INTRODUCTION TO OILFIELD METALLURGY AND CORROSION CONTROL

The American Petroleum Institute (API) divides the petroleum industry into the following categories:

- Upstream
- Downstream
- Pipelines

Other organizations use terms like production, pipelining, transportation, and refining. This book will discuss upstream operations, with an emphasis on production, and pipelines, which are closely tied to upstream operations. Many “pipelines” could also be termed gathering lines or flowlines, and the technologies involved in materials selection and corrosion control are similar for all three categories of equipment.

Until the 1980s, metals used in upstream production operations were primarily carbon steels. Developments of deep, hot gas wells in the 1980s led to the use of corrosion-resistant alloys (CRAs), and this trend continues as the industry becomes involved in deeper and more aggressive environments.1 Nonetheless, the most used metal in oil and gas production is carbon steel or low-alloy steel, and nonmetallic materials are used much less than metals.

Increased emphasis on reliability also contributes to the use of newer or more corrosion-resistant materials. Many oil fields that were designed with anticipated operating lives of 20–30 years are still economically viable after more than 50 years. This life extension of oil fields is the result of increases in the market value of petroleum products and the development of enhanced recovery techniques that make possible the recovery of larger fractions of the hydrocarbons in downhole formations. Unfortunately, this tendency to prolong the life of oil fields creates corrosion and reliability problems in older oil fields when reductions in production and return on investment cause management to become reluctant to spend additional resources on maintenance and inspection.

These trends have all led to an industry that tends to design for much longer production lives and tries to use more reliable designs and materials. The previous tendency to rely on maintenance is being replaced by the trend to design more robust and reliable systems instead of relying on inspection and maintenance. The reduction in available trained labor for maintenance also drives this trend.

COSTS

A U.S. government report estimated that the cost of corrosion in upstream operations and pipelines was $1372 billion per year, with the largest expenses associated with pipelines followed by downhole tubing and increased capital expenditures (CRAs, etc.). The most important opportunity for savings is the prevention of failures that lead to lost production. The same report suggested that the lack of corrosion problems in existing systems does not justify reduced maintenance budgets, which is a recognition that as oil fields age, they become more corrosive at times when reduced returns on investment are occurring.2 It is estimated that corrosion costs are approximately equal to mechanical breakdowns in maintenance costs.

1 Metallurgy and Corrosion Control in Oil and Gas Production, by Robert Heidersbach
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SAFETY

While proper equipment design, materials selection, and corrosion control can result in monetary savings, a perhaps more important reason for corrosion control is safety. Hydrogen sulfide, H\textsubscript{2}S, is a common component of many produced fluids. It is poisonous to humans, and it also causes a variety of environmental cracking problems. The proper selection of H\textsubscript{2}S-resistant materials is a subject of continuing efforts, and new industrial standards related to defining metals and other materials that can safely be used in H\textsubscript{2}S-containing (often called “sour”) environments are being developed and revised due to research and field investigations.

 Pipelines and other oilfield equipment frequently operate at high fluid pressures. Crude oil pipelines can leak and cause environmental damage, but natural gas pipeline leaks, like the corrosion-related rupture in Carlsbad, New Mexico, shown in Figure 1.1, can lead to explosions and are sometimes fatal.\textsuperscript{2} High-pressure gas releases can also cause expansive cooling leading to brittle behavior on otherwise ductile pipelines. API standards for line pipe were revised in 2000 to recognize this possibility. Older pipelines, constructed before the implementation of these revised standards, are usually made from steel with no controls on low-temperature brittle behavior and may develop brittle problems if they leak. Gas pipelines are more dangerous than liquid pipelines.

ENVIRONMENTAL DAMAGE

Environmental concerns are also a reason for corrosion control. Figure 1.2 shows oil leaking from a pipeline that suffered internal corrosion followed by subsequent splitting along a longitudinal weld seam. The damages due to this leak are minimal compared with the environmental damages that would have resulted if the leak had been on a submerged pipeline. Figure 1.3 shows an oil containment boom on a river where a submerged crude oil pipeline was leaking due to external corrosion caused by non-adherent protective coatings that shielded the exposed metal surfaces from protective cathodic protection currents.
CORROSION CONTROL

The environmental factors that influence corrosion are:

- \( \text{CO}_2 \) partial pressure
- \( \text{H}_2\text{S} \) partial pressure
- Fluid temperature
- Water salinity
- Water cut
- Fluid dynamics
- pH

Corrosion is normally controlled by one or more of the following:

- Material choice
- Protective coatings
- Cathodic protection
- Inhibition
- Treatment of environment
- Structural design including corrosion allowances
- Scheduled maintenance and inspection

Figure 1.4 shows an offshore platform leg in relatively shallow water, approximately 30 m (100 ft) deep, in Cook Inlet, Alaska. The leg is made from carbon steel, which would corrode in this service. Corrosion control is provided by an impressed current cathodic protection system. The bottom of the leg is 2.5 cm (1 in.) thicker than the rest of the leg, and this is intended as a corrosion allowance for the submerged portions of the platform legs. Note that the water level goes above the corrosion allowance twice a day during high tides, because the platform is located in water 3 m (10 ft) deeper than was intended during design and construction. Fortunately, the cathodic protection system was able to provide enough current, even in the fast-flowing abrasive tidal waters of Cook Inlet, to control corrosion. This platform was obsolete when the picture was taken, but it was less expensive to operate and maintain the platform than it was to remove it. Thirty-five years later, oil prices had increased, recovery methods had improved, and the platform was economically profitable. Robust designs, adequate safety margins, and continuous re-evaluation of corrosion control methods are important, not just for marine structures, but for all oilfield equipment.

REFERENCES


