the sensors, transferred to the project area and the survey flight is performed. For a classic survey a survey team including all required survey equipment and vessel needs to be mobilized to the sites and good access to the location of the crossing assumed.

In our case the cost per crossing is about 25% less, than a classic approach. This conclusion is justified as followed, 23 crossings and 2 missed ones (which would have to be complemented).The cost per crossing of TAG were 2.000 €, Fugro Germany provided us with a general cost estimation for a classic survey of 3.000 € per crossing with a range of ±20% depending on the specific site conditions. As the cost is not linear increasing per crossing for airborne bathymetric laser scanning, the cost decreases the more river crossings and the longer the stretch.

6.2 SCOPE OF APPLICATION

The conclusion is that airborne bathymetric laser scanning is a good choice for river and water crossings with a water depth up to 1.5 m. Furthermore shoreline survey at landfalls of pipelines can be addressed with the technology as well.

Depending on the expected positive development of the airborne bathymetric laser scanners the possible water depth will increase in the future.

Actually it is the "bridge technology" between topographic survey and echo sounding from the boat and closes the gap between. For the crossings of lakes, big rivers or the sea additional echo sounding will be required.

6.3 RECOMMENDATION - COMBINED SURVEY APPROACH

Based on the on the experience of this project we recommend a combined and stepwise survey approach of airborne bathymetric laser scanning and additional echo sounding or terrestrial survey on demand.

A survey campaign should be started with airborne bathymetric laser scanning, followed with the check of the results, this verifies which river crossings need to be complemented by classic survey and followed with the respective mobilization.

Airborne bathymetric laser scanning shall always include airborne imagery (orthofotos) as this provides the required information of the situation at the site during the survey.

The type of crossing and potential limitations (water turbidity, flow speed) shall be taken into account right from the beginning to choose the right approach.

Potential aircrafts for airborne bathymetric laser scanning are plane, helicopter and UAV (= unmanned aerial vehicle, drone). Depending on the scope of work and the surrounding conditions the right approach and carrier needs to be chosen.

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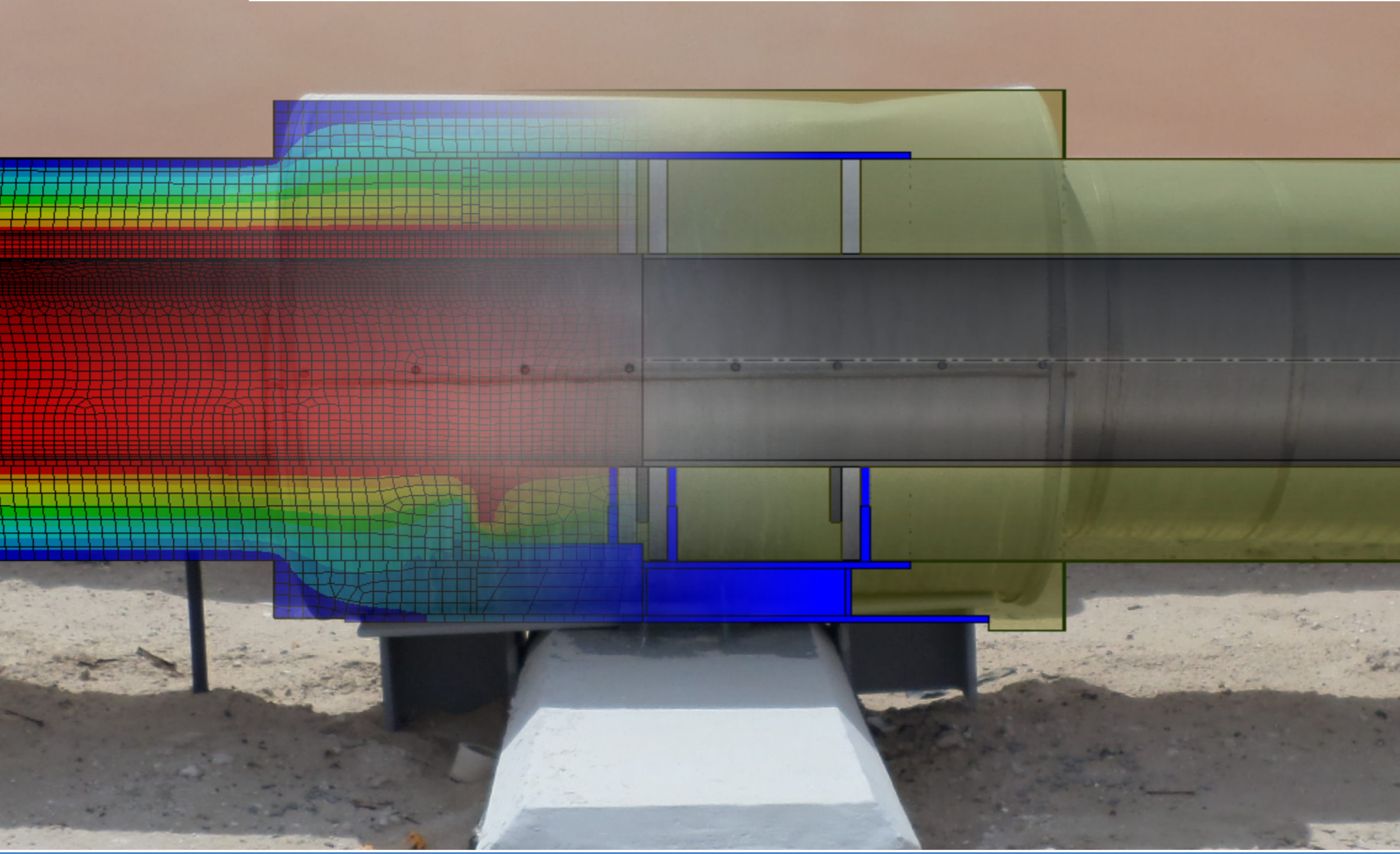
Current View of Design and Evaluation of Sulfur Pipelines



Dr. Kai Bauerbach, Dr. Paschalis Grammenoudis > MMEC Mannesmann GmbH

Abstract

The global production of natural gas is increasing continuously leading to development of gas fields with challenging contents such as sour gas containing highly toxic hydrogen sulfide. In a process called "gas sweetening" the hydrogen sulfide is removed, yielding liquid elemental sulfur. This substance is not just a by- product of the natural gas production. A multitude of industries rely on elemental sulfur as a raw-material to be used in various chemical processes and products.

Transporting liquid sulfur away from the gas extraction site raises the necessity for an infrastructure capable of dealing with the unique properties of this substance at elevated temperatures. Liquid sulfur can only be pumped in a limited temperature interval. Lower temperatures lead to solidification, higher temperatures will cause the sulfur's viscosity to increase rapidly. Additionally, sulfur's volume increases significantly during phase transition from solid to liquid.

A pipeline system transporting liquid sulfur that must satisfy a characteristic set of demands. Hydraulic design ensures the proper operation parameters to meet the capacity requirements of the pipeline system. Thermal design's core task is to ensure that the system can not only maintain the operation temperature and prevent heat loss but also provide additional input of thermal energy whenever needed. To manage the thermal stresses arising in pipelines operating at elevated temperatures appropriate mechanical design needs to be conducted. In a re-melt scenario the solid sulfur inside the pipeline needs to be liquefied. This poses additional requirements.

Each of these demands and tasks such a pipeline system needs to satisfy (including boundary conditions dictated by the extraction plant) must be met with a specific and customized technological answer.

Here, the authors provide a comprehensive overview of the challenges and selected technological approaches in the design and assessment of a liquid sulfur pipeline system.

1 INTRODUCTION

For more than four decades world's demand for natural gas has been growing [1]. There is no current indication that this trend is going to change. This has led to the development of gas fields with increasing challenging contents such as high amounts of hydrogen sulfide (H2S, rotten egg gas). Natural gas extracted from gas fields developed in recent years contains up to 30 % of this this toxic component (see Table 1). An Amine treatment process (Claus process) more commonly known as gas sweetening the hydrogen sulfide is separated from the natural gas. As Hydrogen sulfide is highly toxic the extraction site is considered hazardous area and personnel working in this area is required to carry protective equipment and observe special HSE procedures.

The gas sweetening process yields liquid elemental sulfur. For the transportation with freight trains or ships the sulfur is usually granulated or poured into blocks at a dedicated facility. Since the extraction site is considered a hazardous zone it is advisable to not have the solidification facilities at the extraction site if possible to minimize the number of persons exposed to the hazardous working environment. Transporting the liquid sulfur away from the gas extraction site raises the necessity for an infrastructure capable of dealing with the unique properties of this substance at elevated temperatures.

Methane	CH_4	70-90 %	
Ethane	C_2H_6	0-20 %	
Propane	C_3H_8	0-20 %	
Butane	C_4H_{10}	0-20 %	
Carbon dioxide	CO_2	0-8 %	
Oxygen	O_2	0-0.2 %	
Nitrogen	N_2	0-5 %	
Hydrogen sulfide	H_2S	0-5 %	> 30 % possible
Rare gases	A, He, Ne, Xe	trace	

Figure 1: Typical composition of natural gas, emphasis on possible content of hydrogen sulfide of sour gas

Due to the extraction of sulfur from hydrocarbons (majorly natural gas) the mining of elemental sulfur has been in constant decline for many years [2]. Other albeit rarer sources of elemental sulfur include desulfurization of crude petroleum or coke. The majority of the world's elemental sulfur is used to produce sulfuric acid, a key component in the production of pharmaceuticals, dyes, fertilizer and numerous other industries. Globally, the consumption of sulfuric acid is widely regarded as an indicator of a nation's industrial activity. While the world's leading sulfur producing countries (2016) are the USA, China and Russia the top exporting countries include the UAE and Qatar due to their production exceeding the countries own usage [2].

2 PROPERTIES OF LIQUID SULFUR

Transporting liquid sulfur through a pipeline bears several difficulties. The characteristic properties of sulfur only allow safe operation of such a pipeline within a defined temperature interval. Temperatures below this interval lead to solidification, at higher temperatures the sulfur's viscosity increases rapidly. The lower bound of this interval is given by the solidification temperature at ca. 119 °C. As liquid sulfur reaches temperatures above 155 °C it turns from bright yellow to orange, its viscosity increases rapidly reaching values that prohibit pumping and safe operation [3]. Keeping the liquid sulfur at an operating temperature of 125 °C–145 °C ensures that the liquid sulfur will reach the destination site in a condition allowing for further processing (e.g. granulation). A thermal margin above the freezing temperature must be ensured during transport. Facilities following the pipeline (such as a granulation unit) will require the liquid sulfur's temperature to be within defined limits leading to the operating temperature needing to consider possible thermal requirements of the receiving facilities.

Additionally, sulfur's volume increases significantly during the phase transition from solid to liquid which bears significance in the (rare) cases of a re-melt operation.

During solidification (freezing) sulfur shrinks by approximately 10 %. The reverse phase transition of solid to liquid sulfur (melting) can lead to potentially difficult and dangerous scenarios. While melting, solid sulfur increases its volume by ca. 10 %. If this expansion happens in a confined space the potential structural implications could be devastating. Additional precautions and care is necessary when dealing with liquid elemental sulfur since it can yield a variety of toxic or dangerous compounds. Especially the presence of water and oxygen will lead to sour environment that could potentially harm any equipment.

3 DIFFERENT APPROACHES IN LIQUID SULFUR PIPELINE TECHNOLOGY

While transporting liquid sulfur in a pipeline it is imperative to maintain the operating temperature within a closely defined interval (see above). This includes to compensate for potential heat loss that could result in product solidification. A trace heating together with monitoring provides means to maintain thermal conditions and ensure safe operation. While the station piping for liquid sulfur transportation is commonly steam traced this technology is not advisable for long range or cross-country transportation. Liquid sulfur pipelines around the world rely on one of two technological approaches. The technological solution for trace heating employs either a water heat tracing or an electrical heating system (skin-effect heating).

3.1 PROPERTIES OF AN ELECTRICAL HEATING SYSTEM

Electrical heat tracing is commonly accepted as a heating technology in a wide range of industrial applications such foundation heating, de-icing or heating of high-viscosity hydrocarbons. These pipelines are commonly constructed from pre-insulated pipeline spools. The product pipe and the carrier pipes are encased by insulation layers (see Figure 2). These spools are field welded at the construction site. Any joints, bends or interface locations requiring on-site access to the product pipe are field insulated using mineral wool. An electrical trace heating (Skin Effect) system for liquid sulfur pipelines relies on self-limiting electrical heating cables in dedicated carrier pipes. These pipes are welded to the product pipe containing the liquid sulfur. Upon powering the electric heating cables, the carrier pipes are heated, converting electrical energy directly to thermal energy. Due to the thermal conductivity of the carrier and product pipes the induced heat is quickly available over the whole cross-section. In recent years, several sulfur pipelines at gas extraction sites in the middle east have been built utilizing electrical heating systems.

The driving force of transferring heat to the product in case of an electrical heating system is the direct transfer of energy. This transfer mechanism is essentially independent of the product's temperature.

The possible range of an electrical heating circuit is limited due to the type of available heating cables and their specific classifications, conductivity, electrical resistance and design temperature. This requires the pipeline to be split into segments with dedicated individual heating circuit for each segment. Each of these segments requires facilities with power transformers as well as control units to operate. The heating circuits are installed using pull boxes along the pipeline. Postwelding the heating cables as well as temperature sensing cables are pulled through the carrier pipes.

Accessibility for maintenance and repair requires such a system to be installed above ground. As this approach represents an unrestrained pipeline expansion loops are required to accommodate the thermal expansion. Proper guidance of the axial thermal expansions is provided by a fixation/restraining concept. Thermal deformations must not be restricted excessively to prevent thermal stress concentration points. While management of thermal stresses is a key focus of mechanical design, interference with the insulation concept should be avoided as much as possible.

As a support concept, above ground insulated pipelines commonly utilize a pattern of alternating expansion/contraction loops and anchor blocks. The thermal expansion/contraction loops partially absorb the deformation, the resulting forces are transferred to the anchor blocks. Intermediate supports provide axial or lateral "guiding" rather than load bearing functionality (see Figure 3). The base construction for all supports and anchor blocks is commonly given by sleepers, concrete blocks the pipeline supports are resting on. Special attention is required for the design and construction of the anchors as these locations need to meet the compromise between structural and thermal requirements in a most unique manner. Thermal design requires a uniform profile in heat loss behavior. The concept of a discrete single-point fixation employs materials that can withstand the resulting forces. Commonly, high strength materials also are of high density and thus not well suited for thermal insulation. These partially conflicting demands of structural fixation and thermal insulation can lead to an inevitably increased heat loss at the

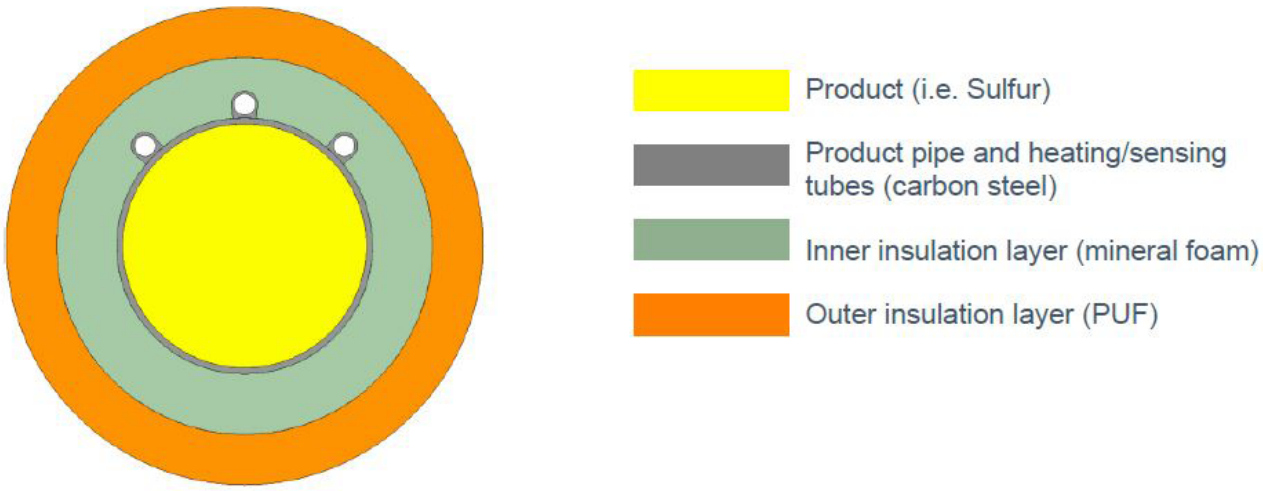


Figure 2: Cross section of an insulated, electrically heated pipeline; smaller tube at 12 o'clock position is used for temperature sensing the other two tubes contain heating cables

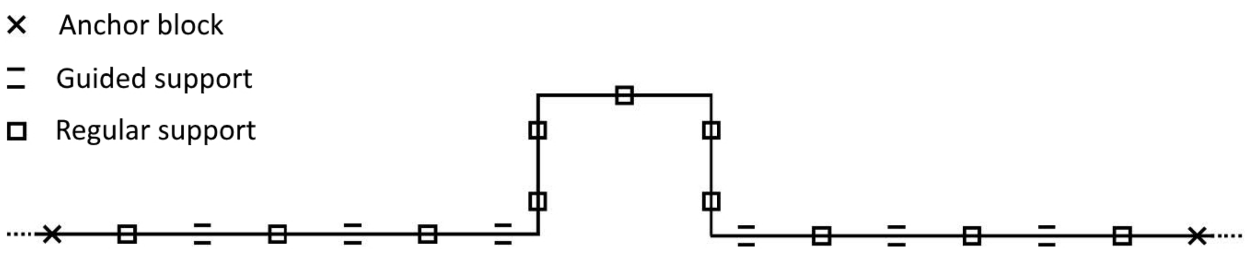


Figure 3: Aerial schematic of a pipeline support concept, alternating pattern of anchors and expansion/contraction loops with regular and guided supports

anchors. A similar, yet not as severe, situation arises at all other support locations where the compressive strength of the thermal insulation will be challenged to withstand the loads resulting from this fixation concept.

3.2 PROPERTIES OF A WATER HEATING SYSTEM

A hot-water heating system is built as a pipe-in-pipe solution with the innermost pipe as the product pipe while the water runs in the outer annular shaped cross section. Both pipes are additionally encased in an insulation layer (commonly high-density polyurethane). As with a steam jacket system this solution results in additional thermal and mechanical requirements for both pipes and welded spacers (see Figure 4) to ensure the concentricity of the two pipes. Proper delivery of thermal energy to the product can only be ensured if the pressure and temperature conditions of the water stream are also monitored and controlled.

The mechanism of heat transfer in a water tracing solution will rely on convective heat transfer from the hot water through the product pipe wall to the sulfur. As the sulfur temperatures rises, this heat flow decreases. This ensures that a higher amount of thermal energy carried by the water stream is absorbed by colder product and thus resembles a demand-oriented heating, delivering thermal energy at the locations where it is needed.

A water heat tracing solution will require almost no additional infrastructure along the pipeline corridor. Instead, all necessary facilities (boilers, pumps) can be installed and operated at either (or both) end of the pipeline. A strict separation of water and sulfur is to be maintained to avoid possible formation of a corrosive environment.

This solution is especially advisable for underground solutions. Still, for a buried hot- water heated liquid sulfur pipeline the thermal expansions and resulting forces must be accommodated. While underground expansion loops or an additional pipe serving as an underground conduit are possible there is also a well-documented example for a pre-stresses solution with long-radius bends, fully restraining the pipeline [4]. In contrast to an above ground approach a buried pipeline system causes less interference with nearby infrastructure and can be considered protected against external impact and influences.

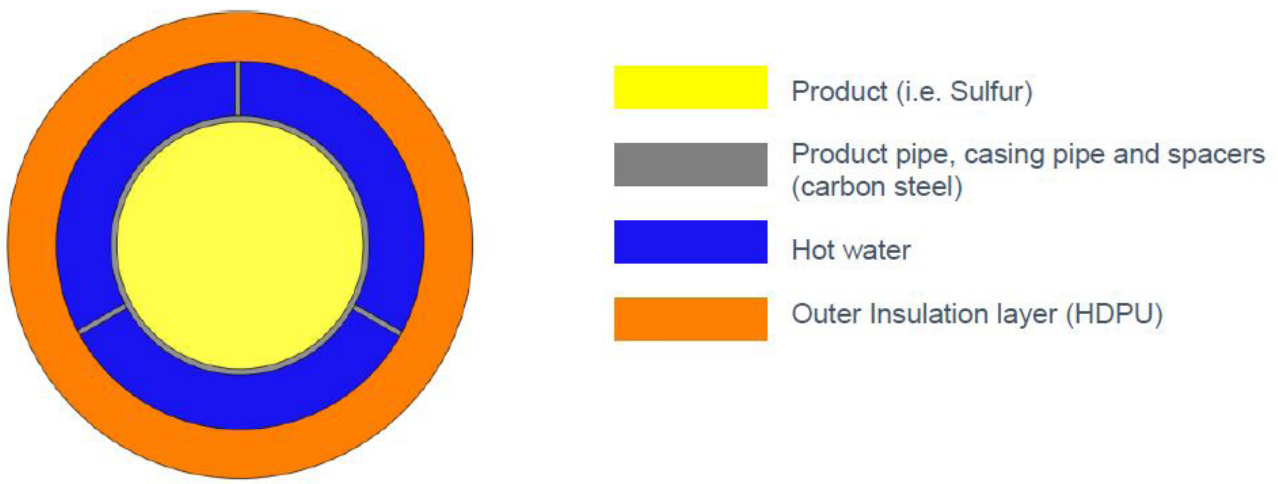


Figure 4: Cross section of a water heat traced sulfur pipeline with product pipe, annular shaped water section and spacers

A buried (restrained) pipeline operating at high temperatures is prone to stability failure [6]. As the temperature difference between installation and operation temperature exceeds 100 K, upheaval or lateral buckling of these pipelines could occur. If the lateral (or upward) displacement of the pipe exceeds the soil's limit displacement as described in [9]. The restraining forces exerted by the backfill need to be considered for the pipeline bends, observing limit values for stresses and displacement limit values in upheaval/lateral buckling calculations.

Transferring the restraining forces of the padding and backfill to the casing and product pipe requires the insulation layer to withstand the resulting pressure and shear forces. These requirements on the structural strength of the insulation are comparable to the requirements arising for the supports in an unrestrained pipeline.

4 STAGES OF DESIGN

One of the early steps in in the planning stage of each pipeline system is the route selection. While parts of this process could be considered basically independent of the selected technological approach some interactions might be necessary to consider. Route selection incorporates the conditions of terrain, soil elevation as well as nearby infrastructure but also non-technical interactions such as land ownership. Depending on the technology selected for a specific project, these criteria will be weighted differently. This process is not independent of the selected technological approach as the questions of heating technology and above/below ground are closely interwoven. For the engineering steps to follow, the resulting elevation profile is the most crucial input information for the hydraulic design.

In addition to the elevation profile hydraulic calculations incorporate operating scenarios (e.g. shutting valves, pump trip) to conduct flow assurance calculations. The investigations include information on the inlet side of the pipeline (pumps) and the pressure requirements on the outlet. Identification of optimal operating conditions and flow assurance in transient operating scenarios. These scenarios are defined based on process considerations and include information defined in the facilities' operating philosophies. As the hydraulic analyses assume that the product remains in a liquid state these calculations are conducted within the specified temperature interval but account for the change of the product's properties in case of heat loss along the pipeline. Hydraulic design ensures the proper operation parameters such as flow velocity and pressure to meet the capacity requirements of the pipeline system.

Thermal design's core task is to ensure that the system can not only maintain the operation temperature and prevent heat loss but also provide additional input of thermal energy whenever needed. To manage the thermal stresses arising in pipelines operating at elevated temperatures appropriate mechanical design needs to be conducted. In a re-melt scenario the pipeline is filled with solid sulfur that needs to be liquefied. This poses an additional set of requirements. Each of the demands and tasks such a pipeline system needs to satisfy (including the boundary conditions dictated by the extraction plant and surrounding location) has to be met with a specific and customized technological answer with regard to insulation/heating, monitoring of operation parameters or above/underground solutions.

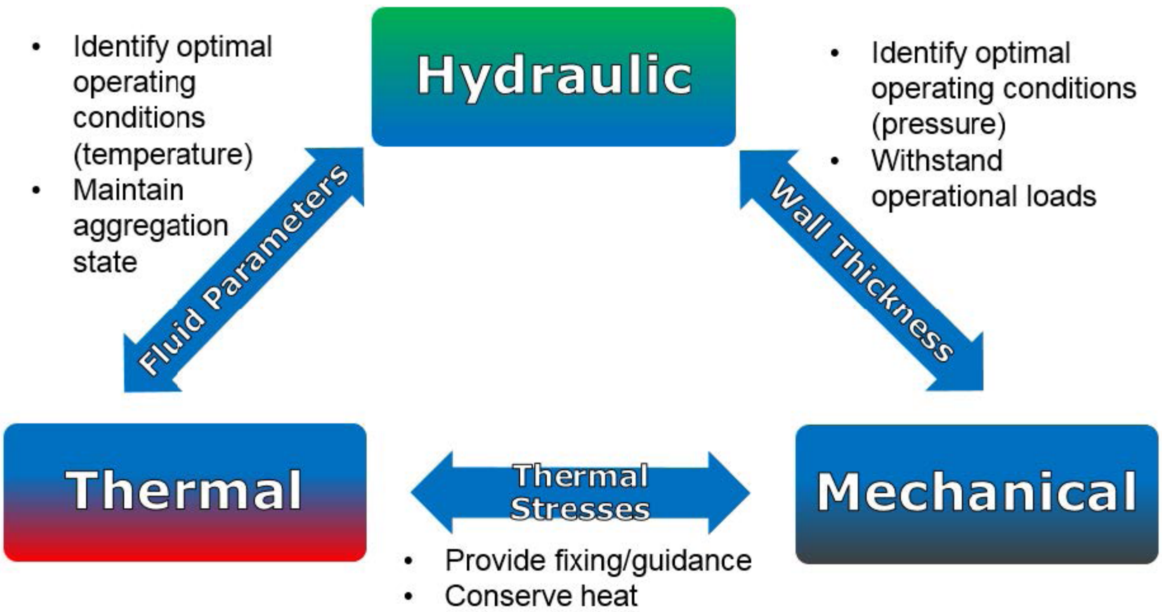


Figure 5: Schematic of the interdependence and principal tasks of different design stages of a pipeline system

In general, materials will experience expansion and contraction when heated or cooled. A material's thermal expansion coefficient relates the temperature difference to the thermal strain. Any restriction of thermal strains will result in thermal stresses. The solution to not have these stresses or deformations exceed the mechanical strength of the pipeline system is to either restrict or to allow for thermal expansion. In underground (restrained) pipelines the compacted padding and backfill provides the necessary restriction while in aboveground (unrestrained) pipelines utilizes a combination of guided supports and expansion loops to accommodate the thermal expansion with only minimal restriction. Mechanical design employs analytical approaches [5]-[7] as well as state of the art numerical simulations to determine the stiffness (loop), forces (anchor), and stresses (pipeline). These approaches model the pipeline as beam sections and calculate the resulting stresses from axial forces and bending moments in each section.

Anchors and supports of an above ground pipelines are a prime example of a specific interface location, where the scope of work for different engineering disciplines will overlap. At the anchors, the interface challenges of pipeline and civil engineering must be met to obtain a consistent engineering solution. Furthermore, at these locations the mechanical strength of insulation materials or the insulation capability of a structural fixation will be challenged. Answering these questions requires custom fit solutions to individual problems to be solved by engineering specialists.

Proper design and solid engineering without neglecting cost-efficiency are necessary prerequisites for safe operation. As Liquid sulfur pipelines are designed for long continuous operation without downtime periods the scenario of regular operation does not include extended no-flow periods. Monitoring of key operating conditions (temperature, flow rate, pressure) is essential to maintain operability and to recognize and avoid undesired scenarios.

4.1 SPECIAL SCENARIOS

For regular operation the aggregate state of the sulfur will not be significantly impacted by any thermal weak spots. This might lead to the misconception that several of these locations might be considered negligible for the thermal behavior of the pipeline if these weak spots do not considerably lower the average insulation efficiency. However, the impact of a local thermal weak spot might be negligible for the scenario of regular operation and yet still heavily impact other operation scenarios. Local heat sinks are of minor importance while liquid is flowing in the product pipe. The flowing product provides a constant stream of thermal energy (or the lack thereof), providing a constant flux of thermal energy to/from the thermal weak spots.

A possible power outage or malfunction in the heating system in conjunction with a no-flow situation may result in partial or complete solidification of the sulfur inside the pipeline. To re-establish the conditions for regular operation, the heating system has to be used to re-melt the sulfur inside the pipeline [8].

The implications of insulation weak spots at low or saddle points might be exacerbated in such a scenario. In demanding elevation profiles with intermediate saddle points or local sags, colder product will accumulate at these locations. At these locations freezing starts and melting will take the most energy input. Additionally, any shrinkage of the product upon freezing will be counteracted by gravitational flow filling the cross section completely at low points, additionally impeding re-melt operations.

This re-melt process is to be undertaken with great care as it is a crucial process that can potentially damage the pipeline beyond repair. Melting sulfur between frozen sulfur plugs without room for expansion will quickly lead to stress states exceeding carbon steel's ultimate strength. In a perfectly horizontal elevation profile the sulfur would provide a continuous air pocket of 10 % vapor space.

A draining system is a possible technology to avoid formation of a frozen pipeline. Such a system uses valves at the pipeline's low points to empty the content into designated draining pits. During a blackout scenario the draining procedure will be initiated to avoid formation of frozen sulfur plugs. For obvious reasons a draining system is exclusive to an above ground pipeline system. The draining system also requires vents to be installed at the pipeline's high points to enable a complete and successful draining of the pipeline's content. Such a system provides an additional redundancy. In case of a looming prolonged shutdown (planned or emergency) the pipeline can be emptied to avoid a re-melting operation. Failure to drain as well as an incomplete draining of the pipeline results in a partially frozen pipeline and bears the same risks and difficulties as a completely frozen system.

The redundancy provided by a draining system is however to be seen in contrast to the introduction of additional potential thermal weak spots. The drain and vent locations represent interface locations.

The re-melt process itself differs considerably between the different heating technologies. A hot-water system will start the re-melt process from the end where the hot water is injected. Thermal energy will be primarily absorbed by the sulfur at the end and the liquified section will extend from there. Since the thermal profile is expected to be mostly uniform without discrete interface locations a continuous re- melt is to be expected.

With electrical heat tracing, it can be difficult to obtain a uniform re-melt particularly near potential thermal weak spots. Depending on the elevation completely frozen and vapor spaces may exist along a single heating circuit. As the circuit can only be switched on or off along the whole running length this leads to a situation with uniform heat input for sections with differing demands. While a re-melt is still claimed to be possible, the procedure can be protracted and needs very close monitoring of heat absorption and aggregate state.

5 ASSESSMENT AND CONCLUSIONS

Depending on a wide range of specific boundary conditions such as, elevation profile, on-site process plants and spatial constraints either technological solution can be considered viable for a liquid sulfur pipeline. Installation and operating cost will doubtless be considered when comparing the technological approaches for a specific project.

While an above ground solution combines the advantages of easy accessibility, possible redundant heating circuits and constructability from pre-insulated spools to achieve an easier constructability it requires additional facilities for the power transformers and is more prone to external interference to its exposed location above ground. This exposed position, however, allows installation of technologies preventing sulfur freezing (drain systems).

A hot-water heated system – especially with a pre-stressed pipe-in-pipe underground system – requires a considerably increased engineering and installation effort. Beyond the increased complexity of the engineering an underground hot-water heated system provides a uniform thermal behavior with lower effort in maintaining a temperature profile due to the absence of discrete interface locations. The protection from external influence is accompanied by increased difficulties of access for repair and maintenance.

Both heating technologies have been successfully installed and are operating at numerous locations all around the world. Design and construction of future systems can rely on the experiences gathered from these existing facilities. This allows to individually identify the best suited technology and economical solution for new liquid sulfur pipeline projects. Currently, MMEC Mannesmann is conducting the EPC for an electrically heated, drainable pipeline solution in the UAE. Construction is expected to be completed in 2019.

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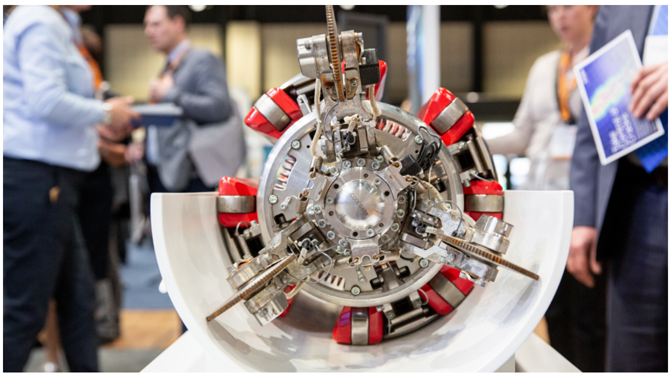

The leading European event for the pipeline industry is now taking place for the 15th time, this time from 30 March to 2 April 2020 in Berlin's Estrel Congress Center. The ptc provides the international pipeline industry with a platform to discuss technical challenges and solutions and to discuss the future of the entire industry. Europe's most important pipeline event is growing from year to year: "For 2020, too, we as organisers expect growth of between 15 and 20% compared to the previous year," says Dr. Klaus Ritter, President of the EITEP Institute.

For them, there is a series of high-ranking plenary sessions and panel discussions, all of which deal with topics of interest to operators worldwide. This includes classic topics such as "Safety" as well as current challenges in the areas of "Qualification & Recruitment", "Difficult to Inspect Pipelines", "Illegal Tapping" and "Climate Adaption". Important future topics such as hydrogen transport and Power-to-X are also included in the programme.

Another unique selling point of the ptc is its internationality: "About two thirds of the participants come from abroad. Last year, we saw the greatest growth from Latin America and Eastern Europe, a large proportion of which were pipeline operators," says Dennis Fandrich, Chairman of the Pipeline Technology Conference. This makes ptc the most international event of its kind in the world.

The conference will be accompanied by a trade exhibition at which leading technology and service providers and pipeline operators will be able to present their innovative pipe solutions. The suppliers will be present throughout the entire lifecycle of the pipeline. With more than 90 exhibitors, a new record is also expected in this area in 2020. The conference and the trade exhibition will be complemented by thematically oriented one-day seminars, workshops and operator discussion rounds in which participants will be able to delve deeper into various topics.

As every year, the conference papers will be made available to the specialist public via the freely accessible "Pipeline Open Knowledge Base":

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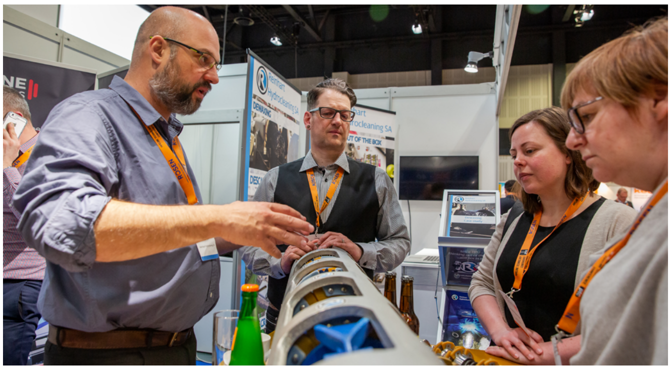

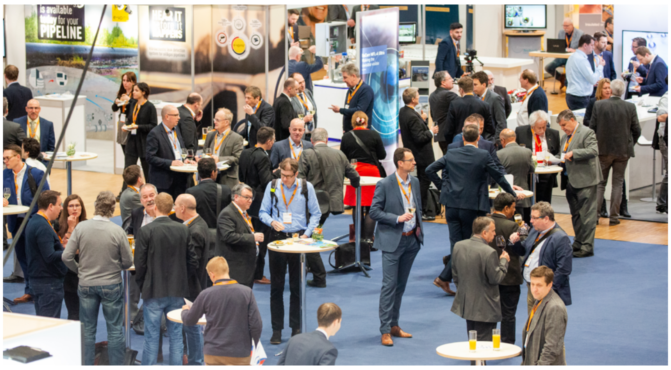

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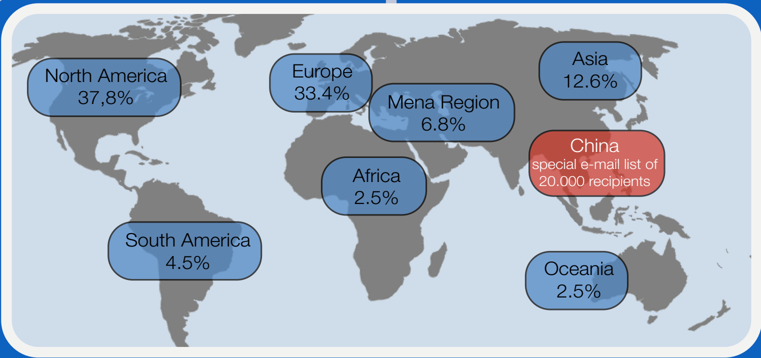

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