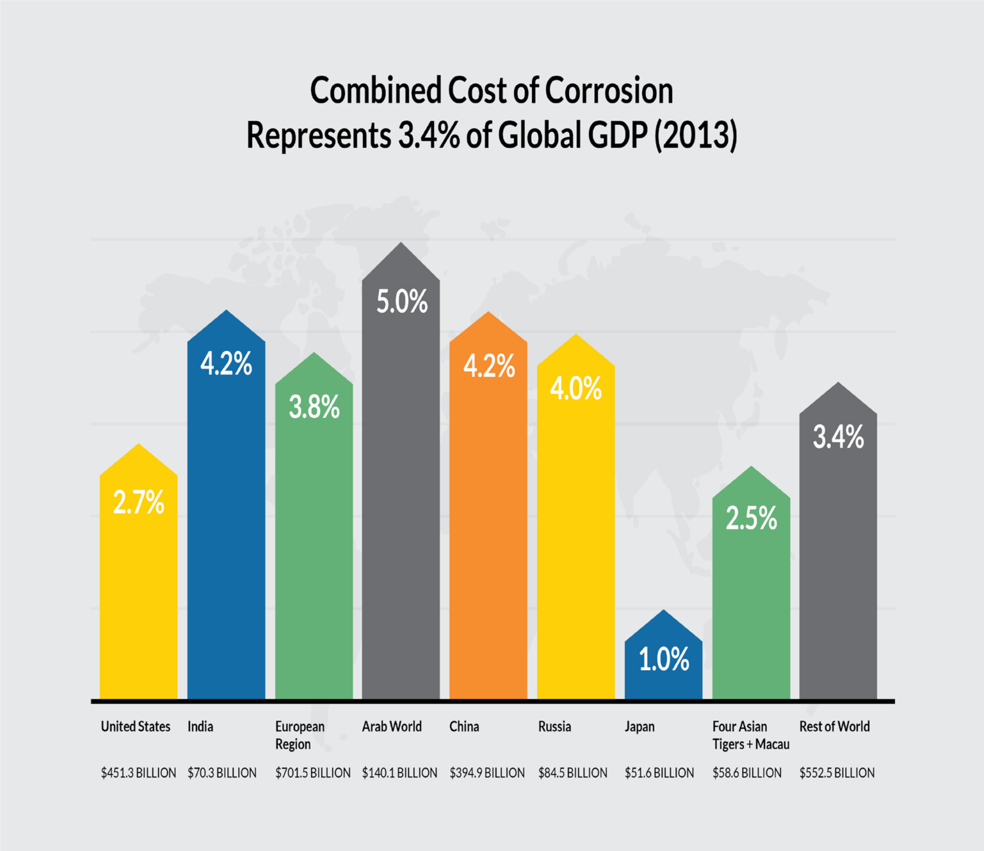
THE STUDY OF CORROSION

INTRODUCTION
CORROSION COSTS!

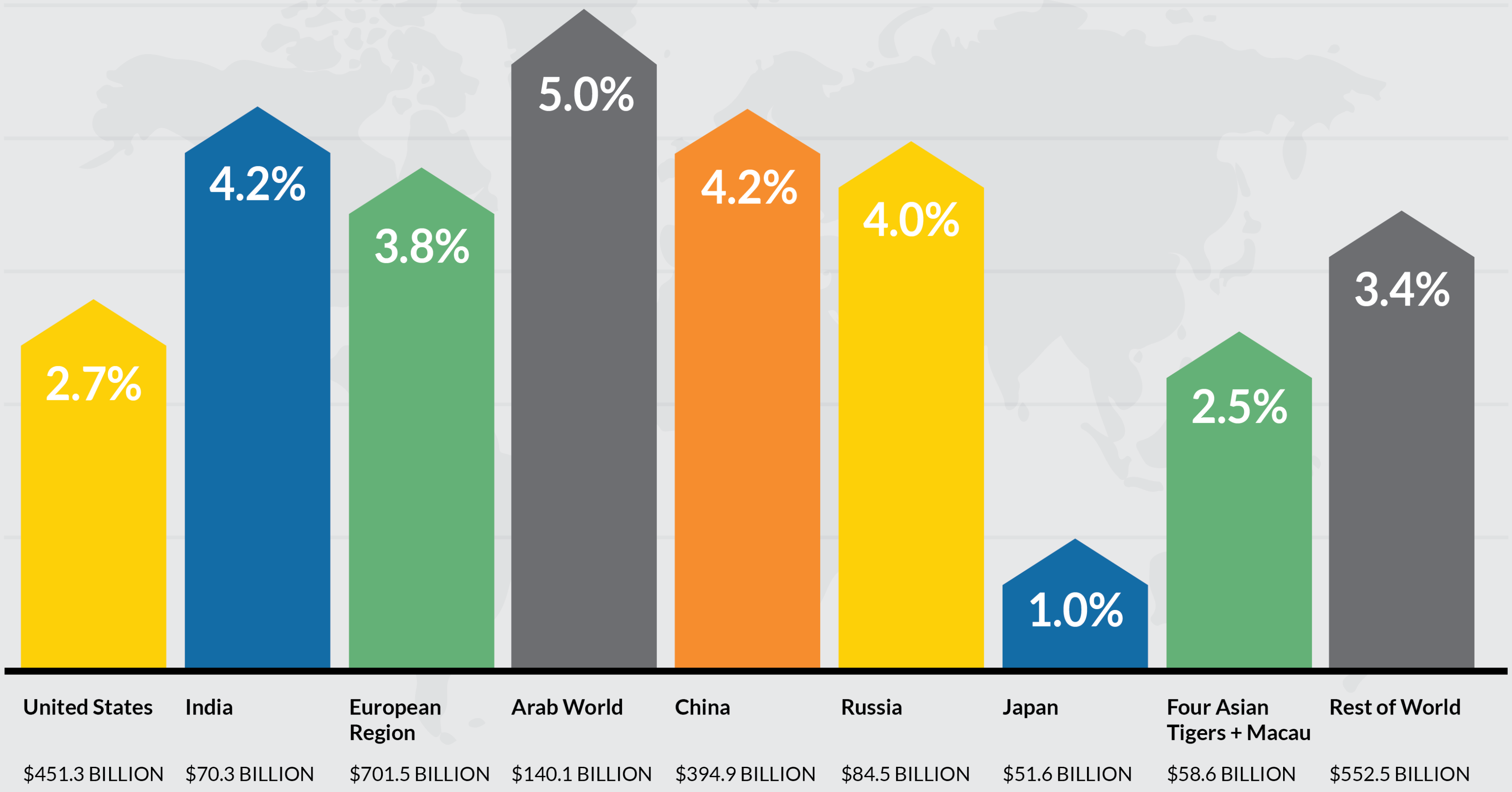
In 1978, the National Bureau of Standards reported to the U.S. Congress that the cost of corrosion in the United States in 1975 was 70 billion dollars plus or minus 30%, and that about 15 % of this loss was avoidable.

This economic loss represented about 4% of the gross national product. In 1983, Cron and Marsh also stated that the cost of corrosion in the United States in 1975 was ~$70 billion of which $10 billion was considered avoidable. The writers estimate that the cost of corrosion and scaling in United States in 2007 was around 400 billion dollars.



Combined Cost of Corrosion Represents 3.4% of Global GDP (2013)

Gross Domestic Product



QUESTION

WHY WE NEED TO STUDY & UNDERSTAND

THE CORROSION?

ANSWER

The principles of corrosion must be understood in order to **effectively select materials and to design, fabricate, and utilize metal structures for the optimum economic life of facilities and safety in operation**.

Corrosion in various forms is the major cause of drill pipe failures, for example, which add significantly to drilling costs. The trends toward

(1) drilling of deeper wells

(2) use of higher-strength steels

(3) presence of higher stresses

(4) use of lower-pH drilling fluids contributes to increased susceptibility of metals to failure due to corrosion.

Corrosion is the principal cause of damage to metals in wells and production facilities. Corrosion damage results in costly maintenance of these facilities (repairs and replacements) in addition to the loss of production.

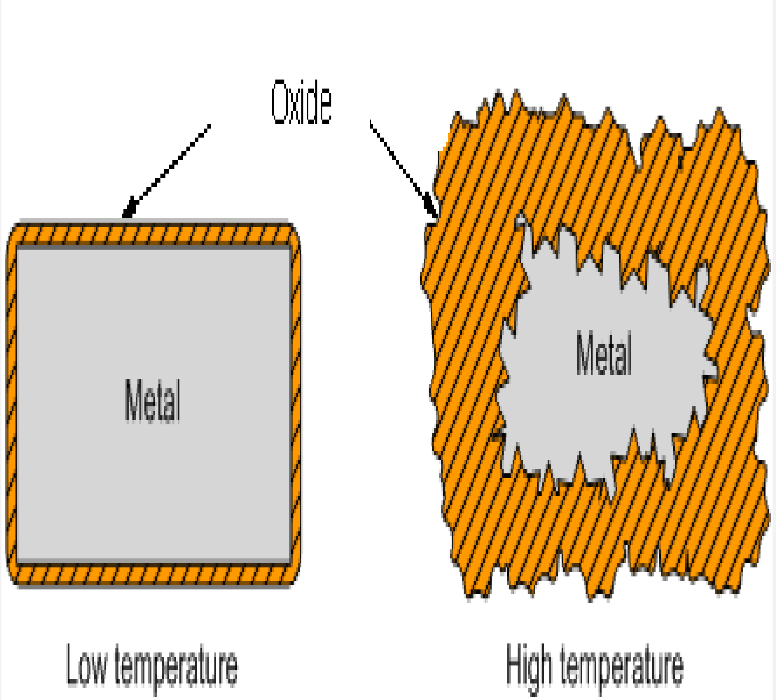
DEFINITION OF CORROSION

In 1946, The American Electrochemical Society had defined corrosion as the "destruction of a metal by chemical or electrochemical reaction with its environment."

The destruction of metals by corrosion occurs by:

(a) direct chemical attack at elevated temperatures in a dry environment

(b) by electrochemical processes at lower temperatures in a water-wet or moist environment.



Corrosion occurs because metals tend to revert to more stable forms in which they were found in nature initially, i.e., oxides, sulfates, sulfides, or carbonates

CORROSION TYPES

- Corrosion_Mechanism.pptx

CORROSION AGENTS IN DRILLING AND PRODUCING OPERATION

The components in fluids that promote the corrosion of steel in drilling and producing operations are :

(oxygen, carbon dioxide, hydrogen sulphide, salts, and organic acids).

The conditions that promote corrosion include:

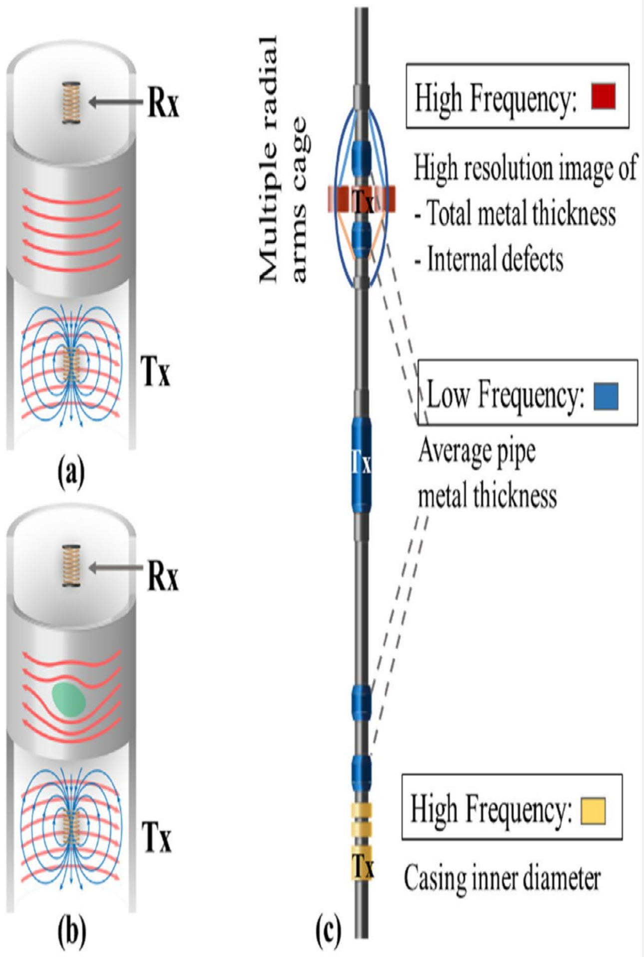
1. Energy differences in the form of **stress gradients** or **chemical reactivities** across the metal surface in contact with corrosive solution.
2. Differences in **concentration of salts or other corrodants** in electrolytic solution.
3. Differences in the **amount of deposits**, either solid or liquid, on the metal surfaces, which **are insoluble in the electrolyte solutions**.

INNOVATIVE TECHNOLOGIES FOR CORROSION DETECTION AND PREVENTION IN OIL WELLS

Innovative technologies for corrosion detection and prevention in oil wells have been developed to enhance monitoring capabilities, improve preventive measures, and prolong the lifespan of oil well components. Here are some of these technologies:

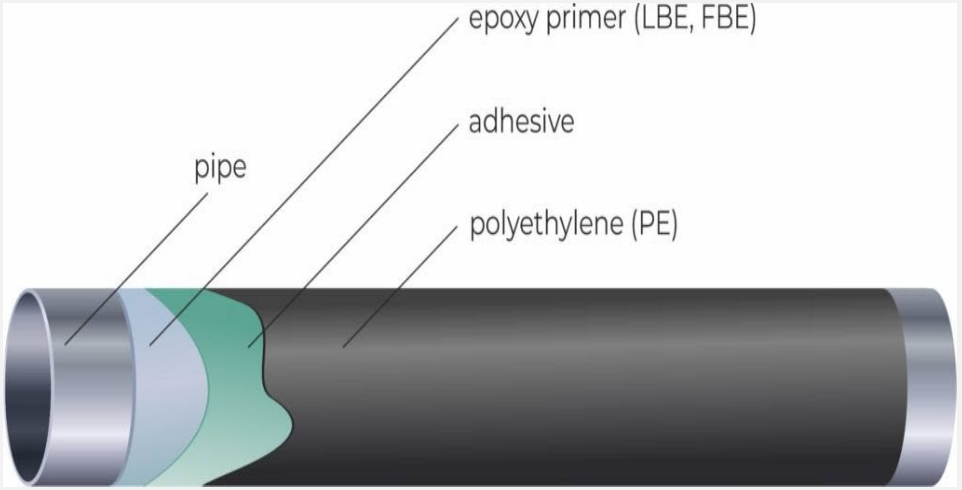
- ❑ Wireless Sensor Networks (WSNs):

WSNs consist of distributed, battery-operated sensors that can be placed throughout the well to continuously monitor environmental conditions, including temperature, pressure, and humidity. WSNs provide real-time data on corrosion rates and alert operators to potential issues.

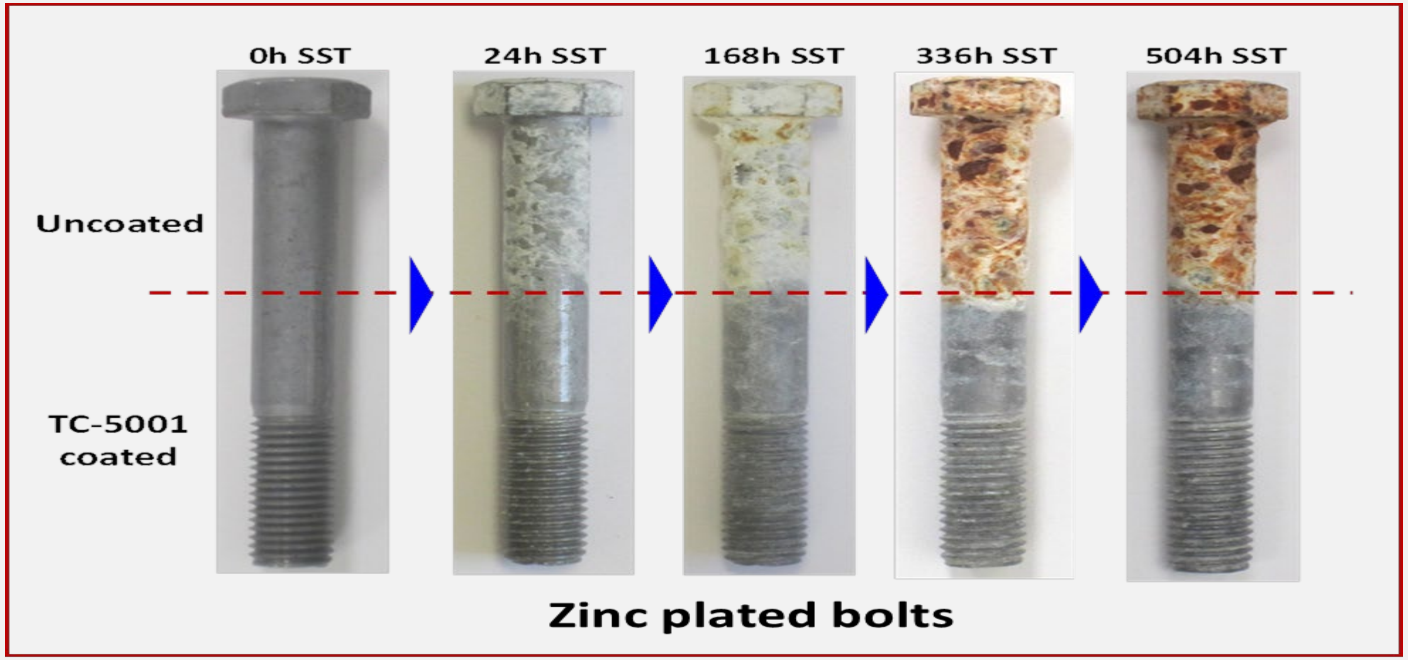


❑Smart Coatings:

Smart coatings or intelligent coatings are designed to respond to changes in the environment.



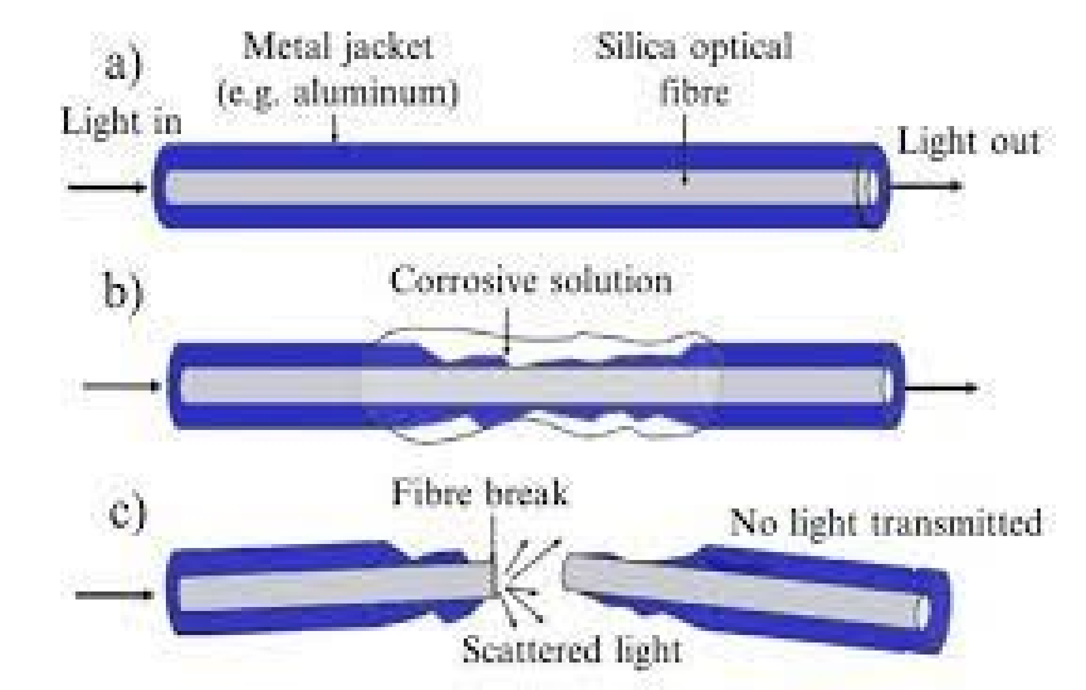
These coatings can release corrosion inhibitors when sensing corrosive conditions, providing active protection to the well components

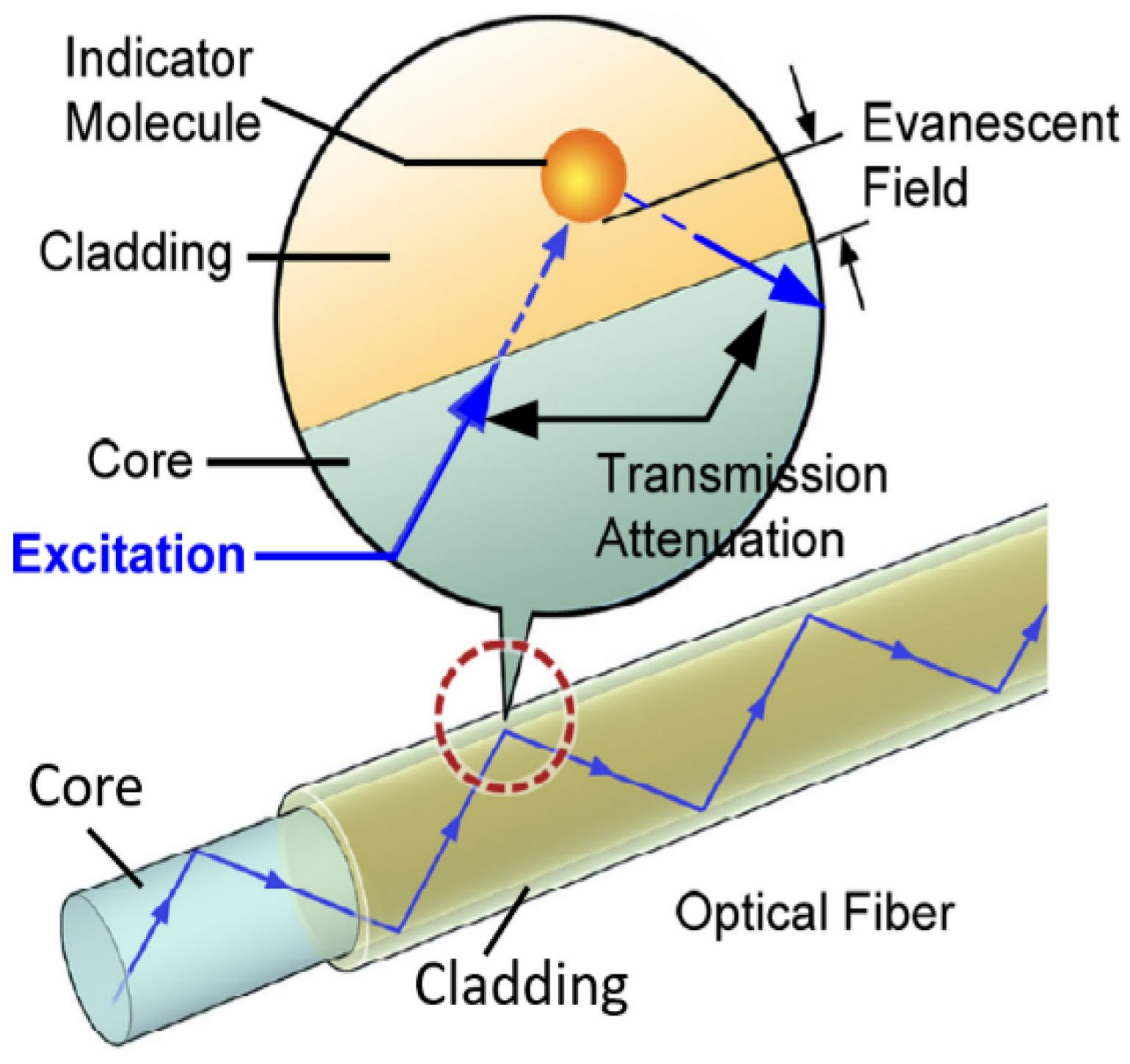


❑Fiber Optic Sensors:

Fiber optic sensors use optical fibers to detect changes in temperature, strain, or chemical concentrations

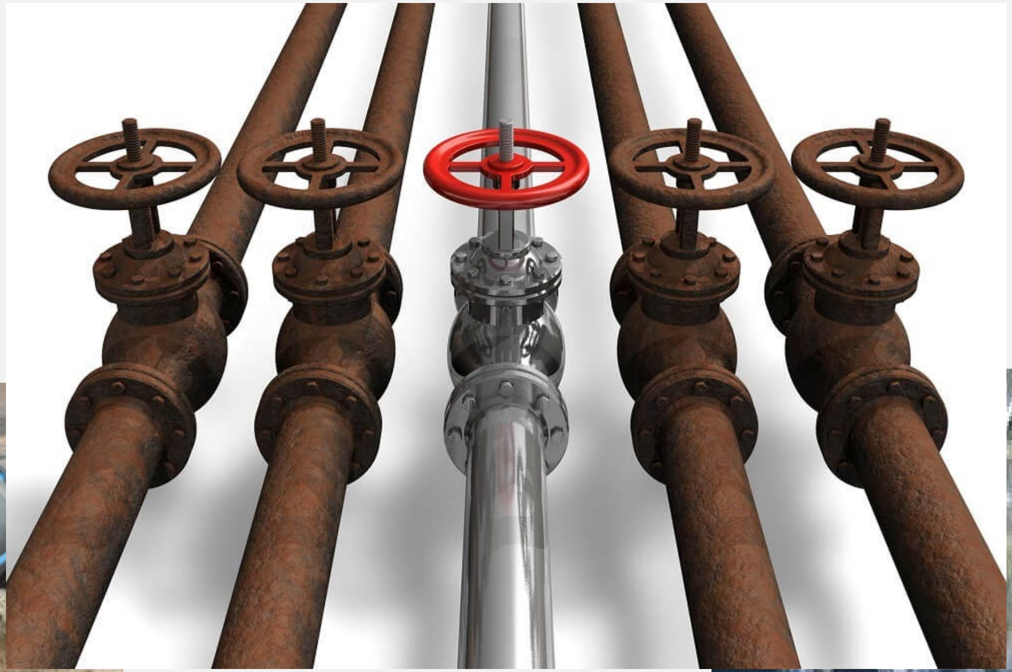
. They can be embedded into well components to monitor corrosion and stress levels in real-time.





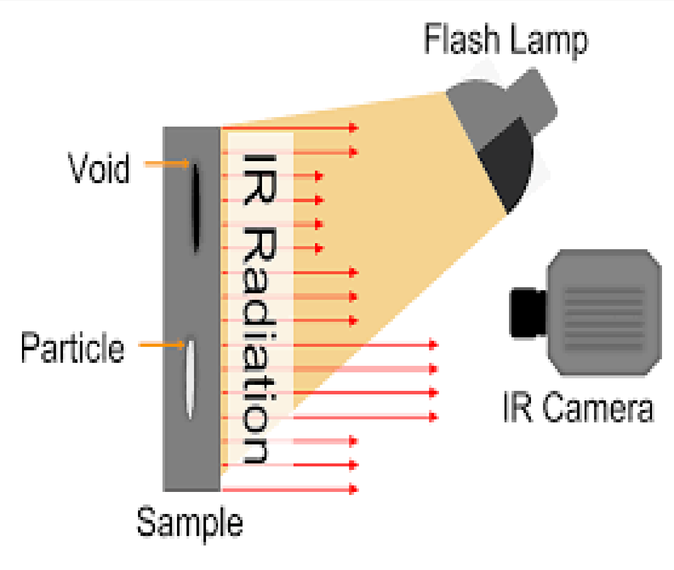
❑ Corrosion-Resistant Alloys and Composites:

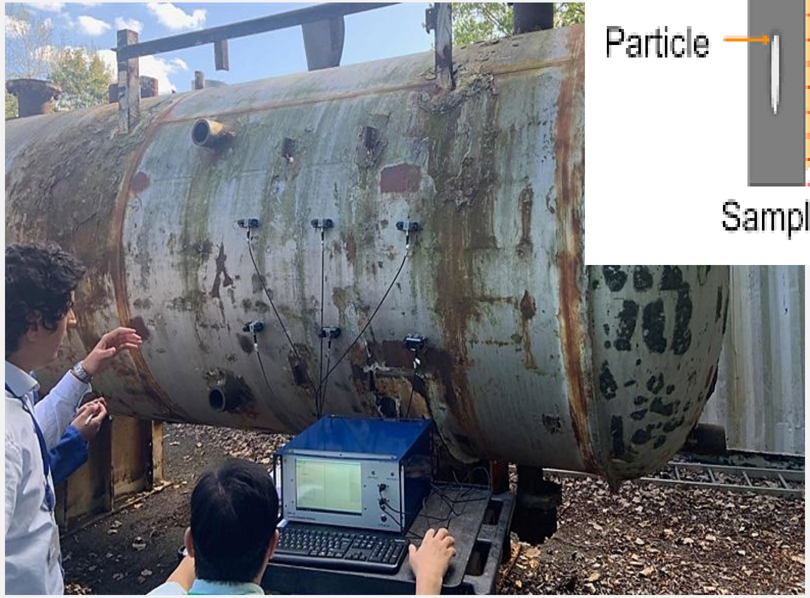
Advances in material science have led to the development of new corrosion-resistant alloys and composites, which can be used in critical well components to withstand harsh environments and reduce corrosion rates.

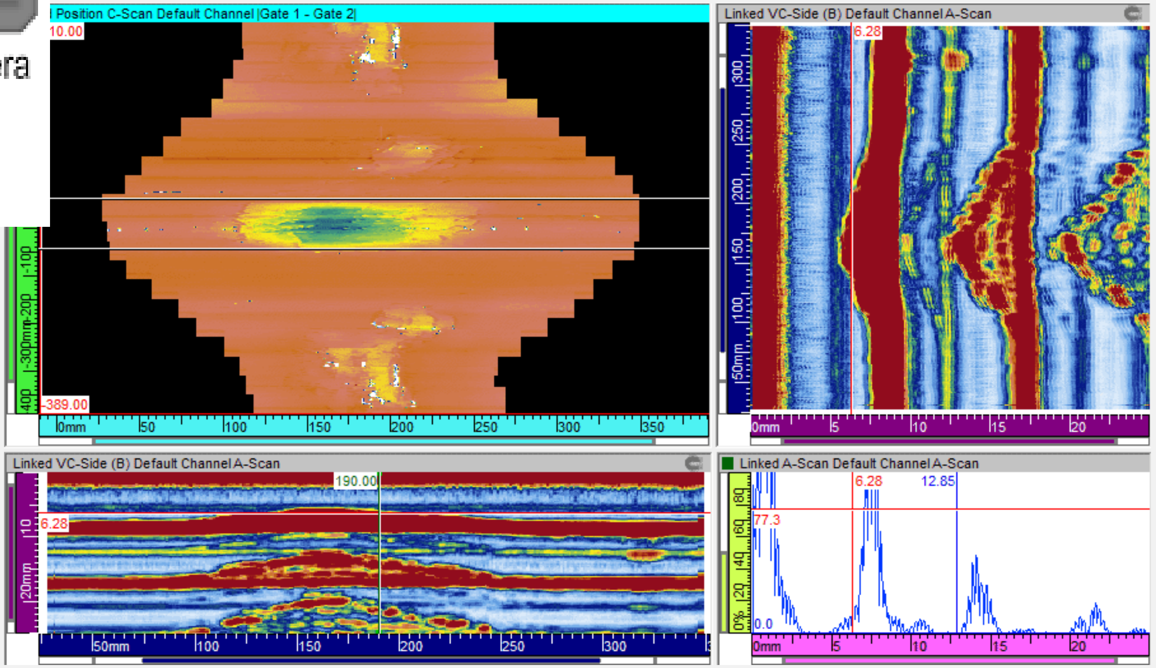


❑ Non-Destructive Testing (NDT) Techniques:

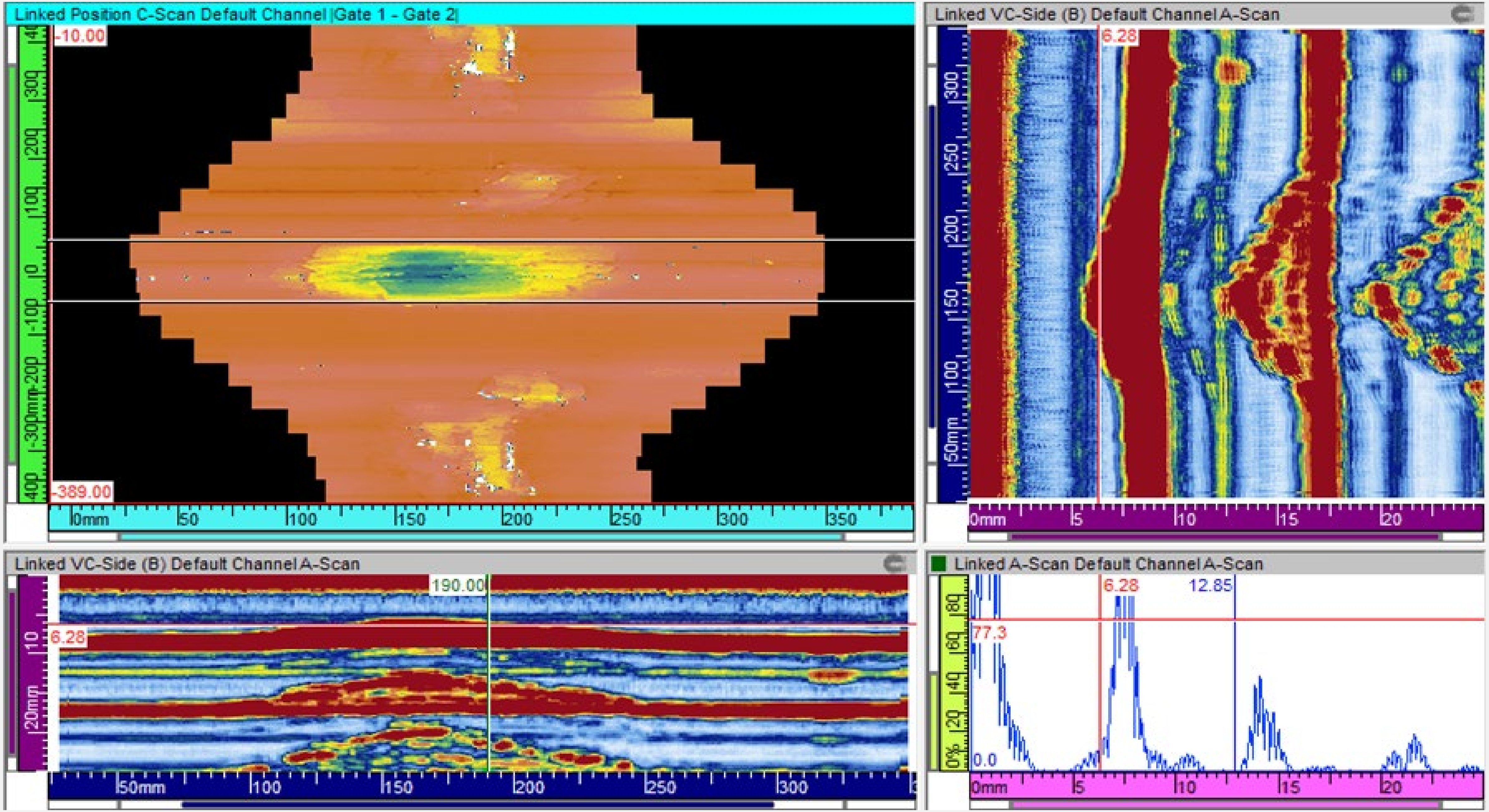
NDT methods, such as ultrasonic testing, electromagnetic testing, and radiography, are continually evolving to provide more accurate and detailed inspection of well components without causing damage to the materials.







Q/ Where the Destructive Testing (NDT) is used?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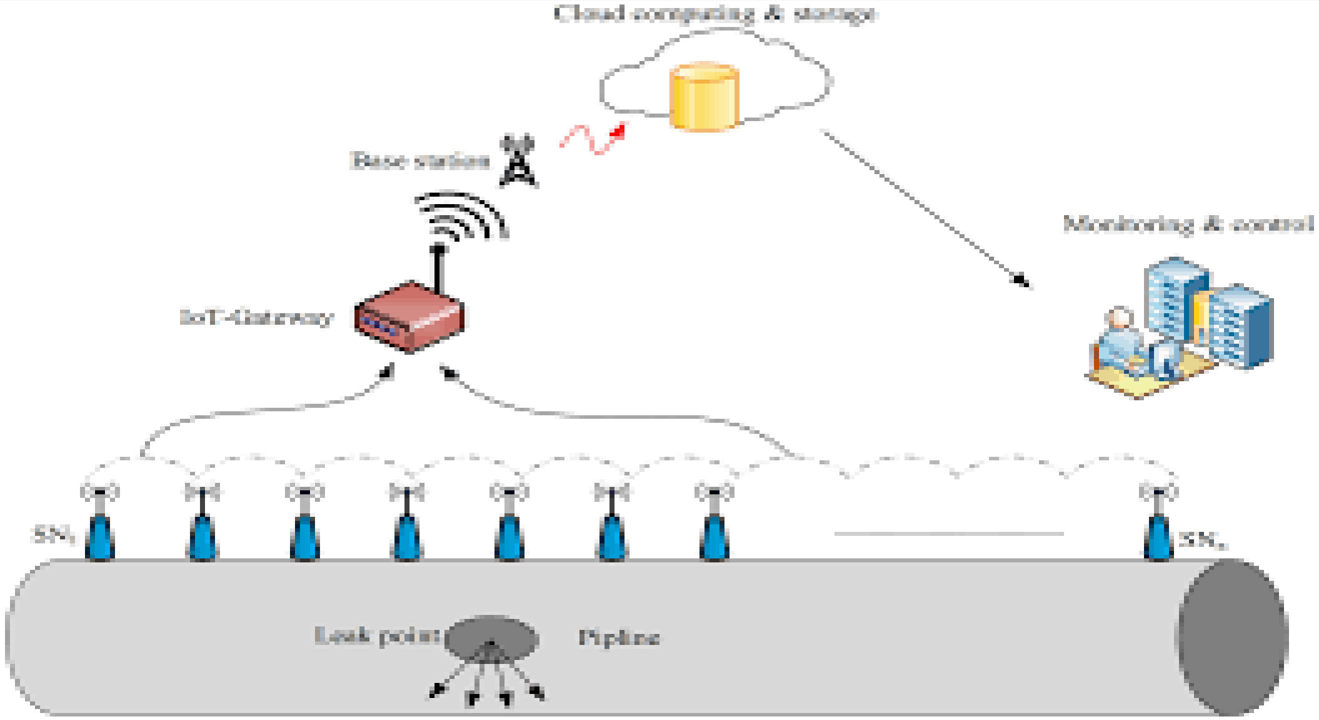
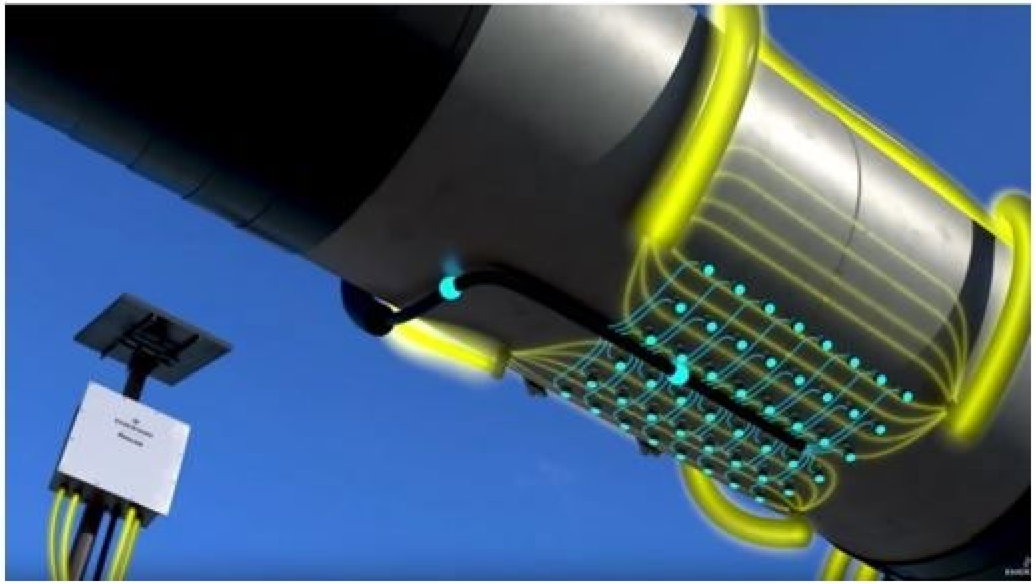
❑Remote Monitoring and Data Analytics

IoT (Internet of Things) technology allows for remote monitoring of wells and the collection of vast amounts of data. Advanced data analytics and machine learning algorithms can process this data to identify corrosion trends and predict potential failure scenarios.

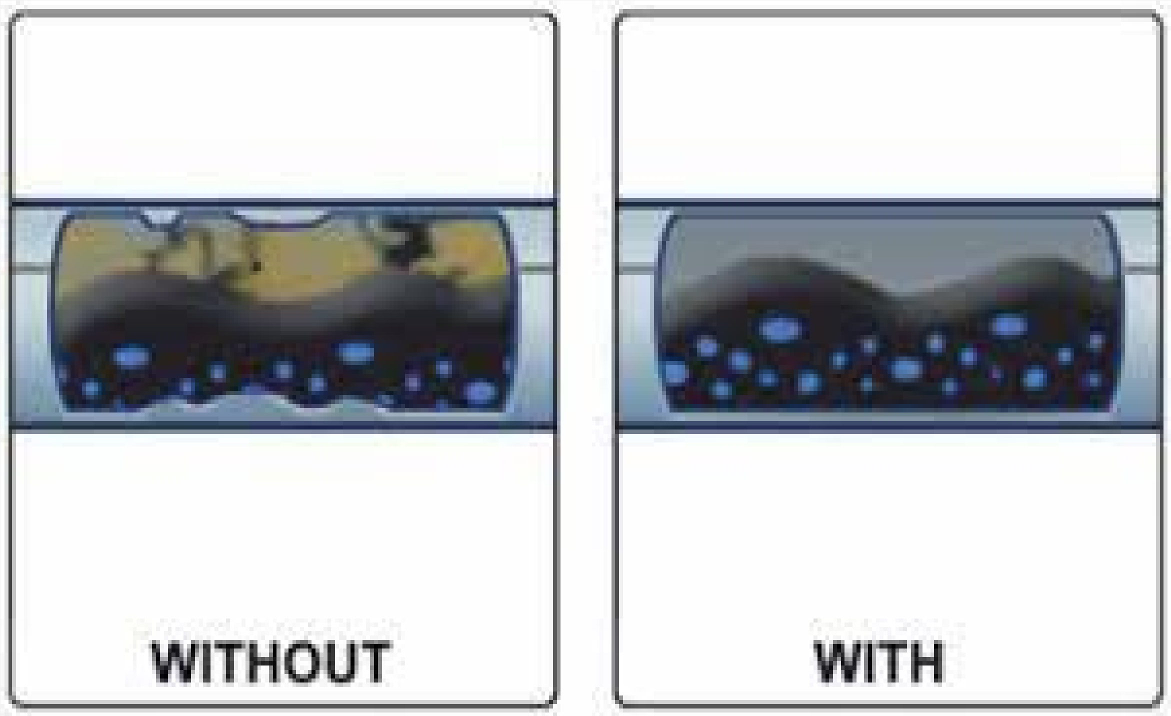


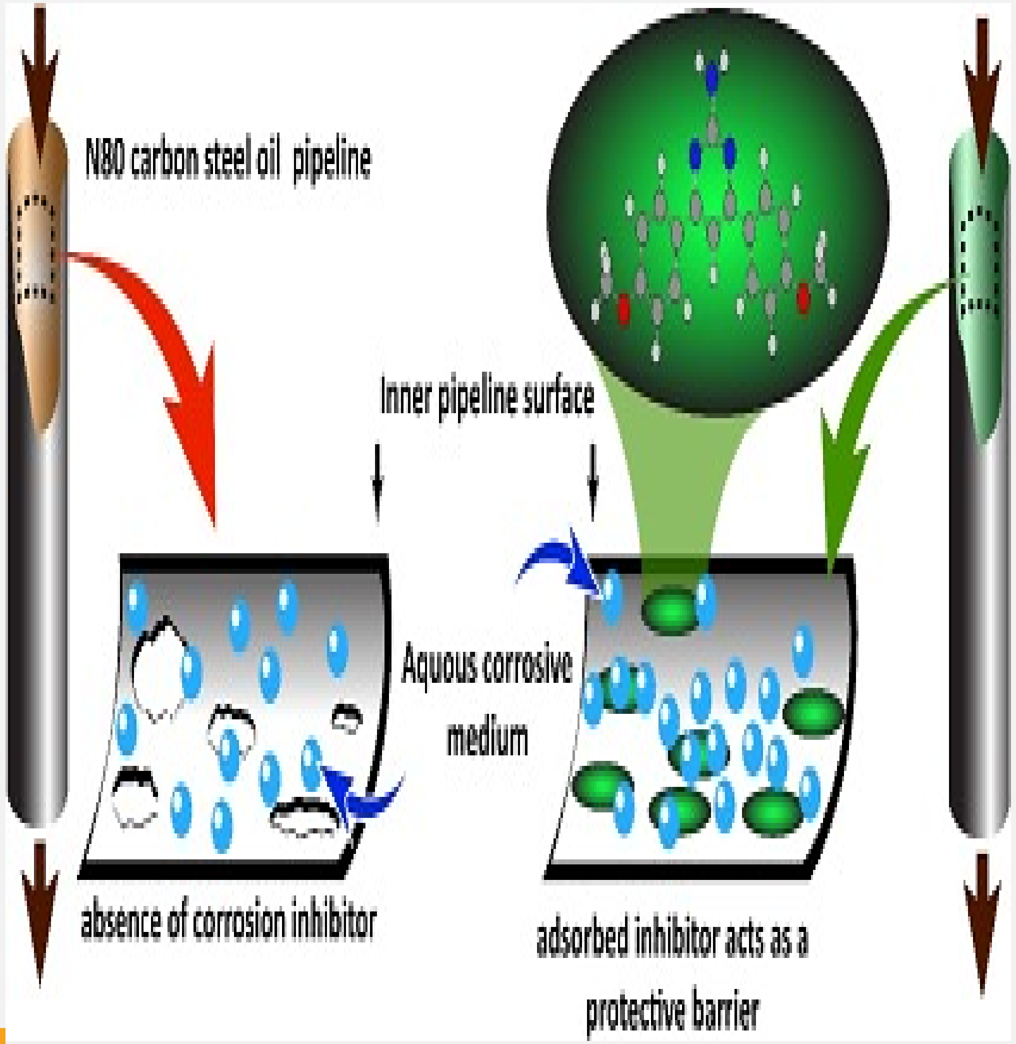


Corrosion Monitoring Systems for Pipeline Corrosion
Source: Emerson Automation Experts

❑Corrosion Inhibitors and Nanotechnology

Nanotechnology is being applied to enhance the performance of corrosion inhibitors by improving their release and distribution at the corrosion site. Nanoparticles can improve the efficiency and effectiveness of inhibition.

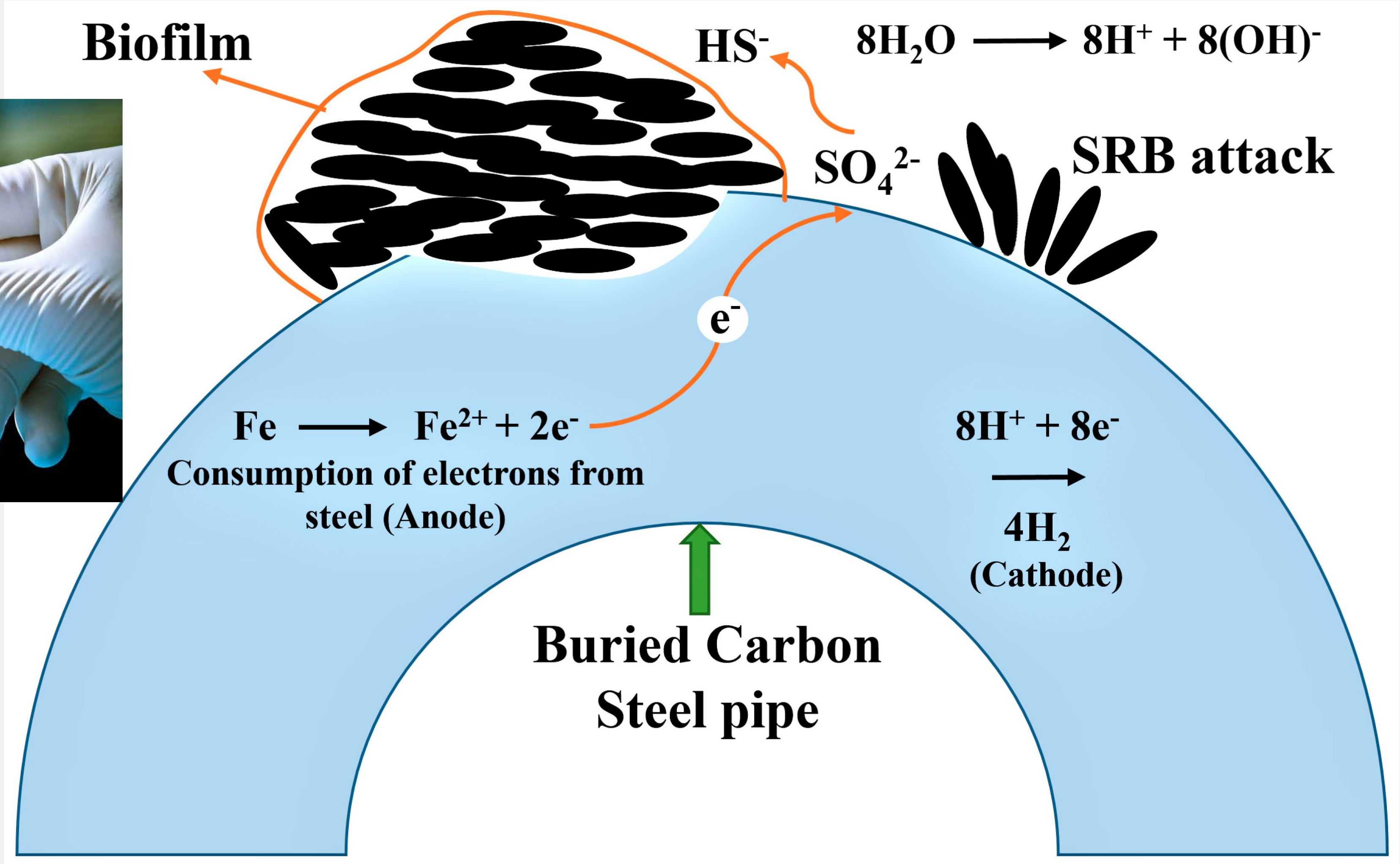




improving their release and distribution at the corrosion site

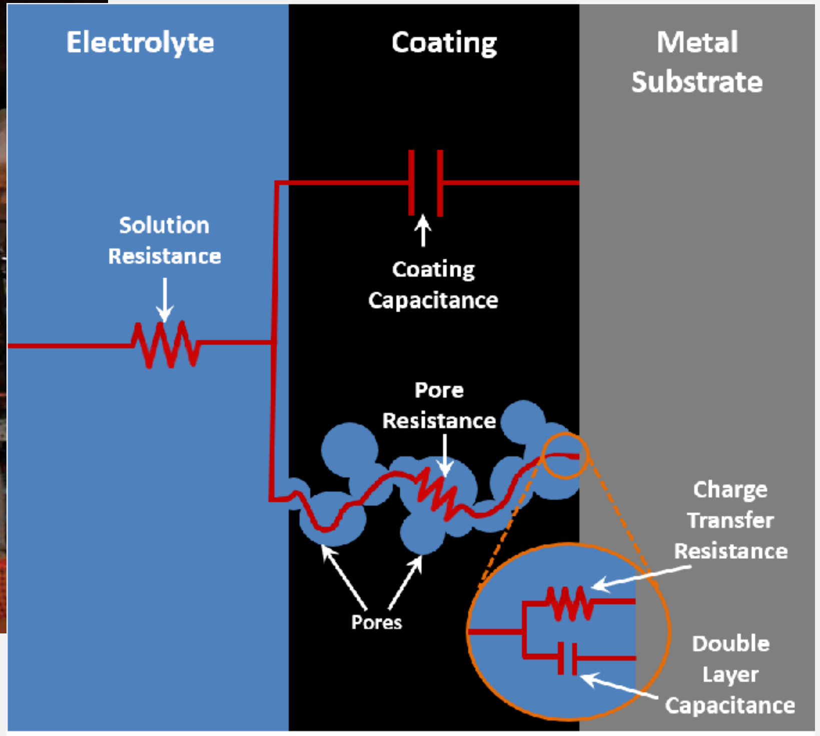
❑Microbial Monitoring and Control:

Microbiologically influenced corrosion (MIC) is a significant concern in oil wells. Advanced microbial monitoring systems can detect harmful bacteria, helping to implement appropriate control measures and biocide treatments.



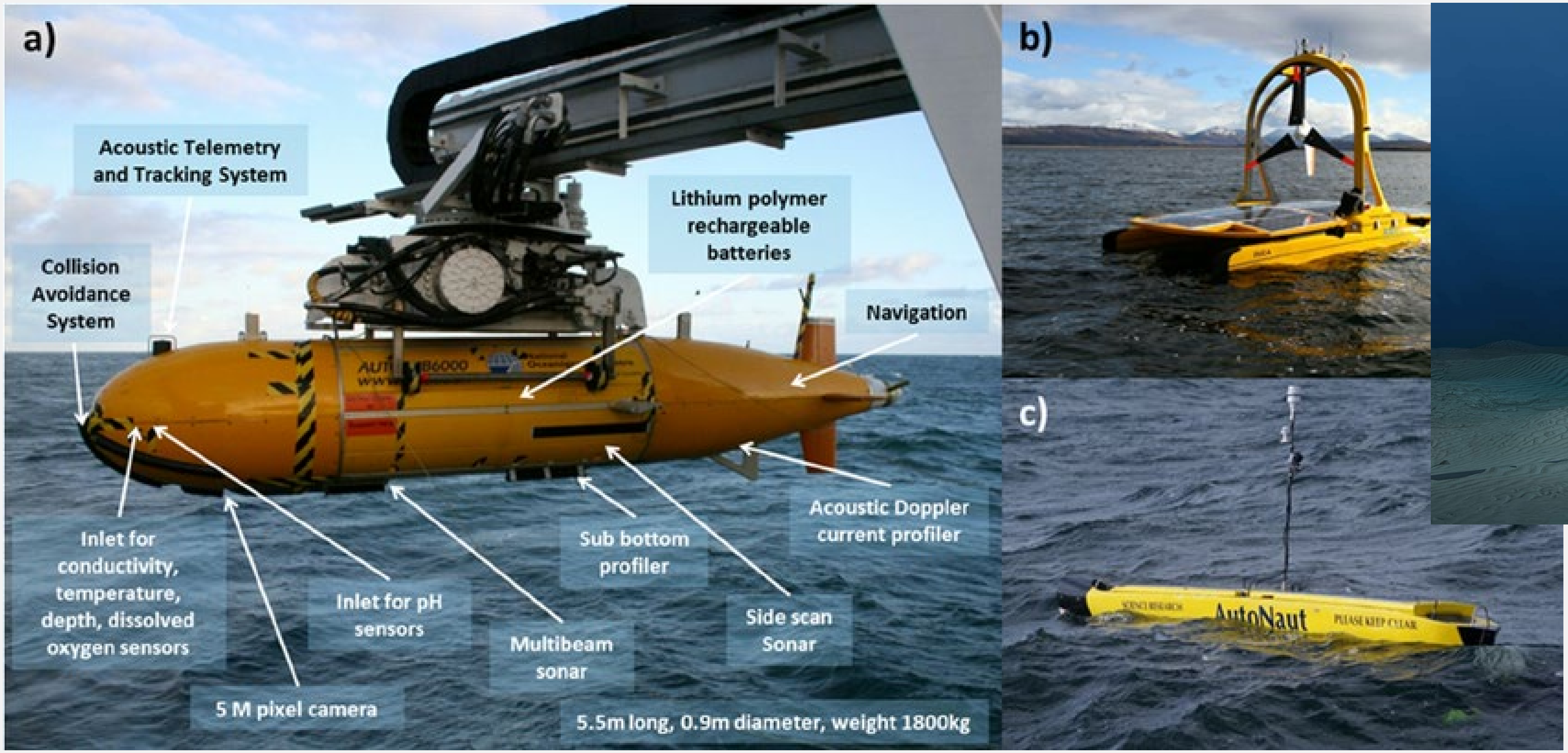
Real-Time Corrosion Monitoring Tools

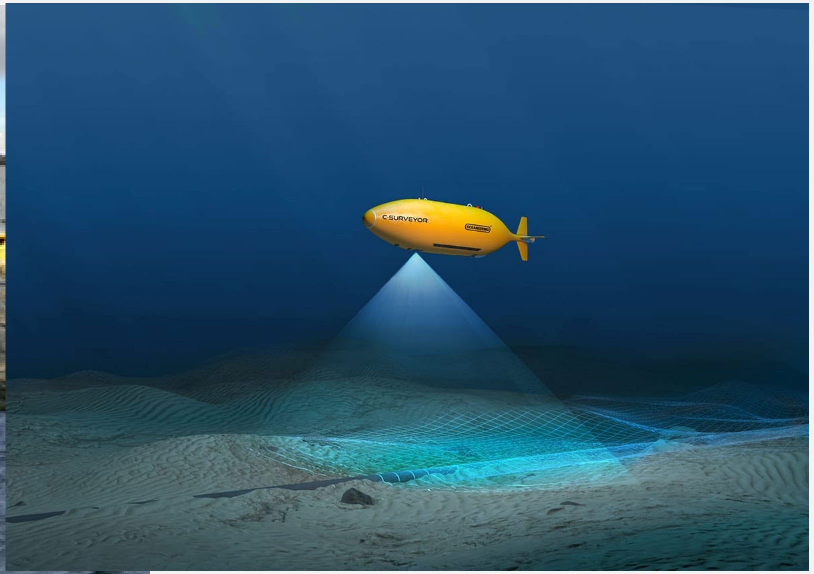
Tools such as electrical resistance probes, ultrasonic thickness gauges, and corrosion coupons are equipped with wireless data transmission capabilities to provide real-time corrosion rate measurements in wells.



Autonomous Underwater Vehicles (AUVs)

AUVs equipped with various sensors can inspect submerged components and pipelines in offshore oil wells, allowing for rapid detection of corrosion and other integrity issues.
The integration of these innovative technologies into corrosion management practices enables oil and gas companies to be more proactive in identifying and addressing corrosion challenges, leading to enhanced safety, reduced downtime, and optimized asset performance in oil wells.





"TECHNOLOGY IS BEST WHEN IT BRINGS PEOPLE TOGETHER."

MATT MULLENWEG

Corrosion Mechanisms

Lecture

Corrosion | Reactions | Chemistry

- https://www.youtube.com/watch?v=TKMgUCq3npg

TYPES OF CORROSION

- Sweet corrosion

> is a common type of corrosion and can be defined as: the deterioration of metal due to contact with carbon dioxide, fatty acids, or other similar corrosive agents, but excluding hydrogen sulfide H2S.

CO, + H,O <--> H,CO,

- 2. Sour corrosion

> The deterioration of metal due to contact with hydrogen sulfide and moisture

H2S+ Fe+ H20 --> FeSx + 2H+ H20 industry standard

provides guidelines for materials selection in H2S-containing environments to prevent corrosion? **NACE MR0175 / ISO 15156**

- 3. Oxygen corrosion
- 4. Electrochemical corrosion

One can also classify corrosion types as follows:

- 1. Uniform attack
- 2. Pitting corrosion
- 3. Crevice corrosion
- 4. Galvanic corrosion
- 5. Erosional corrosion
- 6. Fretting corrosion

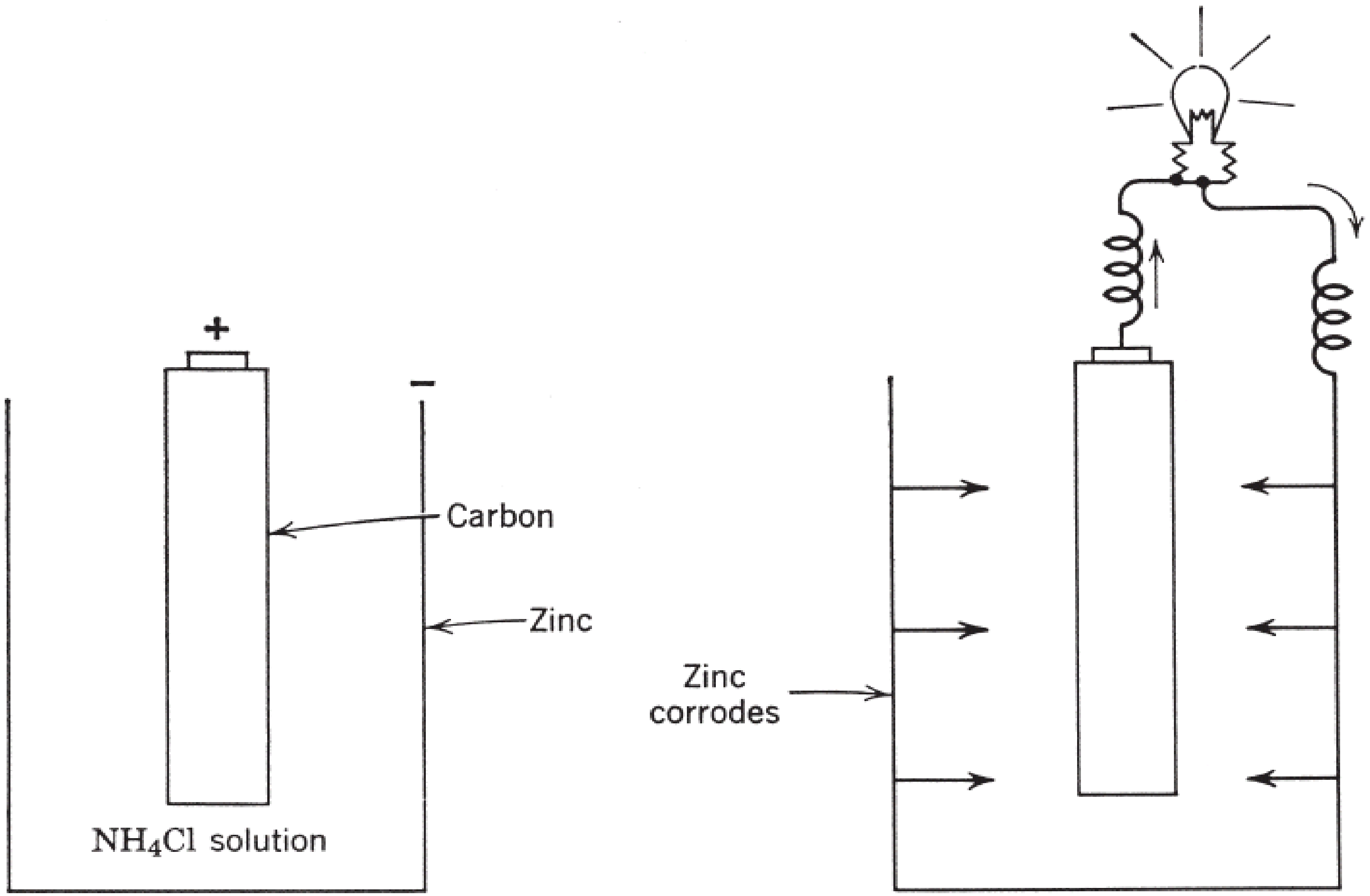
One can also classify corrosion types as follows:

- 7. Cavitation
- 8. Intergranular corrosion
- 9. Stress corrosion
- 10. Dealloying (selective leaching)
- 11. Environmental cracking
- 12. Fatigue
- 13. Exfoliation

Chemical vs. Electrochemical Reactions

- Chemical reactions are those in which elements are added or removed from a chemical species
- Electrochemical reactions are chemical reactions in which **not only** may elements may be added or removed from a chemical species but **at least** one of the species undergoes a change in the number of valance electron
- Corrosion processes are electrochemical in nature

Simplest Example: Dry Cell Battery



(**NH4Cl)Ammonium chloride**: is an inorganic compound with the formula NH_4Cl and a white crystalline salt that is highly soluble in water

Faraday's Law

- The mass of an element discharged at an electrode is directly proportional to the amount of electrical charge passed through the electrode

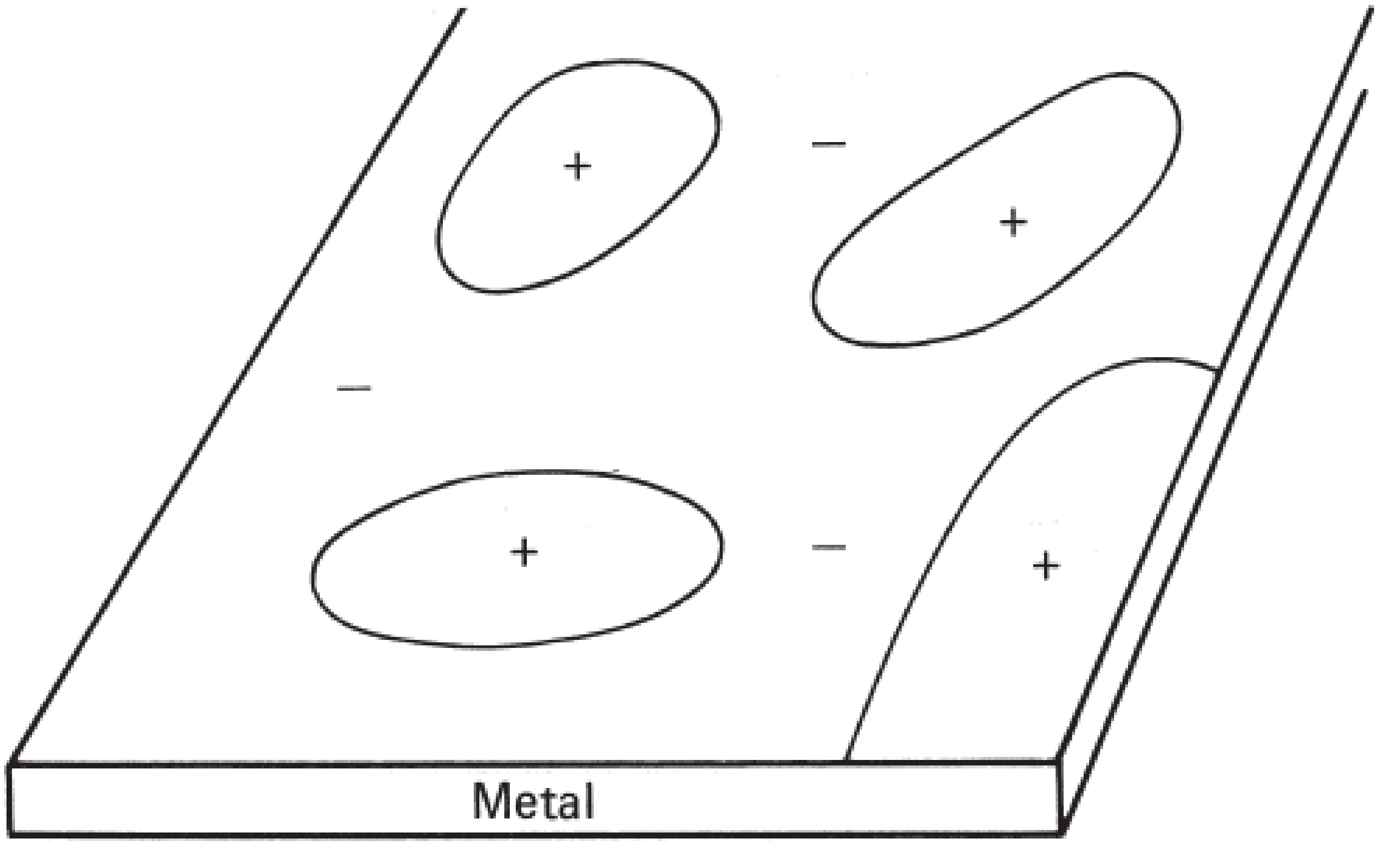
$$\text{weight of metal reacting} = kIt$$

What Happens if the Battery is Not in Use?

- There will be some "local action current" generated by "local action cells" because of other metallic impurities in zinc

- Shelf life of an ordinary zinc-carbon rod battery is limited

Local Action Cell



Anode & Cathode

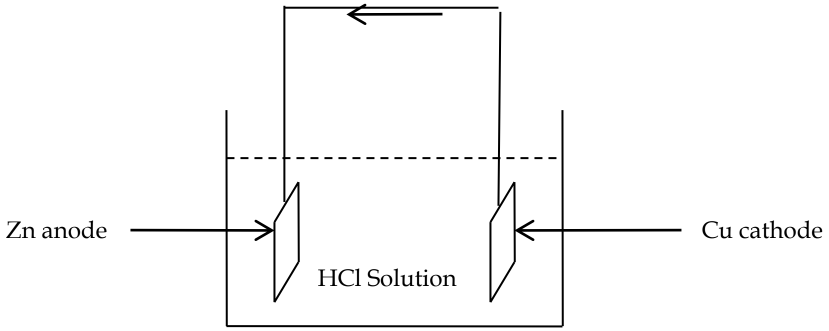
- Anode
  - Loss of electron in oxidation
  - Oxidation always occurs at the anode
- Cathode
  - Gain of electron in reduction
  - Reduction always occurs at the cathode
  - Providing a sacrificial anode to prevent metal degradation

Corrosion Cells

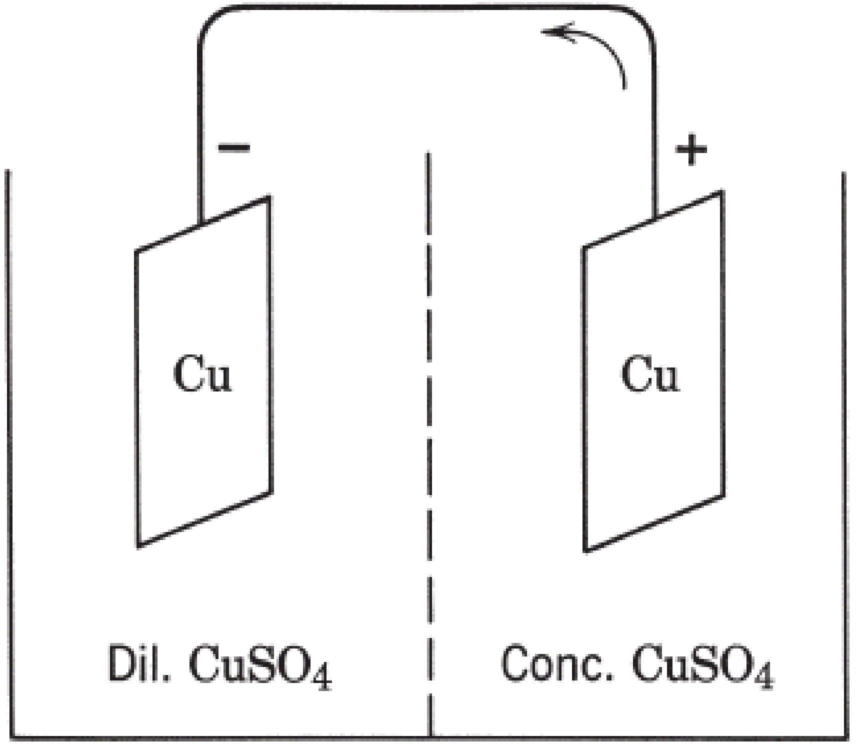
- *Galvanic cell (Dissimilar electrode cell)* – dissimilar metals
- *Salt concentration cell* – difference in composition of aqueous environment
- *Differential aeration cell* – difference in oxygen concentration
- *Differential temperature cell* – difference in temperature distribution over the body of the metallic material

Dissimilar Electrode Cell

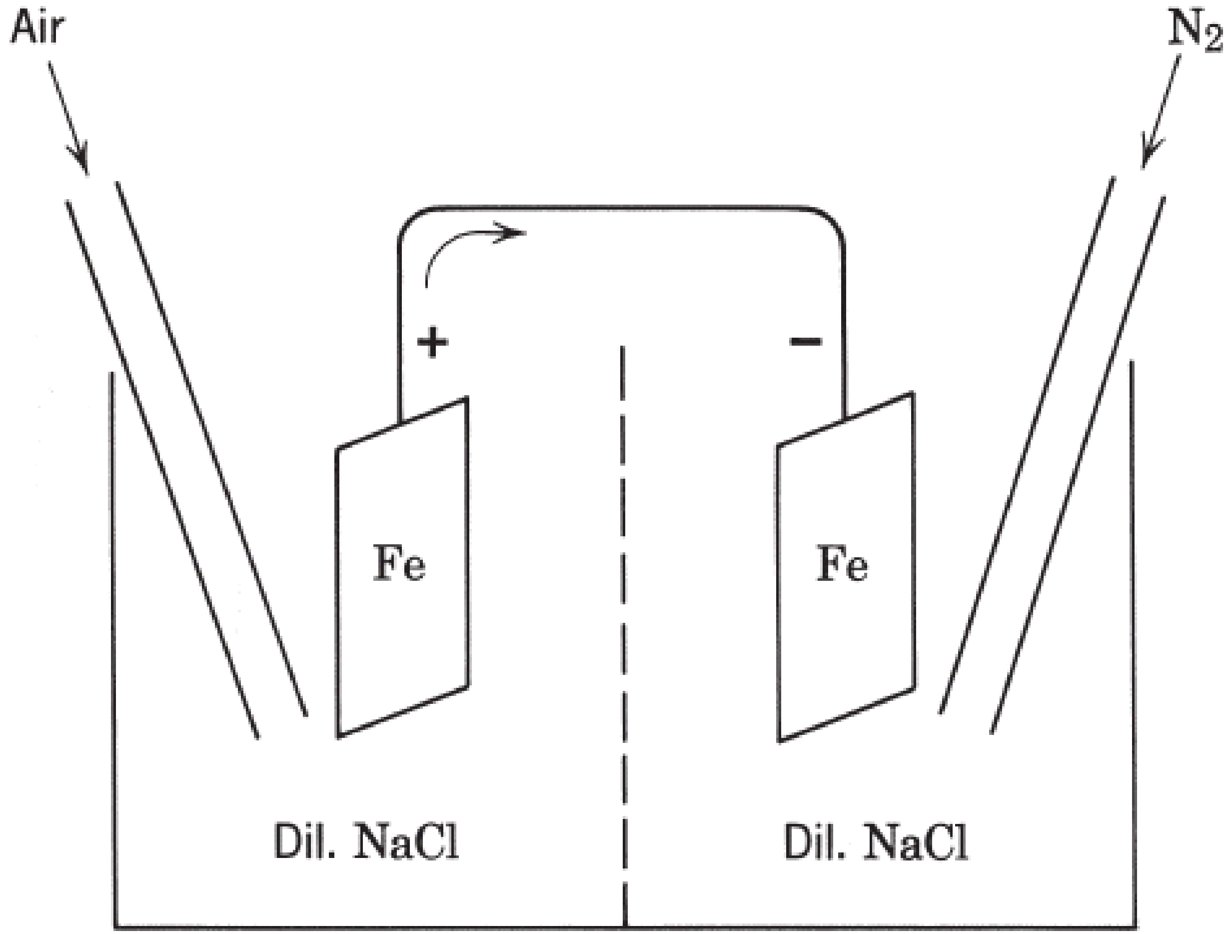
- When a cell is produced due to two dissimilar metals it is called dissimilar electrode cell
  - Dry cell
  - Local action cell
  - A brass fitting connected to a steel pipe
  - A bronze propeller in contact with the steel hull of a ship



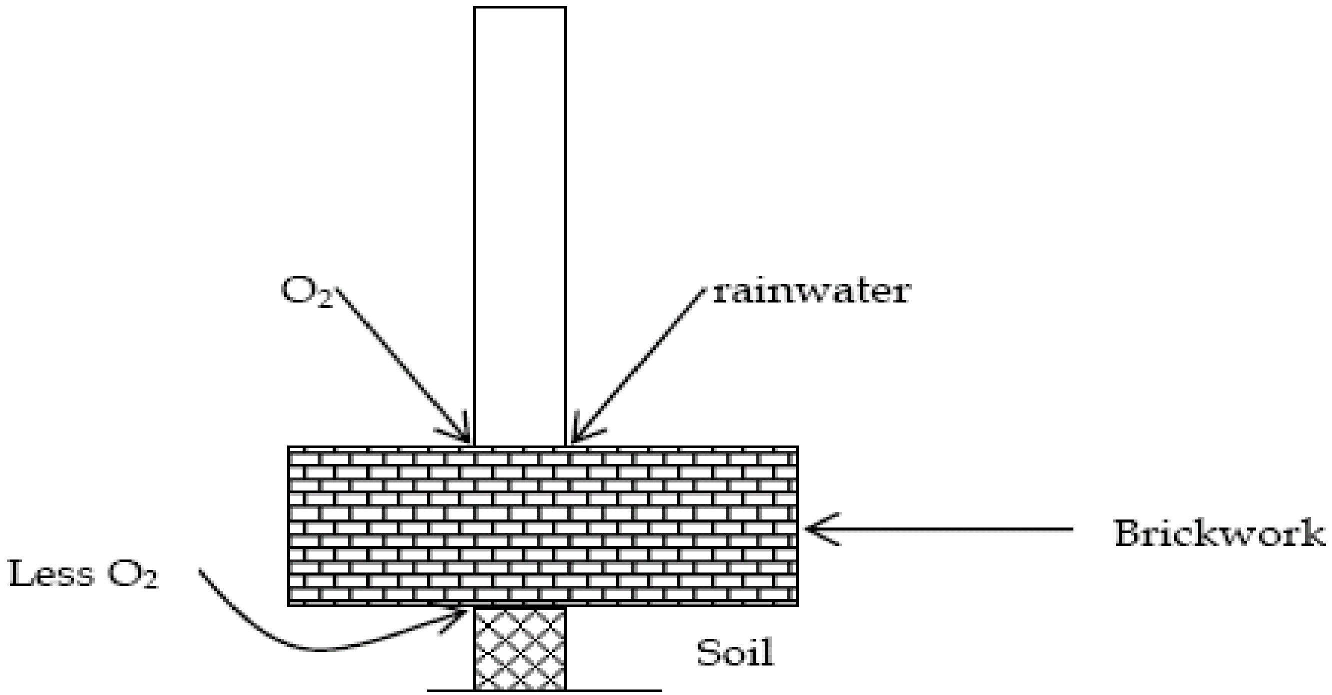
Salt Concentration Cell



Differential Aeration Cell



Corrosion at the bottom of the electrical poles



Differential Temperature Cell

- This is the type of cell when two identical electrodes are immersed in same electrolyte, but the electrodes are immersed into solution of two different temperatures

- This type of cell formation takes place in the heat exchanger equipment where temperature difference exists at the same metal component exposed to same environment

- For example for $CuSO_4$ electrolyte & Cu electrode the electrode in contact with hot solution acts as cathode.

- Cells responsible for corrosion may be a combination of these three types

Forms of Corrosion

1. General corrosion or uniform attack
2. Pitting
    i. Impingement attack or erosion-corrosion
    ii. Fretting corrosion
    iii. Cavitation erosion
3. Selective Corrosion
4. Intergranular Corrosion
5. Cracking
    i. Corrosion fatigue
    ii. Stress corrosion cracking (SCC)

Uniform Corrosion

Corrosion Rate and Classification of Metals

- mm/y – millimeters penetration per year
- gmd – grams per square meter per day
- ipy – inches penetration per year
- mpy – mils penetration per year (1000 mil = 1 inch)
- mdd – milligrams per square decimeter per day

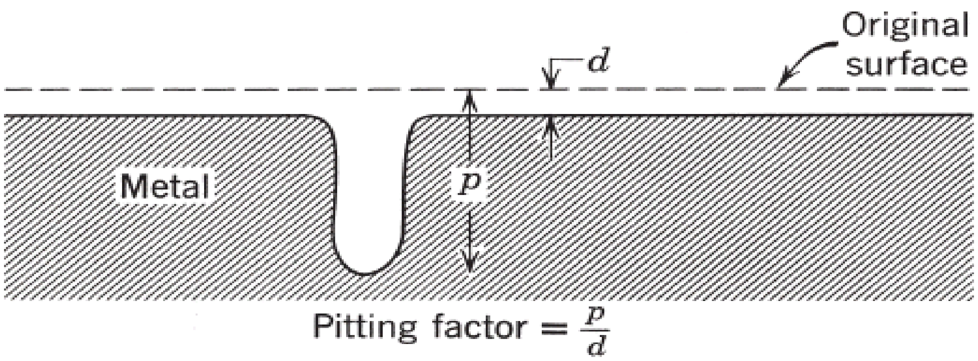
Corrosion Rate and Classification of Metals

- Mils per year (mpy) = 534W/DAT
- mm/y =87.6W/DAT
  - W = weight loss in mg
  - D = density of specimen material in g/cm^3
  - A = area in cm^2
  - T= exposure time in hours

Classification of metallic materials according to their rate of uniform attack

A. <0.005 ipy (<0.15 mm/y) – Metals in this category have good corrosion resistance and can be used for critical parts
B. 0.005 to 0.05 ipy (0.15 mm/y to 1.5 mm/y) – Metals in this group are satisfactory if a higher rate of corrosion can be tolerated
C. >0.05 ipy (>1.5 mm/y) – Usually not satisfactory

Pitting



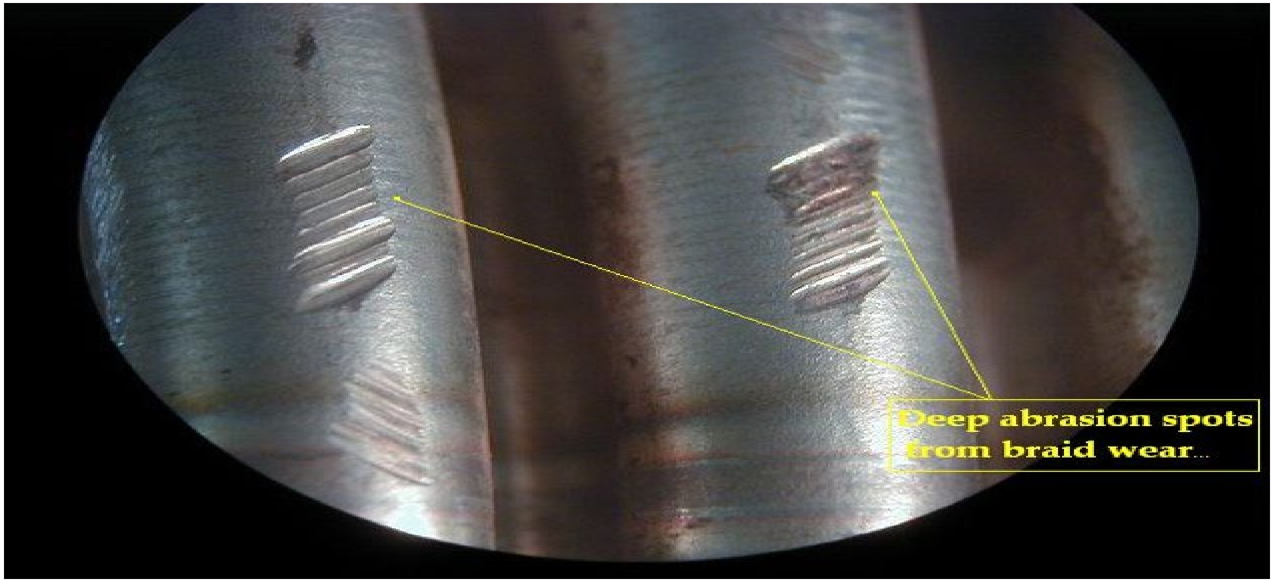
Probably the most common type of localized corrosion is pitting, in which small volumes of metal are removed by corrosion from certain areas on the surface to produce craters or pits that may culminate in complete perforation of a pipe or vessel wall.

Pitting corrosion may occur on a metal surface in a stagnant or slow-moving liquid. It may also be the first step in crevice corrosion, poultice corrosion, and many of It may also be the first step in crevice corrosion, poultice corrosion, and many of the corrosion cells.

Erosion-Corrosion

corrosion is a chemical process that affects metals and alloys, while erosion is a physical process that primarily affects natural materials like rocks and soil through the action of external forces.

Fretting Corrosion



Fretting corrosion is a specific type of corrosion that occurs at the contact interface between two materials under small-amplitude oscillatory relative motion (fretting motion). It is a combination of mechanical wear and corrosion, and it typically happens in small, localized areas, often in the form of microscopic wear debris. Fretting corrosion is known to cause significant damage to metal surfaces, particularly in mechanical systems where there is slight movement or vibration between contacting components.

Cavitation Erosion

Cavitation erosion in oil wells can be particularly problematic in components such as pumps, valves, and chokes, which experience rapid changes in fluid pressure.

The erosion of these critical components can lead to increased maintenance costs, reduced production rates, and potential safety hazards

is caused by rapid changes in pressure, leading to vapor bubble formation and collapse in the fluid

Mitigate Cavitation Erosion

Engineers employ several strategies, such as:

Material Selection

- Using materials that are more resistant to cavitation erosion, such as hardened steels or specialized coatings.

Surface Treatments

- Applying surface coatings or treatments that enhance the erosion resistance of the components.

Reducing Flow Velocity

- Adjusting the fluid flow rates or utilizing flow control measures to minimize the occurrence of cavitation.

Regular Maintenance

- Regular inspection and maintenance to detect and address erosion damage before it becomes severe.

Selective Corrosion

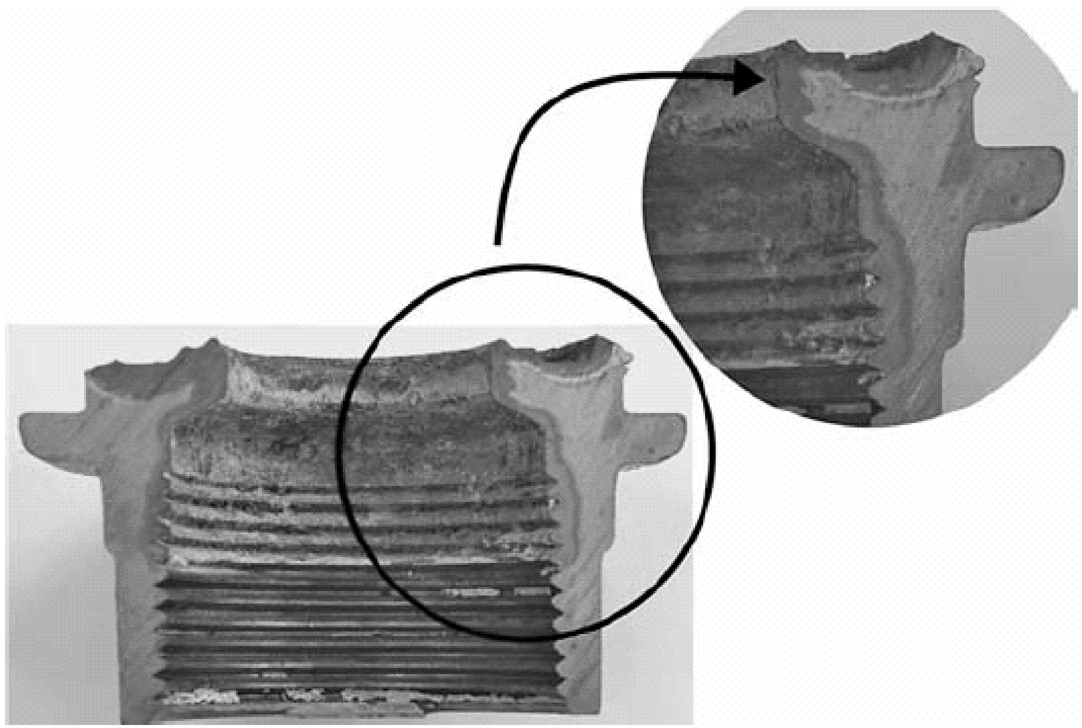


FIGURE 6.35 Layer dezincification of a brass fitting: parent material Cu 59.3 percent, Zn 35.7 percent, Pb 4.9 percent, leached area: Cu 95.0 percent, Zn 0.7 percent Pb 4.1 percent. (Courtesy of Defence R&D Canada-Atlantic)

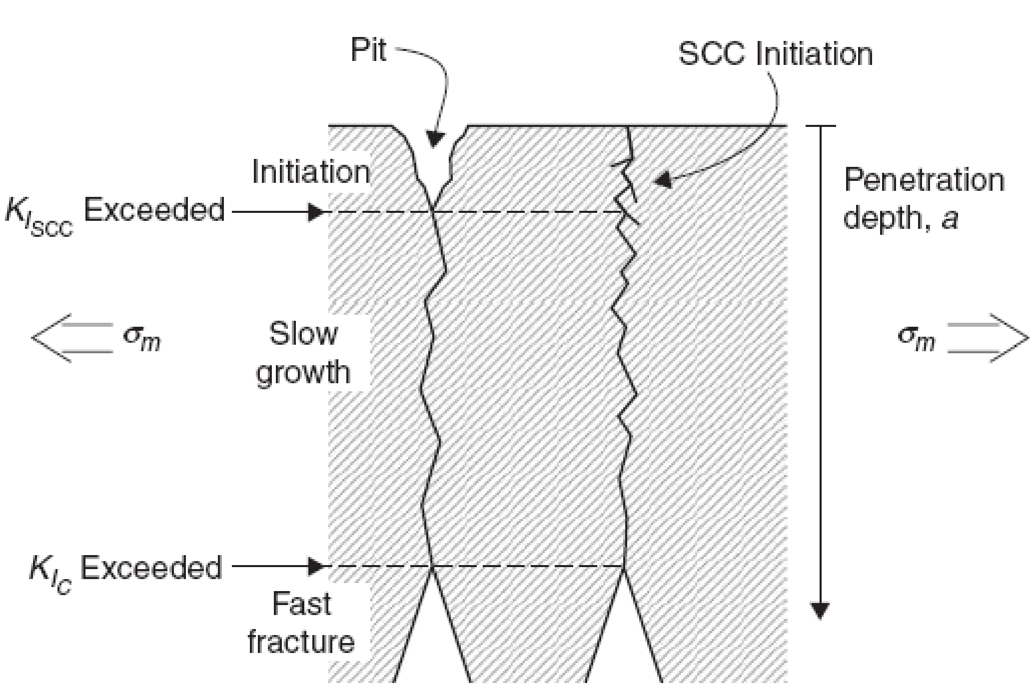
Intergranular Corrosion

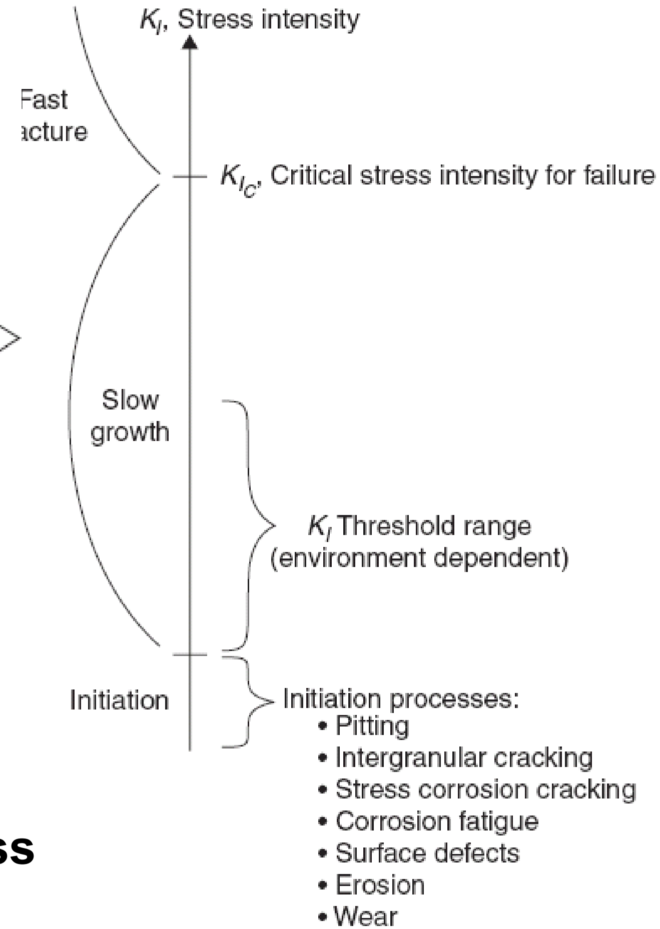
This is a localized type of **attack at the grain boundaries of a metal**, resulting in **loss of strength and ductility**. Grain – boundary material of limited area, acting as anode, is in contact with large areas of grain acting as cathode. **The attack is often rapid, penetrating deeply into the metal and sometimes causing catastrophic failures**. Improperly heat - treated 18 - 8 stainless steels or Duralumin - type alloys (4% Cu – Al) are among the alloys subject to intergranular corrosion. At elevated temperatures, intergranular corrosion can occur because, under some conditions, phases of low melting point form and penetrate along grain boundaries; for example, when nickel - base alloys are exposed to sulfur - bearing gaseous environments, nickel sulfi de can form and cause catastrophic failures. This type of attack is usually called sulfidation .

Corrosion Fatigue

If a metal cracks when **subjected to repeated or alternate tensile stresses in a corrosive environment,** it is said to fail by corrosion fatigue . In the absence of a corrosive environment, the metal stressed similarly, but at values below a critical stress, called the **fatigue limit** or endurance limit , will not fail by fatigue even after a very large, or infinite, number of cycles. A true endurance limit does not commonly exist in a corrosive environment: The metal fails after a prescribed number of stress cycles no matter how low the stress.

SCC





If a metal, **subject to a constant tensile stress and exposed simultaneously to a specific corrosive environment,** **cracks immediately or after a given time**, the failure is called stress - corrosion cracking .

Galvanic Corrosion

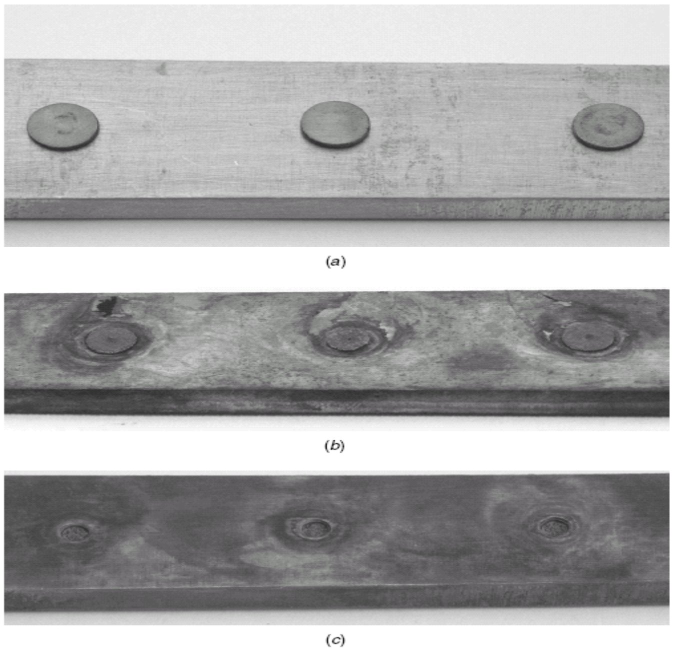


Fig. 2.14. Steel rivets on a copper bar: (*a*) at the start of the experiment; (*b*) 6 months after being submerged in 3% sodium chloride solution; and (*c*) after 10 months in the same solution.

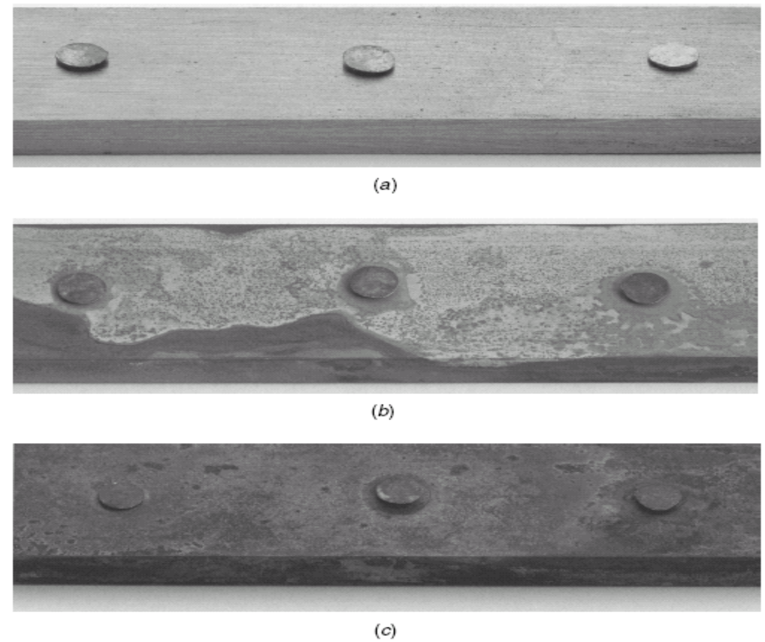
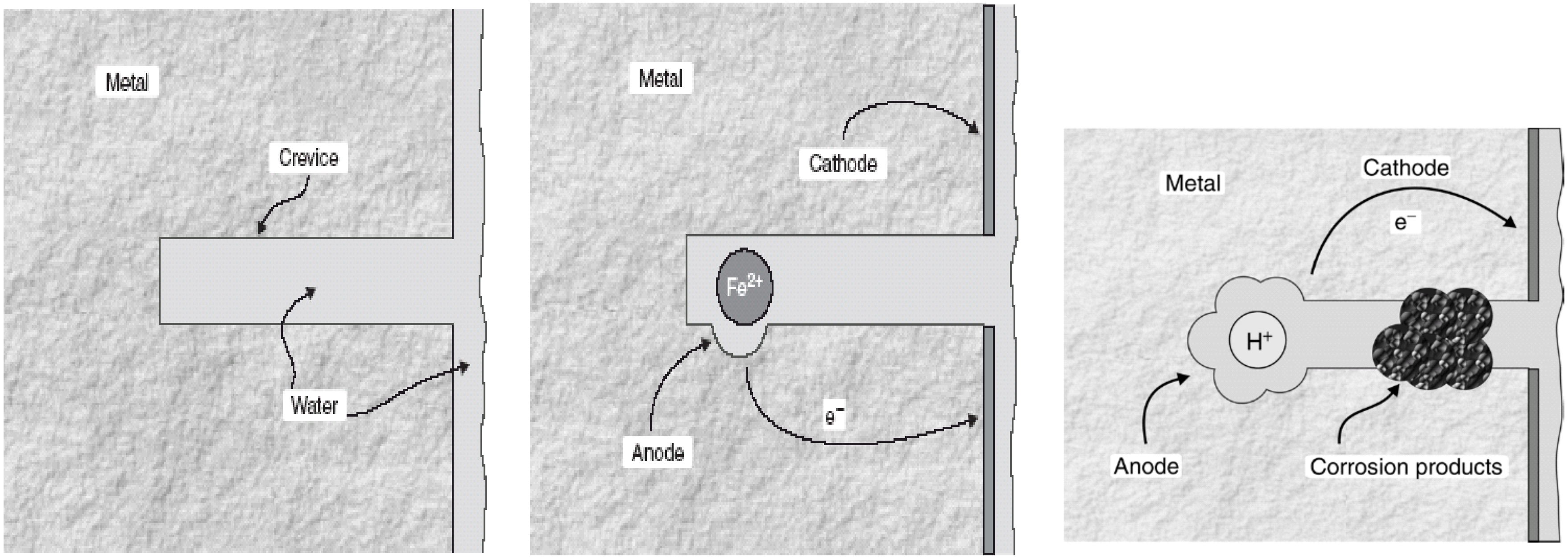


Fig. 2.15. Copper rivets on a steel bar: (*a*) at the start of the experiment; (*b*) 6 months after being submerged in 3% sodium chloride solution; and (*c*) after 10 months in the same solution.

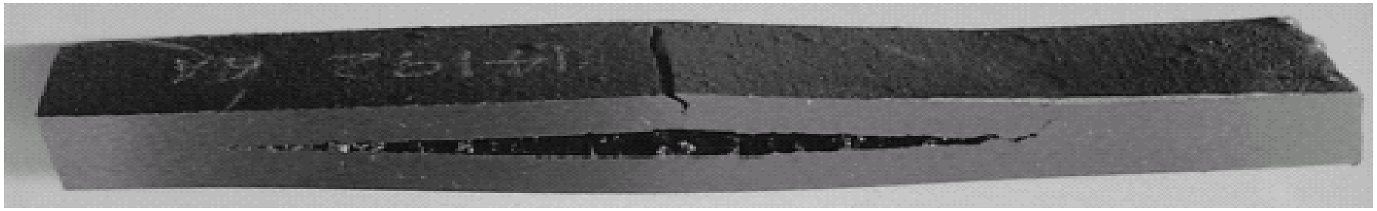
Galvanic corrosion (also called "**dissimilar metal corrosion**") refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte. In a bimetallic couple, the less noble material becomes the anode and tends to corrode at an accelerated rate, compared with the uncoupled condition and the more noble material will act as the cathode in the corrosion cell.

Crevice Corrosion



Crevice corrosion is a form of localized attack that occurs within occluded regions or crevices of metallic components. The attack is caused by an alteration of the conditions within the crevice relative to the bulk solution

Hydrogen Damage

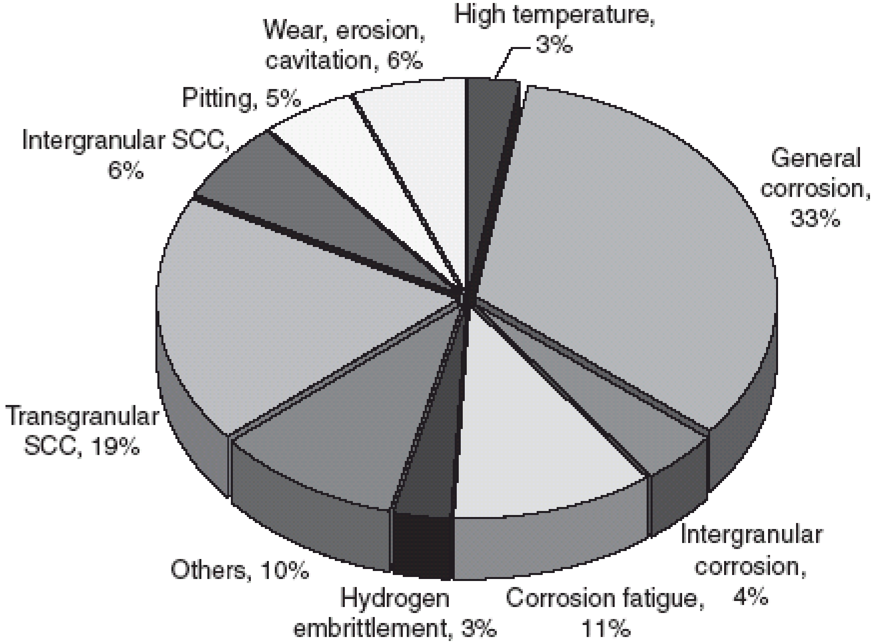


(a)

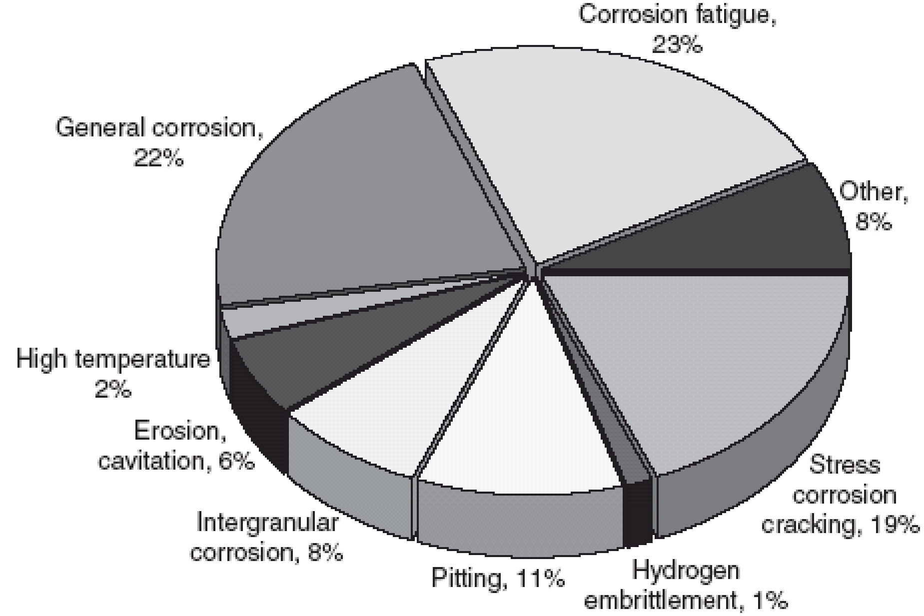
(b)

Fig. 2.29 (*a*) Hydrogen induced cracking with midwall cracks running parallel to the pipeline wall. (*b*) Surface blisters may also contain cracks. (Courtesy of MACAW's Pipeline Defects, published by Yellow Pencil Marketing Co.)

Failure Statistics in Germany (a) & USA (b)



a



b