Summary
Corrosion-related failures pose HSE and financial risks to oil and gas companies. Companies need to know and consider a variety of information for effectively managing corrosion issues. Access to interdisciplinary scientific, technological and engineering information is a must-have for helping companies address, mitigate and reduce the risks associated with corrosion in a cost-effective and efficient way.
Background and economic impact

Corrosion in the oil and gas industry is prevalent and has resulted in substantial investment in materials and technology to help combat and mitigate the loss of containment, leakages, death or injury of personnel, environmental pollution and other impacts. As an example, the result of the application of continuous investment in research in corrosion management has allowed companies to develop new oil and gas fields that in the past were both challenging and not cost-effective to produce. For example, the presence of salts and brines in heavy crude precluded the development of these fields because it was too costly as it required significant investment in monitoring, maintaining and replacing equipment and pipelines due to corrosion. However, developments in new technologies in each of these areas, as well as the development of better materials has made it more economical to produce and refine these heavy and sour crudes.

Corrosion-related problems are estimated to cost all U.S. industries about $280 billion per year, with a portion of that cost being incurred by the oil and gas industry. Globally, corrosion is estimated to cost $2.5 trillion, of which $6 billion is spent by the oil and gas industry alone. Based on a recent study, around 42 percent of failures in all structures relate in one way or the other to corrosion issues. A recent study showcased that an inadequate awareness or attention to management of known corrosion hazards was implied as major contributing factor in 23 percent of all incidents in petroleum refineries. Moreover, the consequences of failing to implement an extensive corrosion management and mitigation program can substantially place personnel, facilities and the environment in an unnecessary risk. More than 35 percent of corrosion-related incidents are projected to have a significant economic impact and the National Association of Corrosion Engineers (NACE) estimates that industries can save between $375 and $875 billion annually on a global basis by deploying corrosion control practices.

Corrosion is a large concern particularly with heavy crudes and blends of oil that carry water—a practice that is common in the refining industry. A small quantity of water in crude oil is inevitable. However, half of a percent of water is not considered to be a corrosion concern unless conditions exists that enable accumulation of this water on the pipe. The main factor that affects internal corrosion in transmission pipelines is flow rate. Higher corrosion rates can be generally expected when the pipe coating has a combination of large damaged areas and defects and when the pipe is exposed to seawater rather than mud. There is also a particular risk of microbiologically influenced corrosion on buried lines with bitumen-based coatings and depleted cathodic protection. If the coated protections have depleted, corrosion will begin in multiple sites all over the pipeline. Unless detected and retrofitted, the first leak could be the end of that segment of the pipeline.
Research output by academic institutions and corporates on corrosion-related topics has steadily increased over the past 30 years, as exemplified by research published on microbiologically influenced corrosion. (Source: Scopus)

Ohio University, Chinese Academy of Sciences, Naval Research Laboratory, NASA Stennis Space Center and the Colorado School of Mines lead the way in research on microbiologically influenced corrosion over period of 1983 – 2017. (Source: Scopus)
Several studies have identified common patterns found in corrosion-related failures in the petroleum industry:

- Inadequate awareness or attention to known corrosion hazards
- Inadequate risk analysis at design and construction stage
- Inadequate risk analysis prior to change, which essentially a failure in the management of change process
- Failure to identify or address process risks in planning inspections
- Inadequate identification of hazards and assessment of risks at critical points in the safety life cycle
- Critical information about the hazard and potential risk was available but omitted from the risk assessment
- Critical information about the hazard and potential was not fully available for the risk assessment

Although it may take some time for corrosion effects to be physically noticed, it’s vital to start corrosion management early.

Research output on corrosion failure

A
1. Chinese Academy of Sciences
2. Ministry of Education China
3. CAS—Institute of Metal Research
4. University of Science and Technology Beijing
5. Dalian University of Technology
6. Southwest Petroleum University China
7. Royal Melbourne Institute of Technology University
8. CNRS
9. China University of Petroleum—Beijing
10. Monash University

B
1. PetroChina
2. SINOPEC
3. TWI (The Welding Institute)
4. Saudi Aramco
5. Electric Power Research Institute
6. Petrobras
7. Chevron Energy Technology Company
8. Dow Chemical
9. Nalco Company
10. NXP Semiconductors

According to Elsevier’s research intelligence tool, SciVal (www.scival.com), research output on corrosion failure of a) Top 10 research institutions and b) top 10 corporations (as measured by Scholarly Output, 2012 - 2017)
Corrosion in crude oil pipelines occurs due to dissolved acid gases and water, which have been mostly extracted before the crude oil enters the transmission pipeline.

Corrosion management and the importance of information

Although it may take some time for corrosion effects to be physically noticed, it’s vital to start corrosion management early. The potential of internal corrosion is initially considered during the pipeline design phase, when the line is designed to operate normally under turbulent flow conditions to prevent the accumulation of water and sediments. Corrosion is identified with scheduled inspections, including measuring the wall thickness and the corrosion rate. The susceptibility to corrosion is determined partly by predictions based on the water chemistry, temperature, and flow characteristics and in part by corrosion measurements. Corrosion in crude oil pipelines occurs due to dissolved acid gases and water, which have been mostly extracted before the crude oil enters the transmission pipeline. In addition, the longer the pipeline, the more difficult corrosion is to manage because it often occurs in unlikely places. However, the effect of corrosion in these pipelines can be mitigated by conventional control practices and can be especially effective, if proactively implemented as part of routine business practices.

The most successful corrosion mitigation strategies require engineering teams to have ready, up-to-date access to a library of interdisciplinary information to support the:

- Selection of appropriate materials. Use of corrosion resistant alloys, nonmetallic materials composites, thermoplastic-lined and polyethylene pipelines. Selection of appropriate and cost effective material during design, construction and major turnaround projects is critical.
- Selection of most appropriate chemical treatments. For example, chemical corrosion inhibitors can be very effective in reducing corrosion rates, with the potential to reduce corrosion rates by 99 percent or more, given a suitable concentration of an appropriate inhibitor. The effectiveness of a specific chemical inhibitor primarily depends on:
  - Type of material interacting with the inhibitor, whether regular carbon steel pipe, iron or other metals or alloys.
  - Analysis of the environment, for example, pH levels and presence of certain corrosive substances in hydrocarbon such as hydrogen dioxide, carbon dioxide and other elements.
  - Type of hydrocarbon being transported, stored, produced or transformed, with heavier crude oils typically carrying or sweeping along the water more easily than lighter crude oils, which impacts corrosion formation.
  - Each inhibitor must be selected according to the specific environment taking into account all variables, because no universal set of corrosion inhibitors can be used in all cases.
- Effective process control, which involves identifying key indicators, such as pH, temperature, pressure, flow rate, water chemistry, dissolved metals, bacteria, suspended solids chlorine, oxygen, and chemical residuals. Process control then correlates these indicators to identify trends to prevent ideal conditions for corrosion formation.

In addition to understanding the tendency and rate of corrosion, companies must understand the end-to-end impacts from corrosion and the effects of such variables as material composition, configuration, function and location. For example, in a recent study, more than 71 percent of corrosion-related failures in the petroleum refinery industry originated in the piping system. The same study identified the actual configuration and design of the pipe works system as key
The purpose of a corrosion risk assessment is to rank facilities in order of their proneness to corrosion and to identify options to remove, mitigate or manage the risks.

Factors that play an important role in creating opportunity for corrosive deposits to accumulate. The function and location of pipes can also determine the level of exposure to corroding agents.

Corrosion risk assessment
The purpose of a corrosion risk assessment is to rank facilities in order of their proneness to corrosion and to identify options to remove, mitigate or manage the risks. Monitoring and inspection program are incorporated in the overall activity schedule of a facility.

One of the critical elements in a comprehensive corrosion management program involves not only understanding the tendency of corrosion but also grasping the rate of corrosion.

Understanding the rate of corrosion requires knowledge of the role of primary environment, metallurgical variables, underlying mechanism of corrosion, which means companies need access to interdisciplinary scientific, technological and engineering information account for impacts of all the different parameters to make timely business decisions. Conducting and maintaining a risk assessment for corrosion requires strong knowledge of the different metallurgy involved in a downstream oil and gas operation and the interactions between the different pieces of equipment, type of hydrocarbon being transported and other variables.

Corrosion monitoring
Corrosion monitoring includes in-line and on-line systems. The in-line system covers the installation of devices directly into the pipeline. These need to be extracted for analysis periodically. On-line monitoring techniques include deployment of corrosion-monitoring devices, either directly into the process or fixed permanently to the facility.

After a corrosion risk assessment is conducted, data collection from monitoring and inspections and analysis are completed and corrective action on the facility may be needed, depending on the level of the deterioration a facility experiences. The approaches available for mitigating corrosion in pipeline include coating surfaces to act as a barrier or perhaps provide sacrificial protection, the addition of a chemical to the environment to limit corrosion, alteration of alloy chemistry to make pipes more resistance to corrosion, and use of alternative material.

Percentage of corrosion-related failures in petroleum refining that originates in the piping system

71%
Conclusion
Effective corrosion mitigation involves a sound approach to assessment linked to inspection monitoring during initial design and re-evaluation of pipeline. Oil and gas companies can prevent or control corrosion by understanding key physical and chemical principles underlying corrosion processes. This understanding has been the basis for the development of a variety of corrosion prevention measures that rely on understanding all the moving parts and corrosion-forming trends.

The proliferation of different empirical, statistical and mechanistic prediction models for corrosion prediction aids in managing the integrity of the pipelines through different mitigation strategies. Access to multi-disciplinary scientific, technological and engineering information that includes a mixture of real-world case studies and laboratory simulations from around the globe helps companies stay up to date and competitive by giving them the knowledge to assess not only what works, but also what failed and why.

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