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Applications & Challenges of the Non-Metallic Material for Hydrocarbon Piping

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Abstract

This paper will explore the various applications and challenges of non-metallic piping for hydrocarbon service and how it helps reduce corrosion costs. According to the NACE study, the total annual cost of corrosion in the oil and gas industry is estimated to be $1.372 billion. It is remarkable how much money can be saved by implementing non-metallic piping solutions. Not only does it reduce corrosion costs, but it also helps improve safety and efficiency in the oil and gas industry. By reducing the need for frequent maintenance, non-metallic piping provides a cost-effective and reliable solution for hydrocarbon service.

This paper highlights two successful case studies for High-Density Poly Ethylene (HDPE) in the oil and gas industry and further elaborates on the challenges. Additionally, the lesson learned from another case for the fire water network is highlighted along with a rout case analysis of the failures.

Introduction

Corrosion is a primary concern in different industries due to the significant financial losses it causes each year. These losses can amount to billions of dollars, making it a critical issue that needs to be addressed. Companies invest heavily in corrosion prevention methods and technologies to reduce the impact of corrosion on their operations and bottom line. Despite these efforts, corrosion remains a persistent problem that requires ongoing attention and management. In 2016, NACE International released the "International Measures of Prevention, Application and Economics of Corrosion Technology (IMPACT)" study, which estimates the global cost of corrosion to be approximately US$2.5 trillion. Based on these studies, the annual corrosion cost in each nation ranged from approximately 1-5% of their gross national product [1].

Corrosion Impact on Oil & Gas Industry

The oil and gas industries experience significant financial losses each year due to corrosion and maintenance management expenses. According to estimates, the global annual cost for the industry is around US$1.372 billion, with surface piping and facility cost accounting for US$589 million, downhole tubing expenses at US$463 million, and CAPEX related to corrosion costing US$320 million [2]. Apart from these direct losses, corrosion also comes with indirect costs such as product spill and fire, loss of revenue, equipment inefficiency, environmental pollution, and over-design

It's alarming to know that corrosion is ranked as the second most frequent cause of loss of hydrocarbon containment in offshore platforms, as stated by the UK's Energy Institute. In the UAE alone, corrosion costs an estimated US$14.2 billion annually as of 2011, and most of this cost has been spent on the energy industries [3]. Meanwhile, the United States spends US$26.8 billion per year on corrosion in various sectors of the oil and gas industries, as shown in the table. It's crucial for industries to invest in preventing corrosion to reduce costs and ensure safety.

Table 1—Annual Cost of corrosion in various sectors of oil and gas industries in the United states evaluated by Koch et al. [4]

Sector	Annual cost of corrosion in the United States (million US$)
Production	1,372
Transmission-pipeline	6,973
Transportation-tracker	2,734
Storage	7,000
Refining	3,692
Distribution	5,000
Total	**26,771**

In general, corrosion is considered one of the main threats to the integrity of any oil and gas assets since most of the industrial infrastructures and equipment are built in metallic. Every metallic part and equipment from exploration, production, transportation, storage, and distribution are subjected to aggressive environments.

According to the below graph, it is clear that internal and external corrosion were the primary culprits behind pipeline failures in Alberta, Canada, between 1980 to 2005.

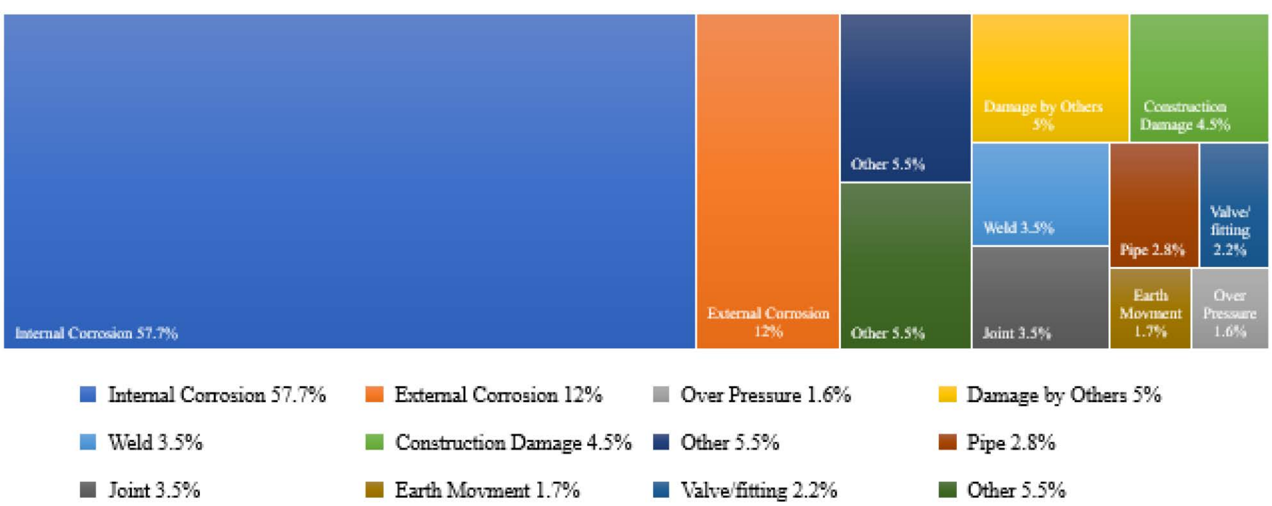

Figure 1—Alberta, Canada Production Pipeline Failure Data for 1980–2005. Source: Adapted from Utilities Board (ERCB) 91-G Report

Another analysis of the Canadian gas transmission system indicated that corrosion is the cause of half of the ruptures.

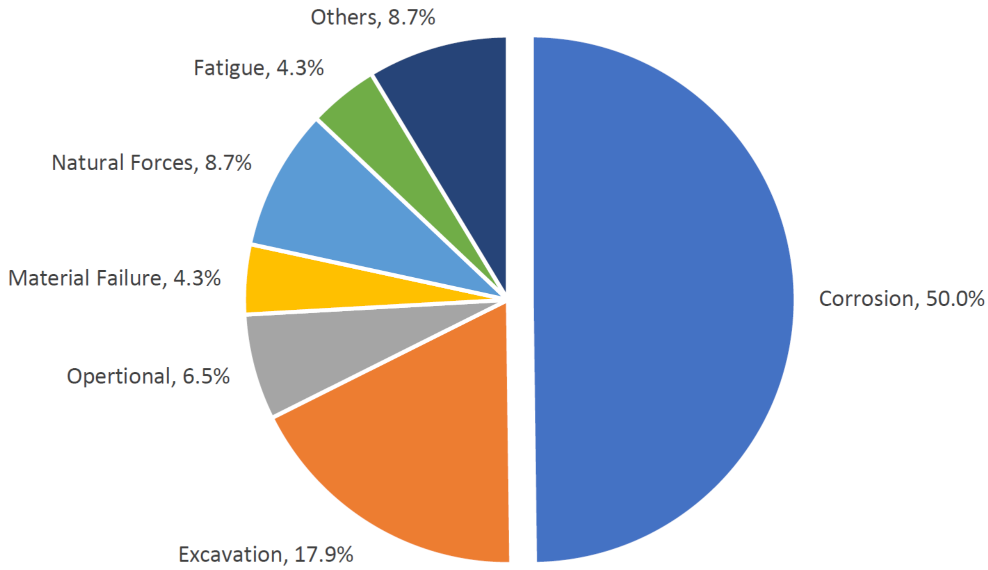

Figure 2—Causes of the 46 ruptures that occurred in Canadian pipelines from 1984-2004 (Source: National Energy Board. [2008, July]. Focus on Safety and the Environment. A Comparative Analysis of Pipeline Performance, 2000 – 2006

Corrosion Prevention Methodology

Corrosion prevention is a vital technique that helps in maintaining the integrity, quality and durability of different assets. This technique is used to protect assets from internal and external factors that may cause degradation. According to NACE, there are various standard methods for corrosion prevention that are widely used in different industries. These methods are specifically designed to provide effective protection against corrosion and ensure the longevity of assets.

- <u>Corrosion inhibitors:</u> chemicals added to the product which can slow the corrosion of the metal. Such a method is standard in the oil and gas industry; however, an additional cost is associated with the requirement of a chemical inhibitor skid (pump, chemicals, flowmeters, etc.)
- <u>Cathodic protection</u> is a method used to control corrosion by making the metal surface a cathode. Galvanic anode and impressed current are the types of cathodic protection.
- <u>Coatings and linings</u> introduce thin layers (organic coating, metallic/nonmetallic coating, superior alloys) above the material surface to isolate and protect the surface from the surrounding effect to prevent corrosion and increase the life of the material.
- <u>Material selection</u> plays a vital role in corrosion prevention. The selection of metal shall be based on the properties of the fluid, and less reactive metal shall be chosen. However, high cost is usually associated with superior material; non-metallic is becoming more attractive in the oil & gas industry. No metal is completely immune to corrosion.

Non-metallic materials, particularly High-Density Polyethylene (HDPE), offer numerous advantages in the oil and gas industry. In the following section, the cases will address the advantages of selecting non-metallic material, especially High-Density Polyethylene (HDPE), through real examples in the oil and gas industry.

CASE I: Enhancement of Dewatering Piping Network for Crude Oil Storage Tanks

At one of the offshore islands, Produced Water from 14 Crude Oil Storage Tanks is transferred to a Sour Water De-oiling plant (SWDP) through a single 8" header for treatment where the oil content of the water is reduced to an acceptable level before being discharged into a monopod.

The dewatering network was generally made from cement-lined steel pipe and one common 8" GRE line to SWDP. Due to corrosion issues, the 8" GRE line was recently replaced from cement-lined steel. Production levels & hydraulic limitations showed that a bottleneck was faced in which considerable time is required for draining, which hinders the operation to provide clean cargo on due time. Hence there is a requirement to enhance the network by installing a parallel line to the existing common 8" line.

The original proposal was to install a parallel line made of GRE similar to the existing one; however, as part of the cost optimization objectives and excellence drive initiative, in-house study was carried out to evaluate the feasibility of using High-Density Polyethylene (HDPE) instead of GRE. Accordingly, a decision was taken to install a parallel line made of HDPE (250mm pipe – PE100 SDR11) instead of GRE, as shown in the below figure.

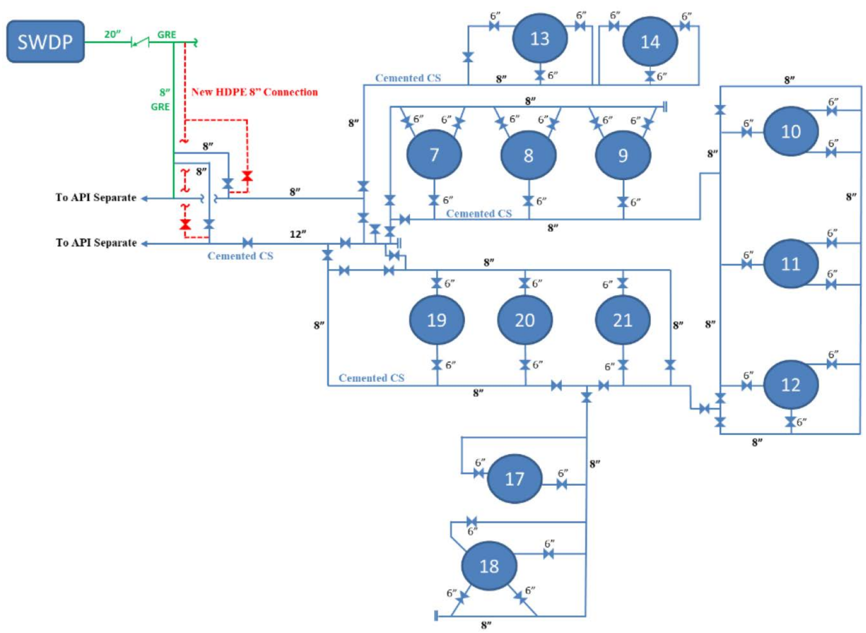

Figure 3—Dewatering Crude Oil Storage Tank Layout with parallel HDPE line

Installation of 300 meters underground line with three road crossings was completed within less than two months, and all required material (piping, fitting, etc.) was secured from the local market. Moreover, stress analysis was conducted through a specialist entity to avoid over-stressing the line, and special precaution was provided as per the manufacturer's recommendation for the above-ground section to avoid ultraviolet degradation.

During this project, the following was the major achievements:

- Cost saving of more than 60%
- Elimination the bottleneck and limitation in a shorter duration
- Smoother fluid movement with less pressure drop due to HDPE smooth internal surface characteristics.
- Remarkable performance improvement in dewatering time was recorded
- Feasibility of simultaneous dewatering process for two Crude Oil Storage Tanks.

CASE II: 16" Diameter Effluent Water Disposal pipeline from Island to Water Disposal Platform

In oil fields, process water is often recycled and injected back into the well to increase production. However, as the well increases in age, the level of hydrogen sulphide and other contaminates in the process water also increases, corroding the bore of the steel water injection pipes.

The 16" diameter Effluent Water Disposal pipeline from one of the islands to the Water Disposal Platform has a length of 4.5 km, was severely deteriorated, and was found unsuitable for continued service. Investigation revealed an urgent need to mitigate the environmental risks of potential leakage from a deteriorated offshore effluent water disposal pipeline connecting the island to a nearby offshore platform. The rate of failures continued to increase, and the risks of a significant leakage into seawater or ruptures were imminent. The sensitive nature of the environmental habitat intensified the problem.

Accordingly, there is a requirement to find an efficient and quick replacement for the damaged pipeline that meets the following criteria:

- Environmental: Eliminate the risks associated with leakage from the deteriorated effluent pipeline that could lead to seawater pollution and damage or disturbance of sensitive habitats and species.
- Timely: Available for delivery and installation as quick as possible.
- Economic: Compensating the production losses while bearing reasonable engineering, procurement, construction, and operating costs.

The operating pressure for the required pipeline is 350 psig, and an internal diameter of 400mm (16") to replace the existing pipeline. As per the HDPE manufacturer, the design pressure of 350 psig would result in a pipeline design of 560mm (22") outside diameter and 80mm wall thickness (Size to Diameter Ratio (SDR) equal 7). The pipeline manufacturer confirmed that this size and thickness combination was unprecedented in the whole Middle East and very difficult from the manufacturing point of view. However, the technical support from the local raw material supplier made it possible to produce this challenging pipeline configuration.

The benefits offered by the HDPE pipeline were beyond the intended objectives, as follows:

- 100% local production, contributing to a shorter delivery period, readily available support in case of emergency, increasing national expertise in manufacturing and installation of subsea HDPE pipelines, and raw materials from local suppliers.
- Replacing the pipeline within a shorter time, mitigating and eliminating the risk of leaks.
- Lower Greenhouse gases (GHG) emissions as a result of shorter installation time compared to the conventional process.
- Energy saving and the reduction of associated GHG emissions result from a smooth internal surface of the HDPE pipeline and the lower pressure drop.
- Lower friction rate and smooth internal surface, which minimize the accumulation of particulate matter inside the pipes leading to lower pressure drop and energy saving.

Figure 4—New HDPE Line during installation activities

Figure 5—New HDPE pipeline in service (Right)

CASE III: Failure of HDPE Fire Water Network

In 2015, a new firewater network was commissioned as part of the island expansion. HDPE as a material was evaluated as the optimum material selection for application since the fire network is a wet system. The old network was made from cement-lined steel pipe, and it is connected to the new HDPE firewater network through two tie-in points. Since commissioning, several failures were reported at tie-in points with existing network and coupler welding joints. Such frequent failures lead to loss of fire water supply and interrupt the operation.

The figure below illustrates the leakage near the tie-in connection point between the old and new fire water network. As detailed in the figure, the piping configuration at the leaked area consists of two HDPE fabricated bends connected to each other by an electro-fusion coupler.

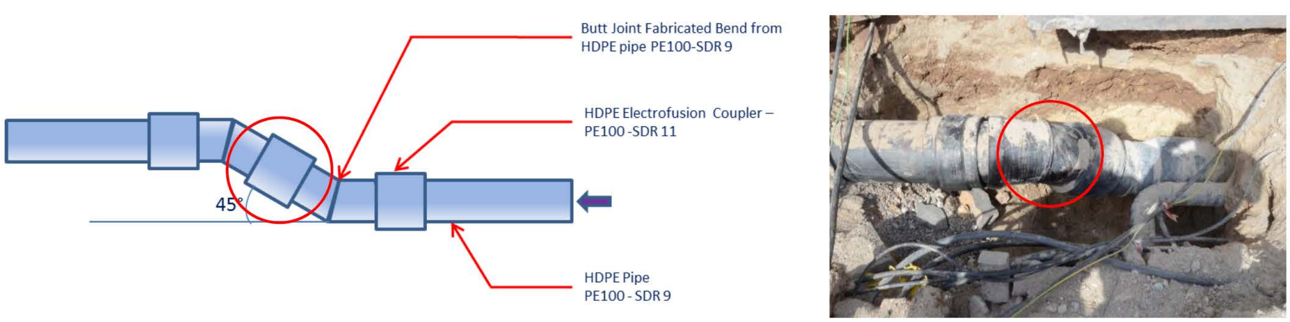

Figure 6—Leakage at HDPE fire water network near tie in connection point

The leakage has occurred due to the pullout of the coupler from the bend pipe; this may be caused due to the following:

- Improper bonding (electrofusion) of pipe with the coupler.

- Unbalanced impact force acting on the bend due to pressure fluctuation / hammering effect.

Another failure happened at the welding joint of the reducing tee coupler 315mm × 110mm.

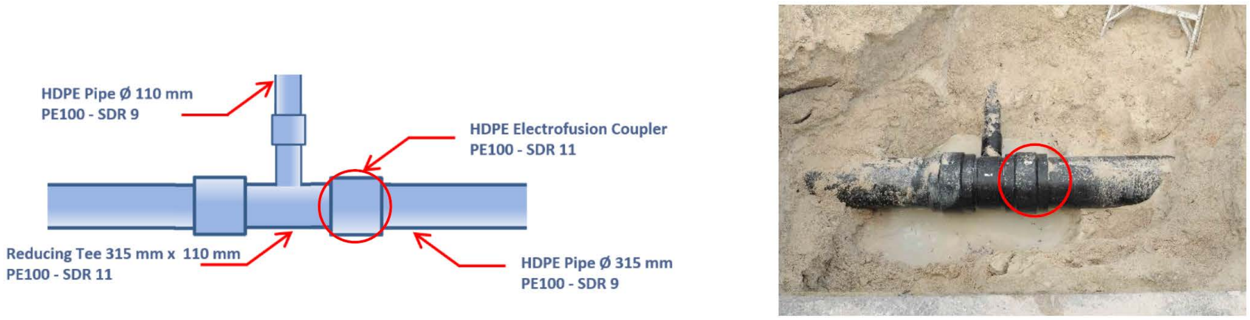

Figure 7—Leakage at coupler welding joint of HDPE fire water network

A more recent failure was reported as a pipe rupture, and the preliminary analysis indicated that the pipe material does not comply with the required standard ISO-4427. Moreover, it was found that the pipe producer added foreign material to the resin used to produce the pipe, which made it deviate from the ISO-4427 requirement.

Figure 8—Pipe rupture near coupler welding joint

From the analysis conducted, it has been determined that the main reasons for the frequent failures are non-compliance with the required standards of the materials used, poor workmanship and installation quality, without any documentation of welding or joining parameters, and an inadequate design and layout configuration. Additionally, it was found that there was no stress analysis performed on the network as part of the initial design process. It is crucial to address these issues to prevent further failures and ensure the safety and reliability of the system.

Advantages & Challenges

As indicated in the above section, corrosion is a significant issue in the oil and gas industry, and it causes considerable losses in both direct and indirect costs. To mitigate this problem, non-metallic pipes have emerged as an excellent alternative to traditional metallic pipes. The following section will address the main advantage and disadvantages of non-metallic pipe over metallic pipe based on the outcome of the above cases.

Corrosion Resistance

One of the most significant advantages of non-metallic pipes is that they are corrosion-free, which means there is no need for additional investments in corrosion prevention techniques. Plastic pipes, in particular, are known for their ability to withstand corrosive chemicals and fluids, making them the ideal choice for harsh environments above and underground. Plus, they offer long-term resistance, which is a huge plus. Overall, it seems like non-metallic pipes are a smart choice for anyone looking for a reliable, durable, and low-maintenance solution.

Flexibility & Handling

Non-metallic pipes are a great choice for ease of transportation and installation. They are lightweight and bend easily, with a large bend radius compared to steel pipe. For instance, polyethylene pipe is made in straight lengths up to 50 feet long and coiled in diameters up to 6 inches, making it a breeze to ship and install. Additionally, non-metallic pipes are flexible enough to eliminate the need for extra design effort for expansion bends or loops. The line can easily incorporate any movement from the ground or system.

Sustainability

Non-metallic pipes are fully recyclable at the end of life, which makes them an eco-friendly option. High-Density Polyethylene (HDPE) is one of the easiest plastic polymers to recycle and is accepted at most recycling centers. According to ESE World BV, a leading manufacturer of waste and recyclables in Europe, HDPE can be recycled at least ten times without any impact on the material properties.

In addition, the manufacturing process of non-metallic pipe is greener compared to the same of metallic pipe. Not only that but buried non-metallic pipes also do not pose any threat of hazardous toxins seeping into the groundwater.

Temperature and Pressure

It's essential to keep in mind that non-metallic pipes have limitations when it comes to pressure and temperature. While there are composite pipes that can withstand high temperatures, metallic pipes are still able to handle even higher temperatures and pressures.

Strength

Non-metallic pipes have lower strength compared to metal pipes. This means that non-metallic pipes require shorter support spans and additional structures to properly support them.

Design Considerations

For above-ground application, a non-metallic pipe will expose to ultraviolet (UV) light which causes premature aging. Depending on the strength and amount of UV exposure, the lifetime of the pipe can be significantly reduced. To prevent this from happening, it's recommended to protect the above-ground pipe with insulation materials or paint it with water-based paint. This will help to prolong the life of the pipe and ensure that it remains safe and reliable for as long as possible.

On the other hand, a non-metallic pipe does not have the ability to withstand the heat from higher temperature environments such as fire hazards. The National Fire Protection Association (NFPA) indicates the mandatory usage of metallic pipe for firefighting systems which may be exposed to fire hazards since such material can withstand higher temperatures in case of fires to limit safety risks.

Moreover, overstress has a high impact on non-metallic networks. Therefore, proper stress analysis shall be conducted to ensure a non-metallic network's proper configuration and layout.

Financial Conditions

Non-metallic pipes have long-term cost advantages. The cost of pipe, the cost of installation, and the cost of the operation are 20-30% lower than the equivalent cost of metallic pipe [5]. Moreover, the non-metallic pipe is considered maintenance-free, with a life cycle of up to 50 years. In general, if technically feasible, the choice of non-metallic is always more attractive.

Quality, Inspection and Workmanship

To avoid frequent failures after installation of non-metallic pipe, proper quality procedures shall be followed from manufacturing until commissioning. All the supplied non-metallic items shall comply with the required standards to avoid frequent failures after installation. Laboratory analysis is recommended to conduct for random samples of supplied items to ensure compliance.

Installation of non-metallic pipes shall be conducted only by skilled manpower with proper workmanship monitor and traceability of welding parameters. Moreover, the advanced non-destructive methodology shall be implemented for non-metallic joints.

Conclusion

Oil and gas industries lose billions of dollars annually on corrosion and further maintenance management expenses. Effective corrosion management in the oil and gas sector will dramatically contribute to reducing overall maintenance activities, leading to cost optimization and an increase in plant availability. The non-metallic pipe is considered maintenance-free, with a life cycle of up to 50 years. In general, if technically feasible, the choice of non-metallic is always more attractive to avoid corrosion issues. The wide use of non-metallic materials in the oil and gas industry will contribute to effective corrosion management and minimize environmental risk due to the material's advanced technology, high corrosion resistance, and awareness of the material lifetime.

Limitations in pressure, temperature, and strength are the main obstacles to further utilization of non-metallic pipes in the oil and gas industry. Moreover, special design considerations for overstress and UV degradation effects shall be taken into account. Quality monitoring from the manufacturing until commission will always play a vital role in ensuring the avoidance of future failures in non-metallic systems.

Reference

1. IMPACT, NACE International. 2016. "International Measures of Prevention, Application, and Economics of Corrosion Technologies." http://impact.nace.org/documents/Nace-International-Report.pdf
2. Anupama R. Prasad, Anupama Kunyankandy, and Abraham Joseph. 2020. "Corrosion Inhibitors in the Oil and Gas Industry." University of Calicut, Department of Chemistry, Thenhipalam, Kerala 673635, India.
3. Oil & Gas Middle East. 2017. "Combatting the Corrosion Curse." *Corrosoin Control*, arabinoilandgas.com.
4. Koch, G., Varney, J., Thompson, N., et al. 2002. "Corrosion cost and preventive strategies in the United States." FHWA-RD-01-156.
5. Hughes, Baker. 2012. *7 things you should know about non-metallic flexible pipe*. https://www.bakerhughes.com/company/energy-forward/7-things-you-should-know-about-nonmetallic-flexible-pipe.