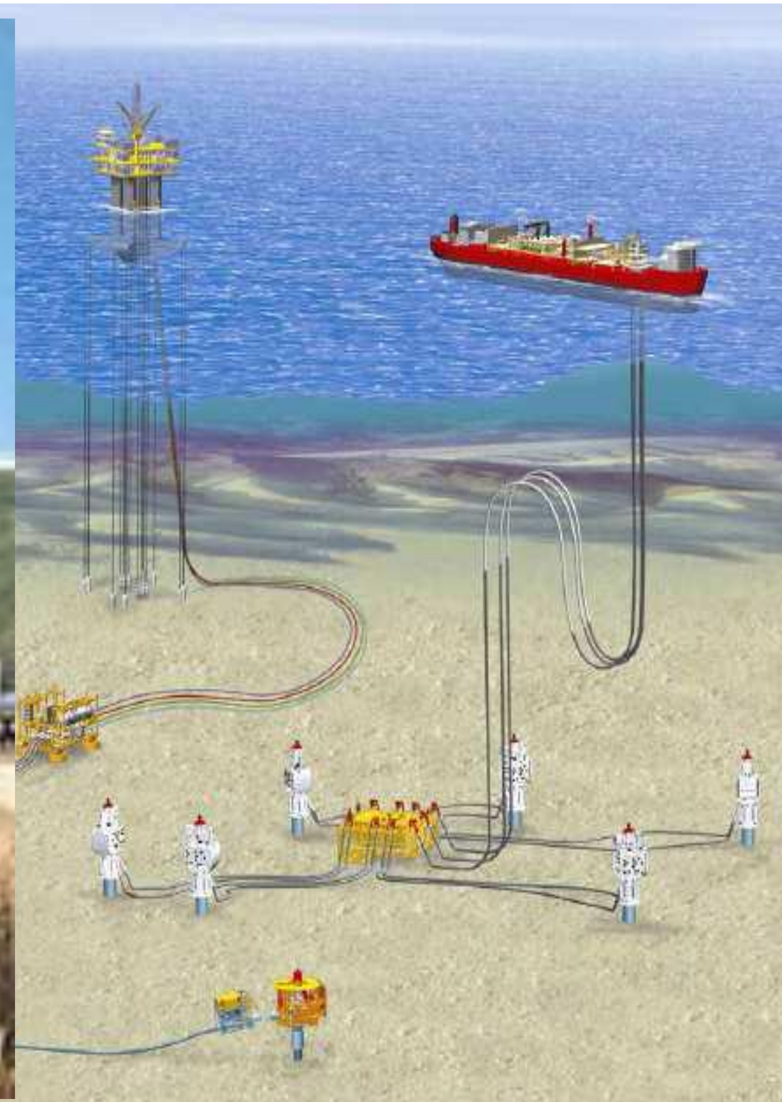
PIPELINE CORROSION



PIPELINES-Various Types

- Flowlines
- Transmission lines
- Distribution lines

ADVANTAGES

- Provides mid-stream function in the oil & gas value chains- join other parts together
- Provide transportation functions
- Safest mode for transportation of oil and gas
- Subject to public scrutiny& regulatory pressure
- Least expensive transcontinental means of transport for gas/oil

SPECIAL FEATURES

- 3-DIMENSIONAL STRUCTURES WITH WELDED SEGMENTS
- OPERATE IN SEVERE CONDITIONS
- CARRY LARGE VOLUME OF FLUIDS OVER VERY LONG DISTANCES
- OPERATIONS CAN BE MONITORED AND CONTROLLED FROM A CENTRAL OFFICE

PIPELINE SYSTEM = PIPES, VALVES, FLOWMETERS ETC

- A PIPELINE SYSTEM IS A COMPLICATED 3-DIMENSIONAL STRUCTURE, COMPRISING OF PIPES, VALVES, PUMPS, DISSIMILAR WELDED JOINTS, PIPEBENDS ETC
- OPERATING CONDITIONS ARE USUALLY VERY SEVERE-INTERNAL PRESSURE, CYCLIC LOADING(VIBRATION), INTERNAL AND EXTERNAL CORROSIVE ENVIRONMENTS.

STEEL PIPES

PLASTIC PIPES

STEEL PIPES

- IMPORTANT CIRCULAR COMPONENT WHICH CAN BE IDENTIFIED AS A NOMINAL PIPE SIZE(NPS) INCHES OR DIAMETRE NOMINAL (DN) METRIC UNITS.
- WALL THICKNESS CAN BE IDENTIFIED IN ONE OF THESE WAYS. STANDARD WEIGHT(STD) ASME CLASS 150 & 300; EXTRA STRONG (XS ASME 600); DOUBLE EXTRA STRONG (XXS)ASME CLASS 900>

VALVES

- PARTS OF PIPELINE SYSTEMS WHICH REGULATE, DIRECT OR CONTROL THE FLOW OF FLUIDS BY OPENING, CLOSING OR PARTIALLY OBSTRUCTING THE PASSAGEWAYS
- USUALLY RATED FOR MAX TEMP. & PRESSURE BY MANUFACTURERS. ALSO WETTED MATERIALS OF VAIVES ARE IDENTIFIED.
- NEVER USE VALVES ABOVE RATED TEMP. & PRESS. ENSURE COMPATIBILITY OF FLUID AND WETTED MATERIAL.

PIPELINE CORROSION

- Leading causes of failure in all pipelines- could be leaks or ruptures & fatal
- Total loss can run into billions of dollars
- Liquid release leading to environmental probs.
- Gas release with attendant fire & explosion
- From info pattern of failure has been consistent & not related to age of pipelines
- Confirms the effectiveness of control measures

CORROSION INFORMATION

- More failures recorded in liq. Than gas pipes
- Corrosion & protection well understood in terms of science & technology deployed
- However, corrosion of pipelines is very complicated. WHY?
- Environment of buried pipelines not well understood, variations in O_2, moisture & chemical composition in soil along route. These also vary with time.

Complicated Corrosion

- Coatings can bicom disbonded, allowing ground H_2 O to contact steel & also shield cathodic protection current.
- Disbonded coating will prevent above ground survey detection of corrosion.
- Stray current from adjacent structures can interfere with cathodic protection system
- Visual inspections require excavations

Definitions

- Corrosion is extractive metallurgy in reverse –
- Degradation of materials of construction
- Aqueous corrosion of metals is electrochemical
- Eg, $Fe \rightarrow Fe^{2+} + 2e^-$ (1) Anodic rxn

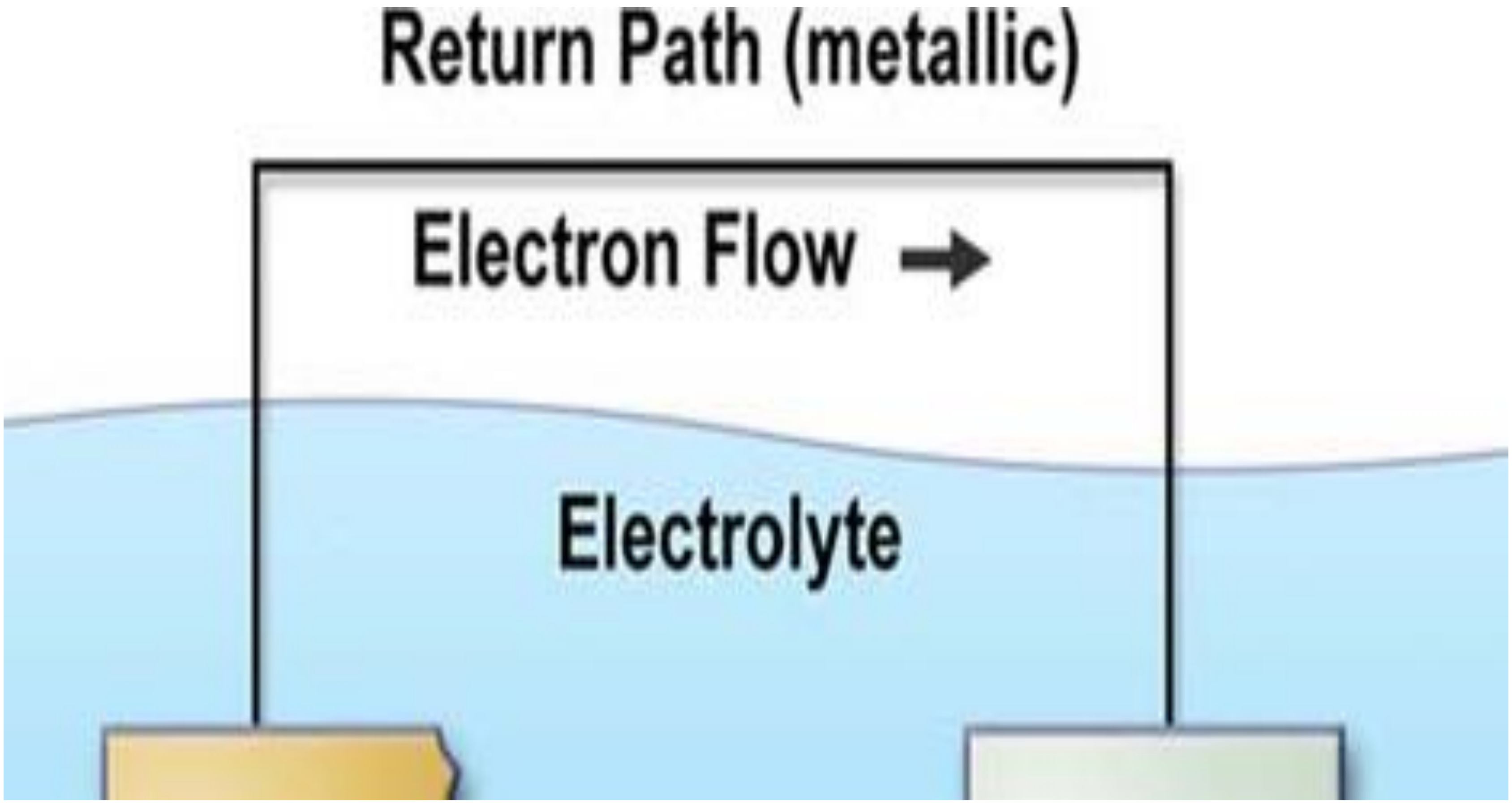
  $O_2 + 2H_2O + e^- \rightarrow 4OH^-$ (2) or

  $2\,H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (3)

equations 2 & 3 are possible cathodic rxns.

- Movement of ions in the electrolyte complete the circuit & Fe^{2+} can rxt with $2OH^-$, S, CO_2 etc to form rust contaminated or otherwise.

Basic Corrosion Cell



Types of Corrosion

- For a pipeline the anodes and cathodes may be next to each other or separated by many metres.
- Electrolyte will be grnd. Water or moist soil for onshore & sea water for offshore.(external)
- For internal, electrolyte will saline formation water, H_2S and/or $CO_{2.}$
- Generally there are 2 types, general and localised corrosion.

Pitting Corrosion

Pitting

- Corrosion in pipelines usually manifests as pits
- Why? Anode area bicoms acidic due to rxn b/w Fe ion & hydroxyl leaving xs H ions. On the other hand cathode area bicoms alkaline. Formation of passivating film can occur leading to reduction in corrosion rate. If FeS is formed, corrosion rate increases. FeS is electronically conducting. If iron carbonate is formed, at relatively high temp., passivation may occur but can lead to mesa corrosion

Mesa Corrosion

Mesa Corrosion

- Special type of pitting corrosion when CO_2 & water are present in pipelines.
- CO_2 & water form carbonic acid; acid corrodes pipeline
- At a critical temp., called scaling temp., carbonic acid forms $FeCO_3$ with steel the layer is protective.
- Problem arises when damages to the layer occur which will result in severe pitting of the less noble underlying metal.

Mesa Corrosion

- Corrosion rates of about 10 -20mm/yr have been observed in practice.
- This localized attack produces mesa-like features , the surface profiles of which look like the mesas produced in rock by wind and water erosion.
- To mitigate avoid flow regimes greater than 10m/s in pipelines.

Selective Seam Corrosion

- Although seamless pipes have been used in some systems, most line pipe contains a longitudinal weld, or seam.
- A submerged-arc weld contains a filler metal that has a composition slightly different from that of the body of the pipe.
- the heat-affected zone next to the weld metal has a microstructure different from that of the rest of the pipe.
- With favourable conditions, Micro corrosion cells can thus be set up.

Microbial corrosion

- Corrosion processes are accelerated by activities of microbes.
- Aerobic and anaerobic bacteria; while first thrives in the presence of O_2, the reverse occurs with the other- anaerobic
- In oil fields & pipelines, have srb- sulfate reducing bacteria and sob sulfur oxidising bacteria. srb reduces sulfate to sulfide, FeS.
- $SO_4^{2-} + 4H_2$ □ $S^{2-} + 4H_2O$; H comes from corrosion rxn or from cellulose or sources in the soil

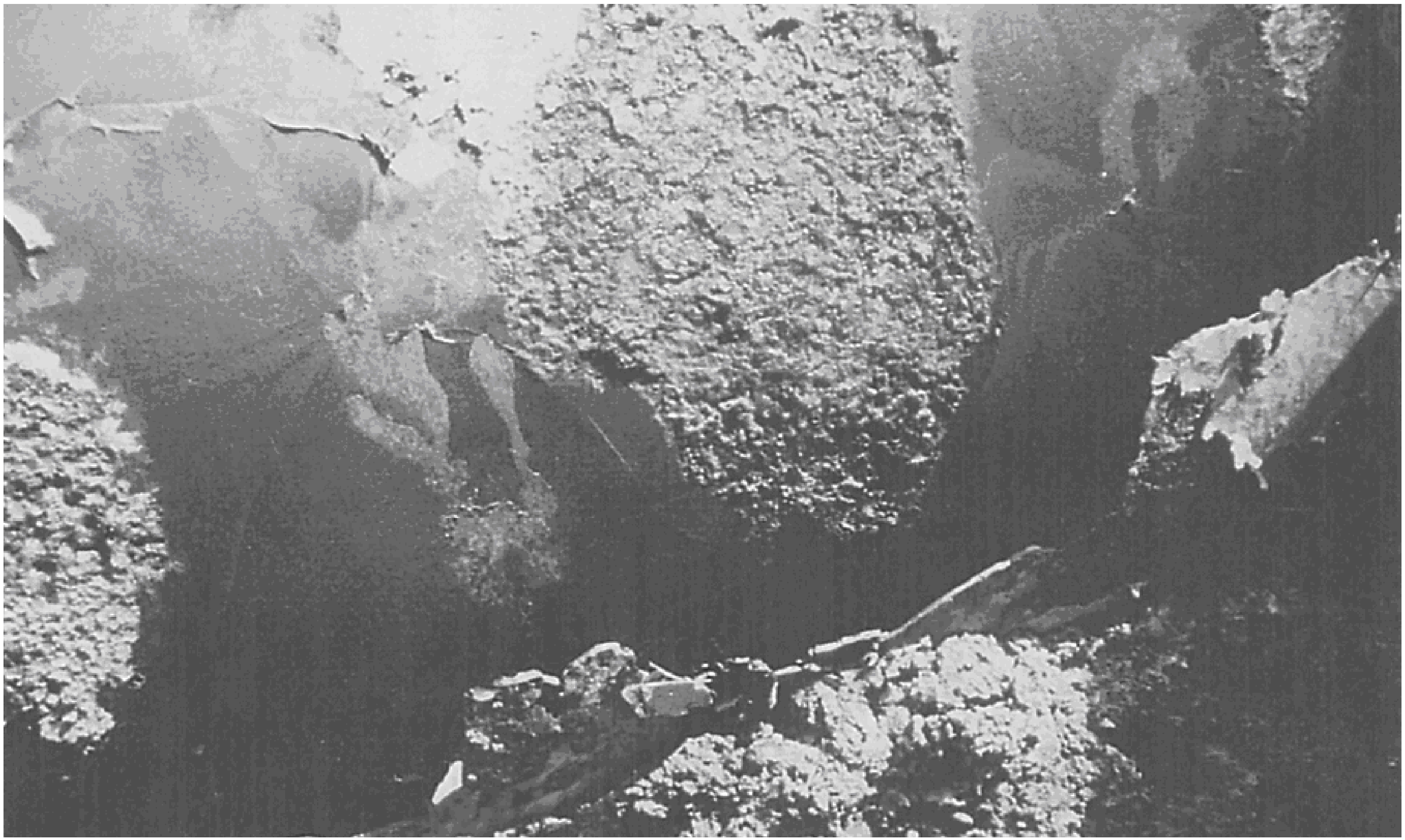
Sulphur Oxidising Bacteria

- $2S + 3O_2 + 2H_2O$ □ $2H_2SO_4$
- thiobacillus thioxidants are capable of oxidising elemental S or S containing compds to H_2SO_4
- thrives at low pH & can produce localised H_2SO_4 up to 5% by wt. –extremely corrosive condition
- requires S for its existence hence found in Sulfur fields, oil fields, sewage disposal pipings & others which contain organic waste products.

SOB

- srb and sob can operate in cyclic fashion when soil conditions change. In wet season, soil is moist and O_2 excluded srb functions rapidly; dry season when O_2 can enter soil sob takes over causing extensive corrosion damage.
- to remedy use cathodic protection & coatings

Disbonded Coating Associated with MIC



Mitigating External Corrosion

- Primary method of preventing or mitigating external corrosion on buried pipelines involves a combination of cathodic protection and coatings.
- Cathodic protection involves applying a current to the pipeline through the soil from an external source and rendering the entire exposed pipeline surface cathodic.
- Coatings function to separate the steel from the electrolyte, and thus prevent corrosion.

Cathodic Protection

- Draw E/logi diagram.
- Raise E_{cor} to A, Fe dissolves more ie anodic rxn increases, cathodic rxn decreases.
- Flood corroding surface with electrons ie depress E_{cor} to B, anodic rxn decreases, & cathodic rxn increases.
- Depress E_{cor} further to E_{fe} iron will not corrode.
- This is the principle of CATHODIC PROTECTION

Over Protection

- However, lowering of the potential below E_{Fe} leads to over protection. Such is of no benefit in as much as corrosion control is concerned. In addition, a greater expenditure on current than required for full protection is needed.

Cathodic Protection & Coatings

- Usually, cathodic protection is used in conjunction with coatings.
- In such instance, the current demand for protection is low.
- While the coating affords the majority of the protection, current from the cathodic protection system protects flawed and damaged regions of the coatings where the bare metal is exposed to the corrosive environment.

Powerful Tools in Corrosion Protection

- As the coating deteriorates with time in service, the cathodic protection is activated to provide more current to protect the damaged regions. Thus, the conjoint use of coatings and cathodic protection is an eminently powerful tool in corrosion control.
- The rates of both cathodic reactions i.e. hydrogen evolution and oxygen reduction, are increased during cathodic protection.

Avoidable Problems

- Since rates of both cathodic rxns increase, the environment becomes more alkaline.
- D4 avoid use of alkyds & oil based paints. They are saponnified by alkalis. Instead use epoxy coatings and bituminous coatings.
- when hydrogen evolution is the cathodic reaction. Rxn takes place on the bare metal at holidays in the coatings. Rapid evolution of H_2 during over-protection will blow off coatings creating larger regions to be cathodically protected.

More Associated Problem

- In high strength steels, hydrogen generated on such surfaces may enter into the metal causing what is known as hydrogen embrittlement. These problems only occur when the cathodic protection is badly designed or during an over enthusiastic operation of the system which normally leads to wasteful over-protection.

Environments where Cathodic Protection is Applicable

Electrolytic conducting environments. E.g structures in sea water such as piers, jetties, pipelines, production platforms, ships.

Soils – Buried pipelines, piling of buildings etc.

- In all cases cathodic protection can be used to protect against general, microbial, stress corrosion cracking, pitting, and cavitations etc

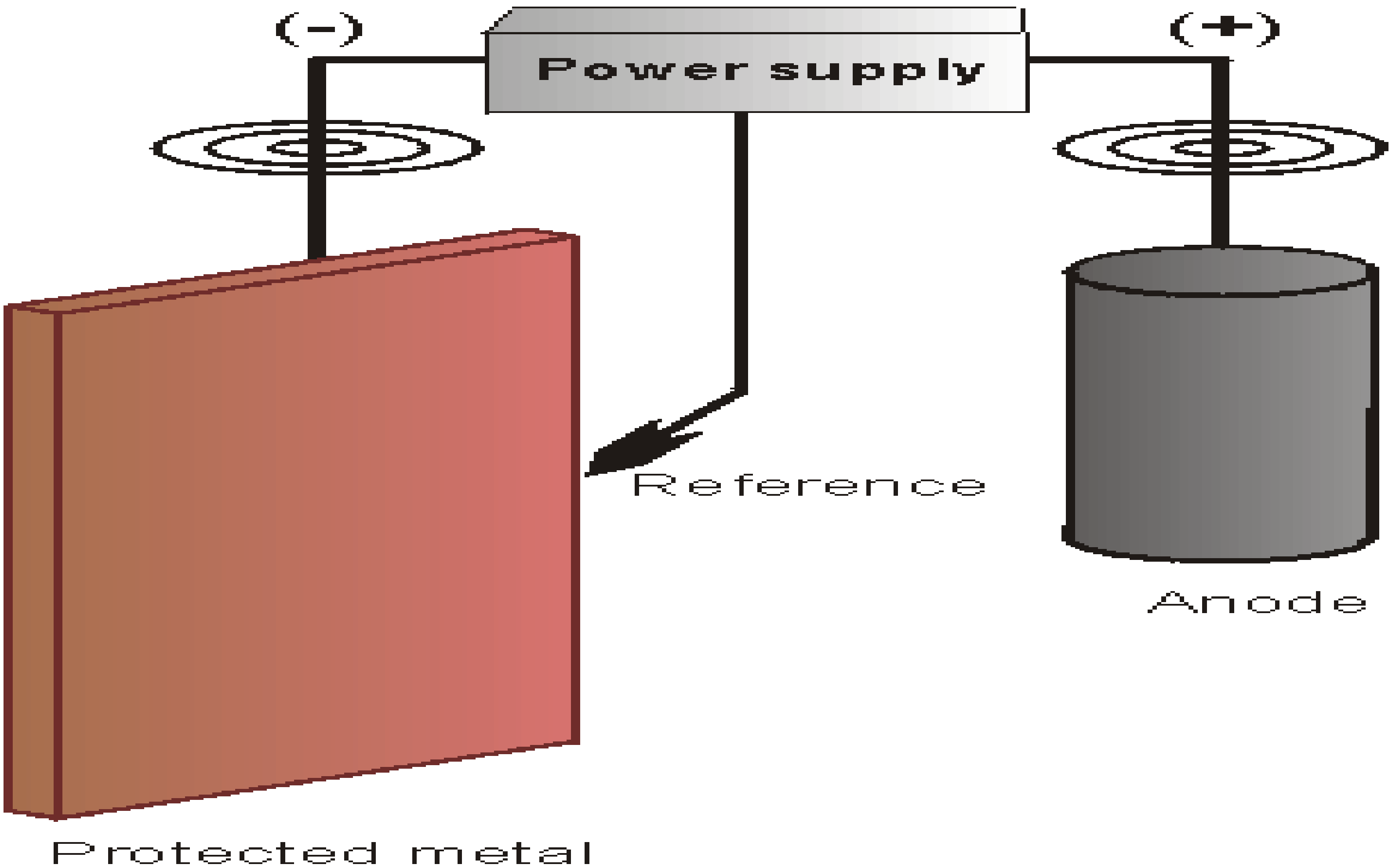
Application of Cathodic Protection

- Two methods: Impressed current technique and sacrificial anode method.
- Impressed current- the current is forced in, or impressed through an auxiliary anode from an external source of power.
- Sacrificial anode- practical use of Galvanic corrosion.

Impressed current

- The current is delivered to the structure from a dc power source through an auxiliary anode.
- Structure will act as a cathode in the cell formed and, in the presence of an anaerobic aqueous environment will sustain the hydrogen evolution reaction.
- If the solution is aerated, the reduction of oxygen becomes possible and may occur in place of, or together with the hydrogen evolution reaction depending on the potential to which the structure is depressed.

SCHEMATIC DESCRIPTION OF AN ICCP SYSTEM



Sacrificial Anode

- Galvanic cell is formed between the structure and the sacrificial anode in which electrons pass spontaneously from the latter to the former. Thus the source of the electrons (the sacrificial anode) must have a more negative electrode potential than the structure.
- When sacrificial anode is attached to the structure, which now bicoms the cathode will sustain the hydrogen evolution and/or the oxygen reduction reaction.
- The anode dissolves and may be said to be scarified in favour of protecting the structure.
- Hydrogen evolution will usually only occur when magnesium alloy anodes are used.

Sacrificial Anode materials

- Galvanic cell is formed between the structure and the sacrificial anode in which electrons pass spontaneously from the latter to the former. Thus the source of the electrons (the sacrificial anode) must have a more negative electrode potential than the structure.
- The cathode(Pipe) will sustain the hydrogen evolution and/or the oxygen reduction reaction.
- The anode dissolves and may be said to be scarified in favour of protecting the structure.
- Hydrogen evolution will usually only occur when magnesium alloy anodes are used.

Design features in CP

Essentials are:

- estimate anode output & life span
- From above, calculate anode spacing and hence number of anodes to protect the entire structure

The anode current output can be obtained from Ohm's law: $\Delta V = I_a R$ Where ,

$\Delta V = E_{\text{Protection (steel)}} - E_{\text{working (anode)}}$

E_{protn} is determined by designer; its value must be adequate to protect over its life expectancy.

Other variables

- $E_{working\ (anode),}$ value is supplied by manufacturer
- R, is the anode resistance. Usually calculated using standard formulae which depend on the shapes of the anode in addition to resistivity of the environment.
- for slender, stand-off anodes (at least 30cm from structure),
- $R = P\ (\ln \frac{4l}{r} - 1)/2\pi l$
- Where P is the resistivity of the environment, l is the length of anode, r is the radius of anode

SA – Other Shapes

- Flush mounted plate anodes, for which

  $R = P/2S$, where S is the mean length of the sides of the anode

- For bulkier shapes, $R= P/0.58A^{0.727}$

  or $R = P\ 0.315/A$, where A is the exposed area of the anode.

- In reality, the formulae give differing results. The choice of a formula is thus, a matter of experience with a particular anode design.

Anode Current, I_a

- I_a is usually calculated for the dimensions of the anode when it is 40% consumed.
- We can obtain values for the followings: the anode current output, $I_{a.,}$ the current required to protect a unit area of bare structure (steel), I, the area of the structure at risk.
- Calculate the number of anodes required to protect the structure or if the structure is coated, the number of anodes to protect it, assuming, X% deficiency in the coatings.

Number of Anodes

- the spacing of the anode can be determined to give an approximately uniform current density over the structure.
- If i is the current density needed for the desired protection, then,
- $i = I/A$, where A is area of the structure at risk.
- Thus, $i \times A = I$ (structure)
- i, current density for protection are usually given. $I_{structure} / I_{anode}$ = no of anodes

Anode Lifetime

- The anode lifetime, L can be obtained using Faradays laws: $L = W/ I_aE \times U$, where W is the weight, in gm, of the anode, I_a is the anode current output in amperes, E is the capacity of the anode in Kg/A year and it depends on the equivalent weight of the anode material and its efficiency, etc.
- U is the utilization factor. It is the amount of material consumed compared to the initial weight when the remaining material fails to deliver current. Usually, U is taken as 0.9

Coatings

- Pipeline coatings have undergone dramatic technological changes over the decades.
- Coatings now must perform at higher in-service operating temperatures, must not be damaged in handling, during construction or in operation by soil stress or soil movement, and must provide exceptional corrosion protection.
- Coatings also must be user friendly and must be able to be applied in a mill or in the field.
- From Asphalt, bituminous to PE, FBE etc.

Field Applied Joint Coating

Procedure for Coating Application

- There are standard procedures which must adhered to in order to prevent failures.
- Grit blast to agreed std e.g Sa3, 2 or 1, after removal of dirt and grease. Vacuum clean to remove dust.
- Conversion coat with chromating solution for added corrosion protection
- Apply coating as per manufacturers' direction. Avoid application in inclement weathers
- QA procedure demands that each step conforms to std. Do it once and do it correctly.

Shrink Sleeve Application

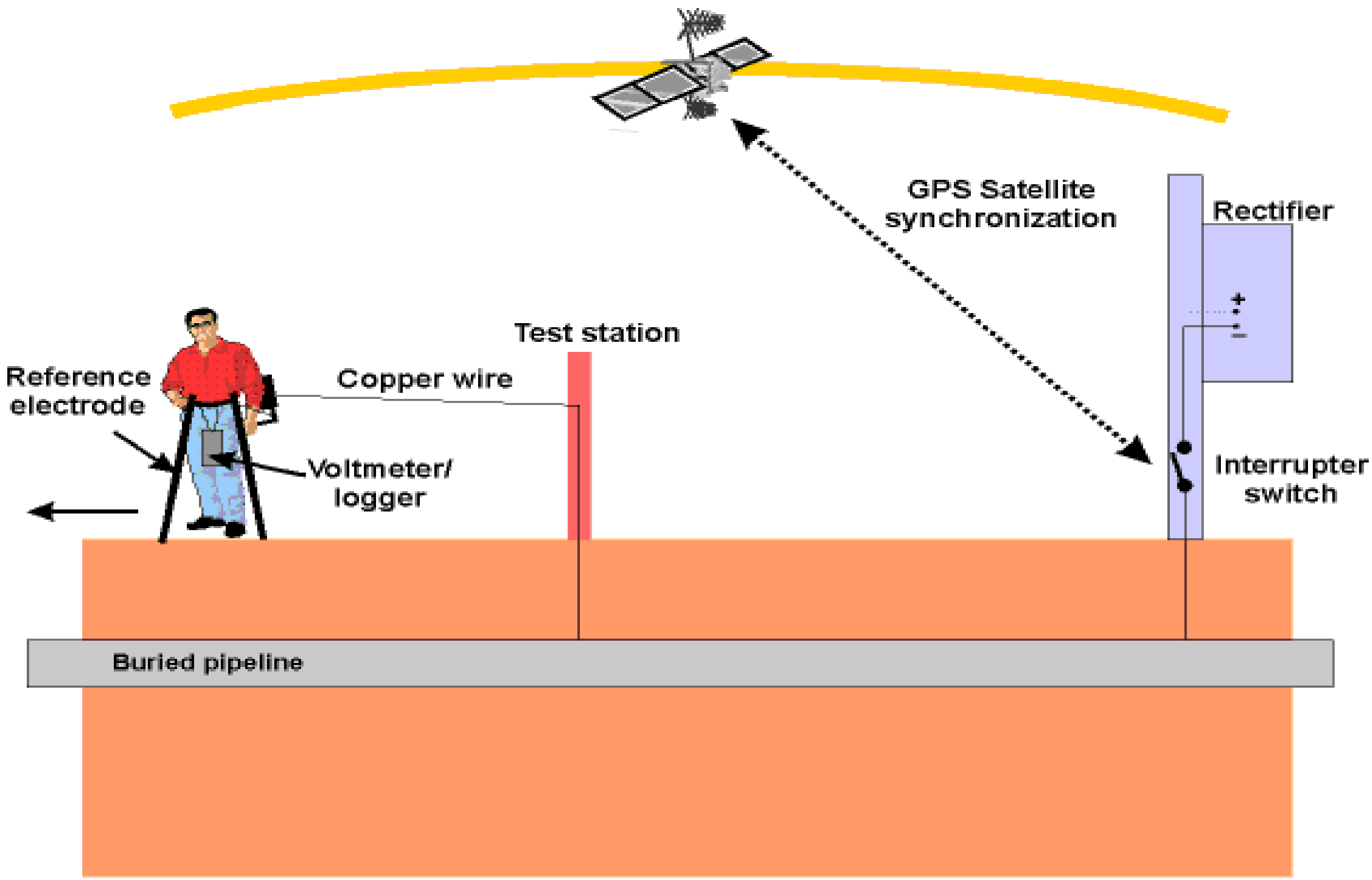
Recent Developments in Coatings

- The use of thermal sprayed metallic coatings (Aluminum and Zinc) has been gaining popularity in submerged offshore applications, including some pipelines.
- Offers the benefits of low cost with excellent corrosion protection over a wide range of temperature and conditions.
- Do provide a measure of cathodic protection, they still require supplemental anodes. These coatings are still under development, expect to see continued progress.

Monitoring External Corrosion

- Monitor pipe to soil potential using $Cu/CuSO_4$ reference electrode
- experience has shown that a value more negative than –850 mV or at least 100 mV more negative than the native (freely corroding) potential is indicative of no significant corrosion
- If MIC is involved, a potential of –950 mV or a shift of at least 300 mV is recommended.
- Potential reading for cathodically protected pipeline systems must be taken annually.

Pipe to Soil Potential Survey



Mitigating Internal Corrosion

- Corrosion generally cannot occur in a pipeline unless there is an electrolyte.
- Water or other aqueous materials (such as glycols from dehydration processes) must be present & wet the internal surface of the pipeline.
- Other chemicals usually present are:CO_2 for the formation of dilute organic and inorganic acids or sulfur compounds, hydrogen sulphide, for the formation of acid or growth of bacteria.

Internal Corrosion of a Pipeline

Dehydration of Fluids

- Best available method is to remove the water contents, physically or chemically
- Various methods are available for both gas and liquid hydrocarbon, e.g gravity, use of dehydrating salts, pigging to remove water from low spots etc. Use scrubbing for gas.
- These methods are not 100% efficient, possibilities exist for water in the pipes.

Inhibitors

- Inhibitors reduce the rate of corrosion by adsorbing on to the metal surface or react with it to form a protective film.
- Many different chemicals are available commercially. Choice will depend on the type of product in the pipeline. Other considerations include cost, availability, toxicity, and environmental friendliness
- Inhibitors employed in the oil/gas industries are mostly organic compounds containing electron – rich centres, like N, S, O.

Other Preventive Methods

- Internal coatings- very adequate but could led to massive failures if coatings or liners are damaged.
- Cleaning pigs can effectively direct both liquids and corrosive solids to pig traps for removal from the pipeline.
- Biocides can be used in the pipeline to inhibit the corrosive actions of microbes that cause MIC and thereby reduce or eliminate MIC.
- Design features to trap contaminants e.g separators & drip legs.

Monitoring Internal Corrosion

- Use removable corrosion coupons placed in susceptible areas. Not very effective. Could be placed at low points, but electrolyte may be a thin film.
- Others are conductivity probes to detect presence of electrolytes &pH probes. All fall short of giving replicable data.
- Permanently placed ultrasonic measuring probes can be utilized to measure the pipe wall in areas believed to be at risk for internal corrosion. Cannot detect pitting, & gives false confidence.

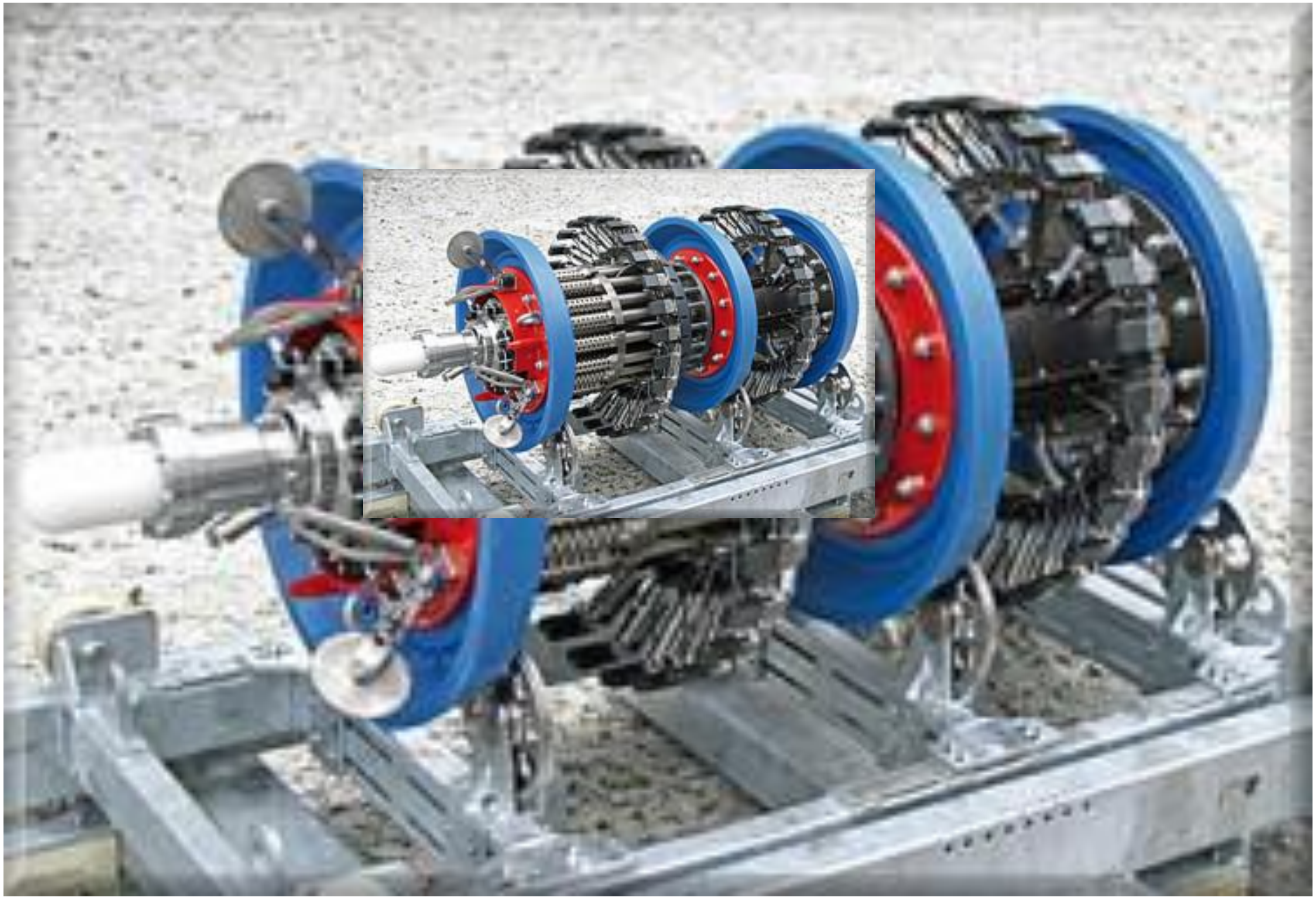
Corrosion Damage Assessment

- Structural integrity pipelines can be assessed by:
- In- Line-Inspection (ILI), Direct Assessment (DA) and Hydrostatic Testing
- All have advantages and disadvantages in terms of costs and information provided by the different methods.
- ILI is expensive, Direct assessment will involve excavations at probable corroded areas while Hydrostatic testing has least expensive direct costs but cumbersome & high operational costs.

In –Line Inspection

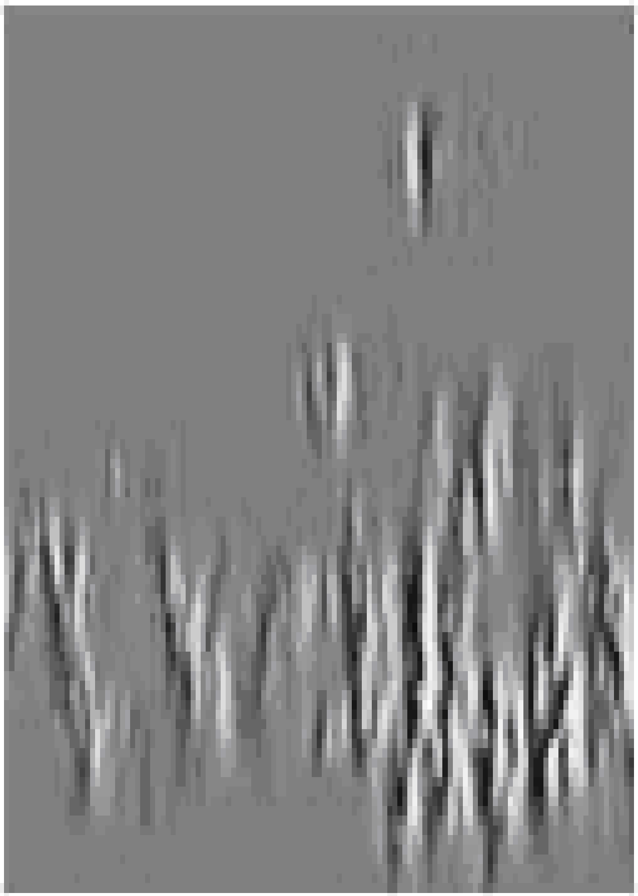
- ILI tools are referred to as pigs (pipeline inspection gauges). Different types:
- Caliper, or geometry, tools measure the internal dimensions of the pipeline and are used to identify locations where the pipe may be out of round or exhibit dents or wrinkles..
- MFL tools, induce a magnetic field into the pipe wall. At any change of wall thickness, such as would be caused by corrosion or cracking, some of the flux will leak from the pipe and can be detected by the tool's sensors.

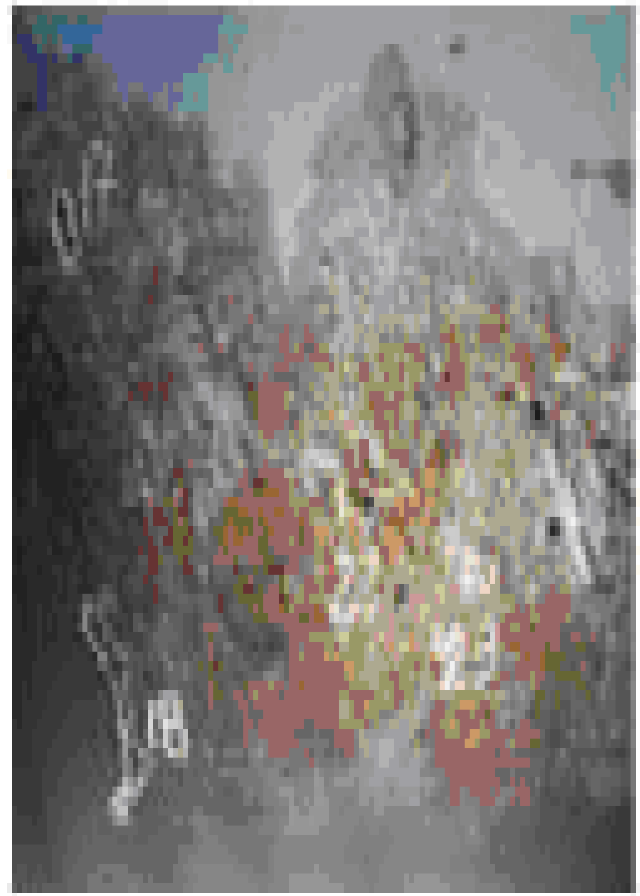
Geometry Inspection Tool



Magnetic Flux Leakage (MFL)

Info from MFL(left image from software & right, micrograph of actual corroded site.





Info from MFL Tools

- MFL tools can be low or high resolution, depending on the number and the sensitivity of their magnetic pickup points. The low-resolution tool enables general sizing of pitting and indications.
- The high resolution tool permits a more precise determination of the pit depth and length so that the remaining pipe strength can be calculated.

Hydrostatic Testing

- Hydrostatic testing involves filling a section of the pipeline with water and pressuring it to a level significantly above the normal operating pressure.
- Main purpose is to detect and remove joints of pipe that contain defects, such as corrosion pits or cracks, by causing them to leak or rupture to demonstrate the structural integrity when the pipe passes the test. It also is used to determine whether leaks exist in the pipeline
- Provides 100 percent inspection.

Direct Assessment

- DA four steps, the first two of which are directed at selecting appropriate excavation sites:
- Pre-assessment – involves obtaining as much information about the pipe as possible
- Indirect inspections – involves making measurements in the field to supplement the data gathered pre-assessment.
- Direct examinations – involves excavating and examining the pipe at selected sites.
- Post assessment – involves analyzing the data & implement appropriate actions.

Indirect Inspection info Gathering

Inspection Digging (ECDA)

Emerging Technlogies

- Numerous with varying degrees of development.
- Long-Range Guided-Wave Ultrasonic Testing (LRGWUT or GWUT). Introduced in 1998. Long segments of pipeline can be inspected. Can detect metal loss within xsectional area.
- Remote Field Testing (RFT) uses eletromagnetic waves and an array of receivers to determine if a pipe has incurred metal loss.
- Robotic Investigation assess segments of pipe that are difficult to access, the use of robots with various technologies e.g MFL, Ultrasonic Testing

Emerging Techs

Direct Assessment of fluid

PIPELINE INTEGRITY MANAGEMENT

- Pipeline integrity management is a process for assessing and mitigating pipeline risks in order to reduce both the likelihood and consequences of incidents
- .Basic steps in the integrity process
- **High-consequence area (HCA) identification**
- **Threat identification and risk assessment**
- **Baseline assessment plan**
- **Integrity assessment**

P I M

- For PIA, Use, Inline inspection (PIGS)

  Pressure Test (Hydro test)Direct Assessment = excavate & examine.
- **Remediation**
- **Preventive and mitigative measures**
- **Continual evaluation and assessment** ie reviewing updated information about the pipe, analyzing risk, and performing reassessments at regular intervals

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