Corrosion and Control Monitoring

MAIN TOPICS

1. DEFINITION OF CORROSION
2. CORROSION MECHANISM
3. CORROSION DAMAGES
4. CORROSION MONITORING
5. CORROSION EFFECT
6. CORROSION THEORY
7. ANODIC REACTION
8. CATHODIC REACTION
9. CATHODIC PROCESSES
10. CORROSION CONTROL
11. PRINCIPLES OF CORROSION CONTROL
12. GLOSSARY

DEFINITION OF CORROSION (1)

Physical-chemical interaction between a metal and its environment which results in changes in the properties of the metal and which may lead to impairment of the function of the metal, the environment or the technical system of which these form a part.

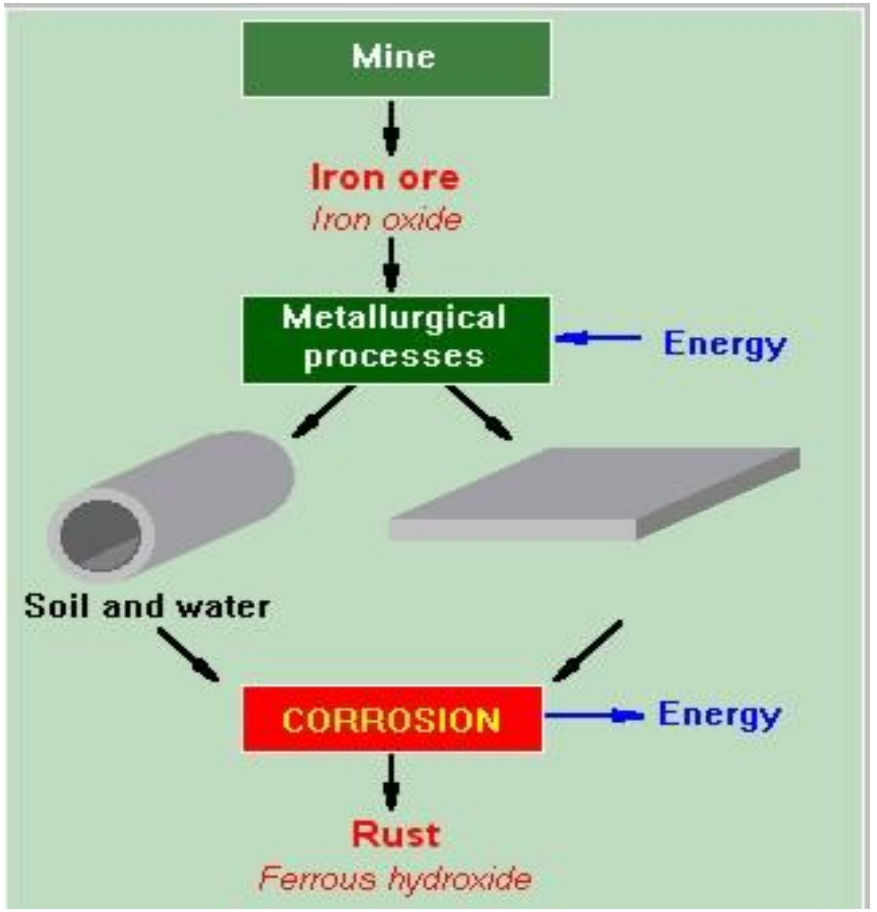
DEFINITION OF CORROSION (2)

- ✓ is a natural phenomena, it must be controlled at reasonable cost
- ✓ is inherently probabilistic by nature, affected by a great variety of parameters, then frequently difficult to be predicted in detail (unexpected)
- ✓ has consequences that can be catastrophic and tremendously expensive

CORROSION MECHANISM

The corrosive process tends to take the metallic materials back to their natural state, that is the state of oxide, salt, thermo-dynamically more stable, state from which they had been drawn through the metallurgical processes producing energy by means of electrical, chemical or heat sources.

The corrosive process can therefore be seen as the extractive metallurgy in reverse. Because this fundamental cycle cannot be avoided, much can be done to reduce the rate of degradation to an acceptable level.



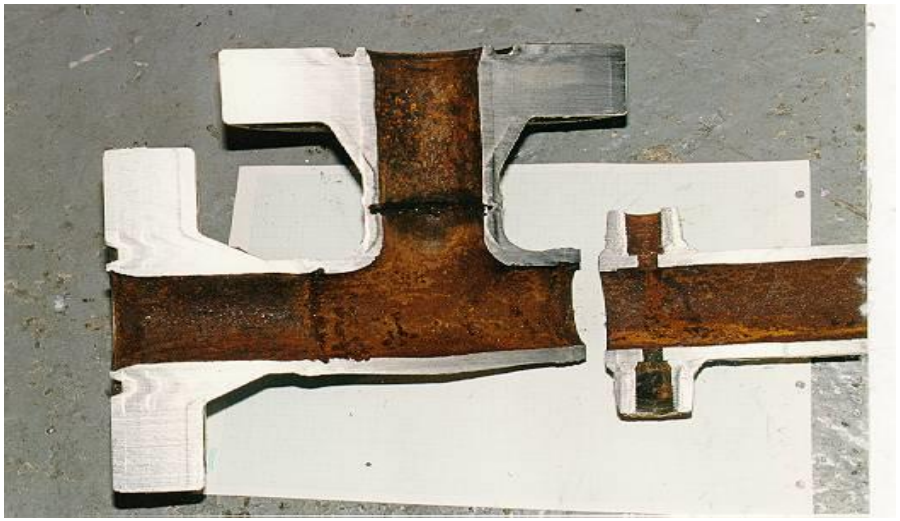
CORROSION DAMAGES

- ✓ Maintenance and operating costs
- ✓ Plant shutdowns
- ✓ Loss of product
- ✓ Effects on safety and reliability
- ✓ Product liability
- ✓ Contamination of product
- ✓ Appearance

CORROSION DAMAGES

A corrosion attack can cause leaks, explosions, fire, in equipment like pipelines and pressure vessels, and can cause cracks and metal embrittlement

Corrosion is often identified with atmospheric rusting of iron base alloys, but that is only a sub-class of the mechanisms of corrosive attack to construction equipment in the oil and gas industry.



CORROSION MONITORING

Corrosion monitoring can be defined as

systematic monitoring of corrosion processes or corrosion consequences (deterioration) to obtain the information that can be used in the control of the corrosion and its consequences

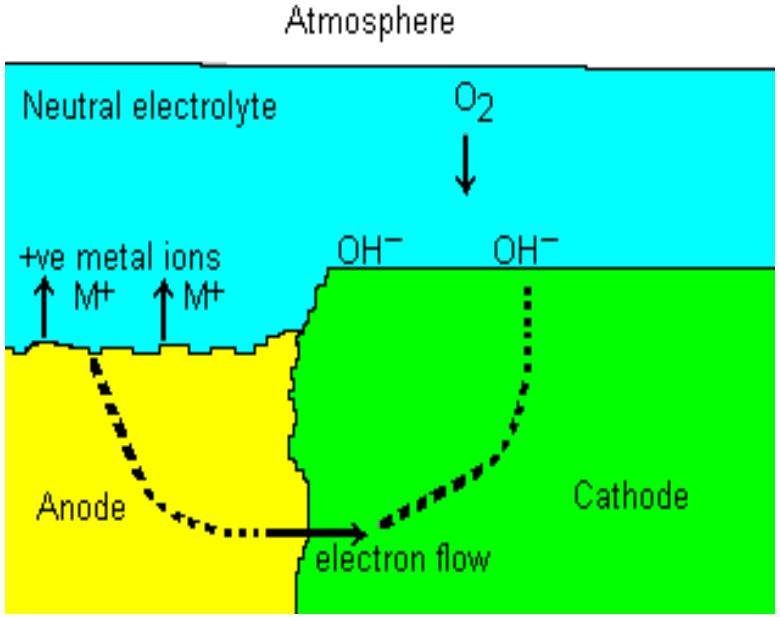
or

establishing a trend of corrosion-rate for use in service life prediction and apply possible prevention methods

CORROSION THEORY (1)

Corrosion is an electro-chemical process in which four conditions must be present:

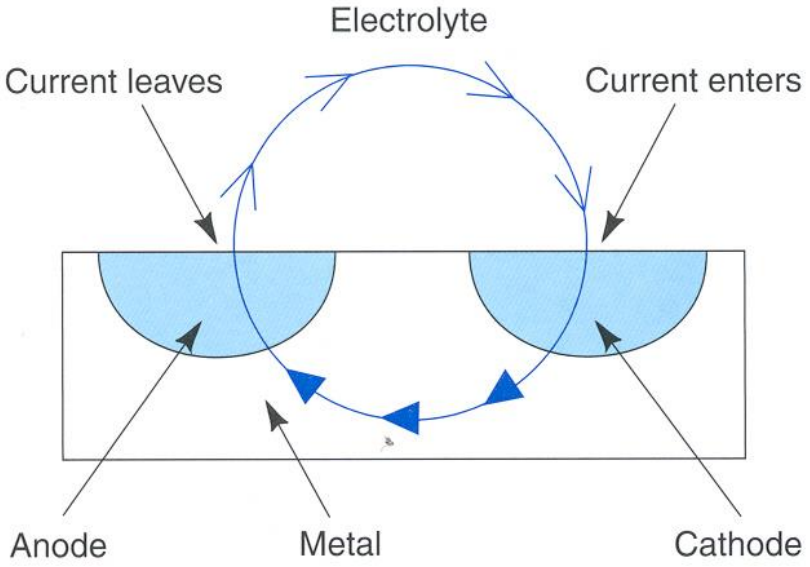
- There must be a positive or anodic area, referred to as the "***anode***."
- There must be a negative or cathodic area, referred to as the "***cathode***."
- There must be a path for ionic current flow, or "***electrolyte***."
- There must be a path for electronic current flow, which is normally a "***metallic path***."

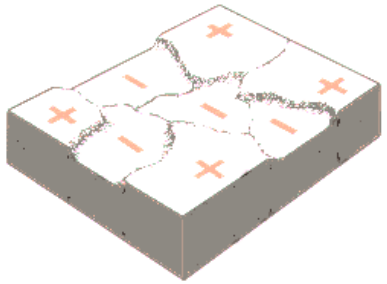


CORROSION THEORY (2)

The distances over which these currents flow can vary from microns to many metres.

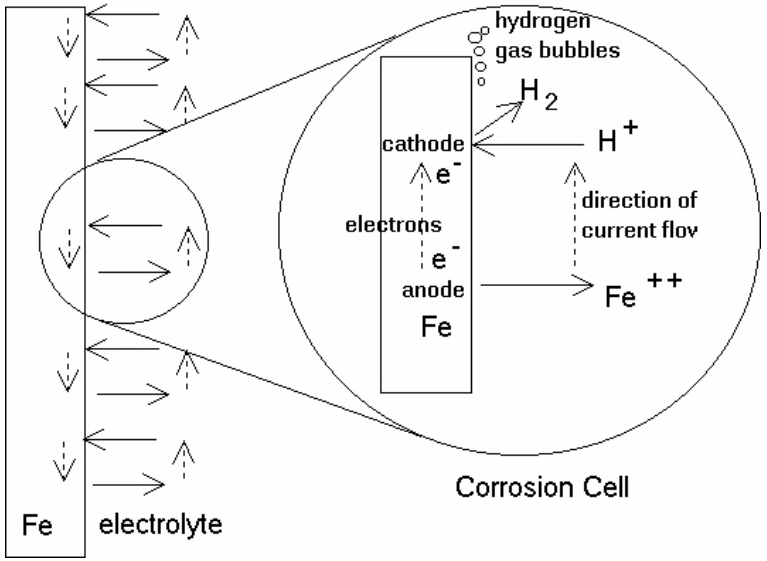
The rate of current would vary from metal to metal, and is recorded as thousandths of ampere, or mill amperes.

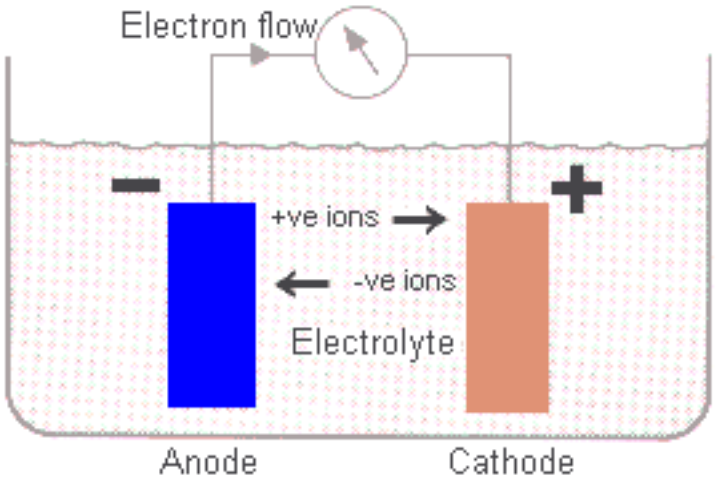




CORROSION THEORY (3)

The electrical potential between the anode and cathode causes the corrosion current to flow. The anode is the area that suffers metal loss and corrosion. The amount of metal that will be removed is directly proportional to the amount of current flow.





ANODIC REACTION

Reaction on the Anodic Surface

When metal corrodes, the atoms release electrons to the metallic matrix and go into the solution (positively charged ions).

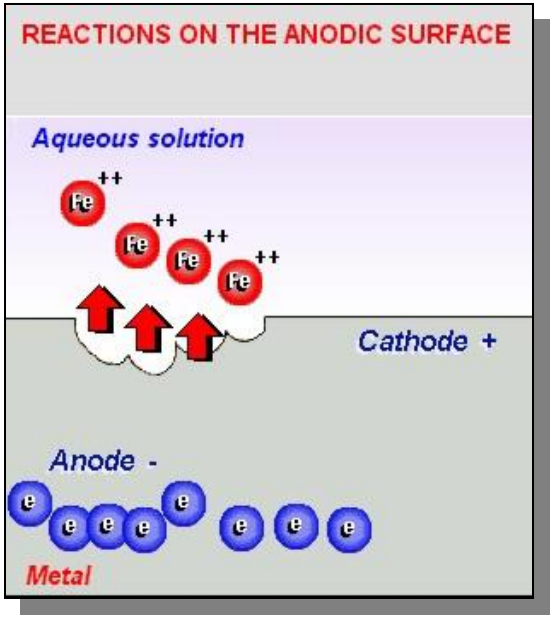
Metal ion

Metal atom

Electrons

The loss of electrons is called oxidation, and the anode is therefore the source of the oxidation reaction.

The anode (or anodic area) is the portion of the metallic surface which is undergoing corrosion.



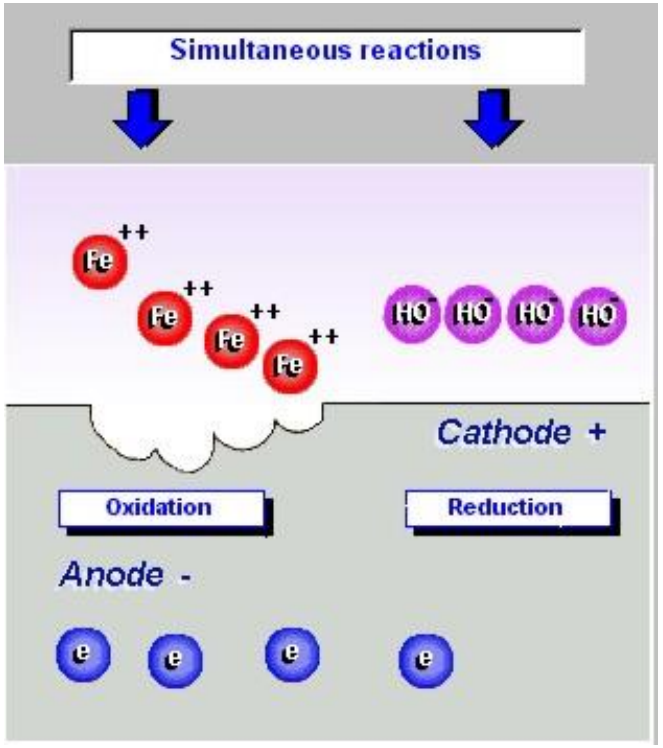
CATHODIC REACTION

Reaction on the Cathodic Surface

The cathode is the portion of metallic surface which becomes the site of another half-reaction (or of more reactions) necessary for the corrosion process.

The electrons produced by the oxidation process are transferred, through the metal, from the anode towards the cathodic area where they are consumed by reaction with dissolved ions.

The consumption of electrons is called reduction, therefore the cathode corresponds to the area where the reduction reactions take place.



CATHODIC PROCESSES

Cathodic Process

Theoretically, many different reduction processes are possible. In practice, the cathodic processes which can cause technologically significant corrosion can be reduced to the following cases:

an evolution of hydrogen : $2e^- + 2H^+ \rightarrow H_2$

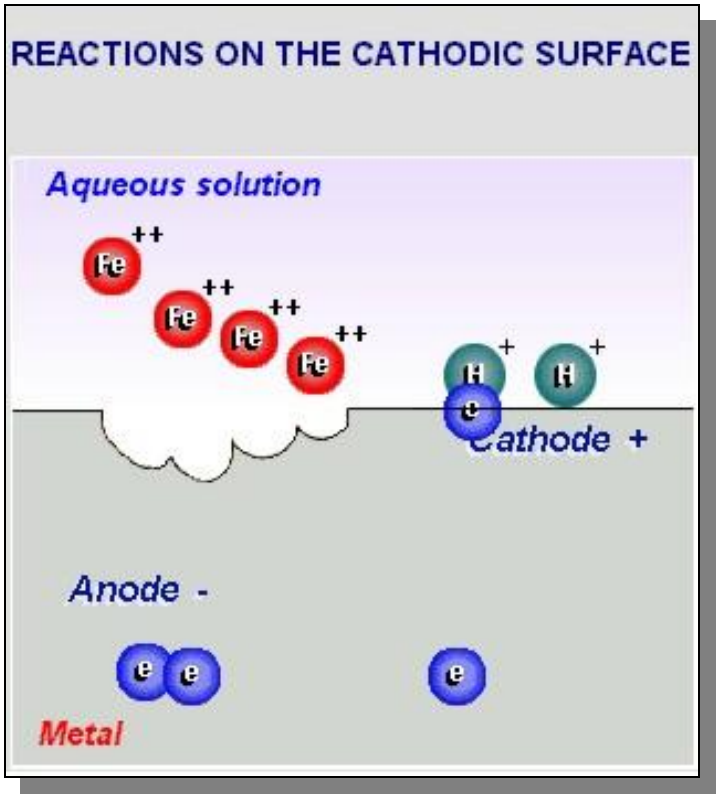
a reduction of oxygen:

$O_2 + 2\,H_2O + 4\,e^- \rightarrow 4\,OH^-$ (in neutral solution)

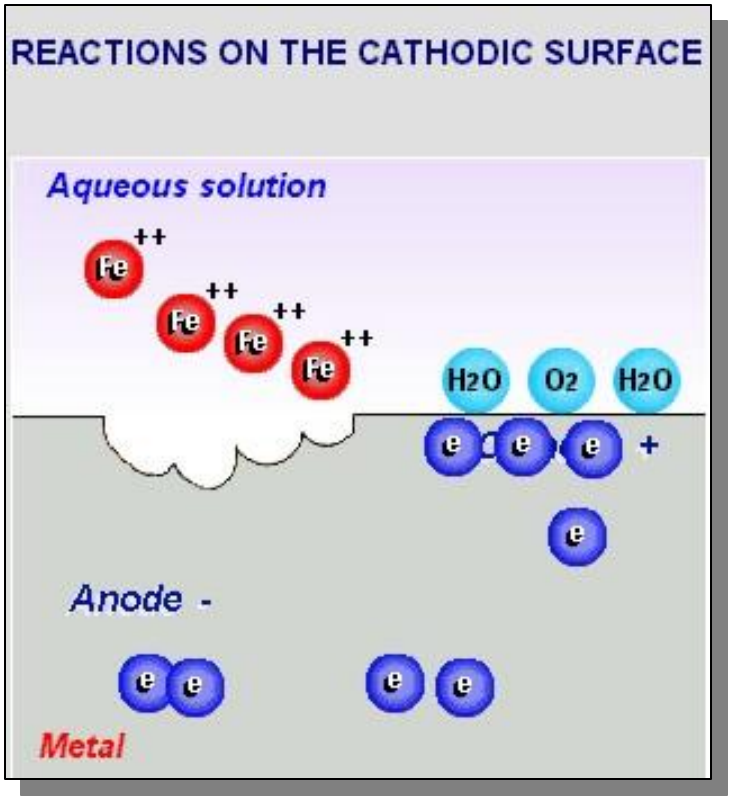
$O_2 + 4H^+ + 4\,e^- \rightarrow 2\,H_2O$ (in acid solution)

a reduction of metallic ion: $M^{n+} + ne^- \rightarrow M$

CATHODIC PROCESS



evolution of hydrogen



reduction of oxygen

ELECTRO-MOTIVE FORCE (EMF)

The value of the electro-motive force created by a metal in contact with an electrolyte is denominated oxidation-reduction potential (or redox potential). The values of the potential depend on the chemical-physical properties of the metal and of the electrolyte, since they are properties of the half-reactions. However, the relative values (at the same reference point) remain constant. Although any reaction can be taken as a reference point, the hydrogen electrode is commonly assigned a zero.

It is important to specify which electrode the potentials are referred to before assigning them a certain meaning in terms of energy.

Other electrodes of interest are the calomel electrode (SCE), the silver/silver chloride electrode and the copper/copper sulphate electrode.

CORROSION PREVENTION (1)

Corrosion can be avoided or delayed by:

a. Detecting the corrosion danger at an early stage and arresting the "undesirable interaction"
b. Choosing the proper material for a given environment
c. Applying/devolping corrosion resistant coating and surface treatment techniques
d. Reducing the corrosivity of the environment by chemical treatment (inhibitors, …)
e. Learning how to design structures, components and equipment to minimize corrosion failures

CORROSION PREVENTION (2)

It is impossible to stop corrosive process since it is thermo-dynamically spontaneous.

On the other hand the elimination of corrosion is unnecessary and not economical.

In general, we use the term "reduce corrosion" to indicate the objectives of corrosion control.

CORROSION PREVENTION (3)

- Selection of resistant materials
- Permanent protection (zinc-plating, galvanization, enameling, double layers)
- Passive protection (protective paints, tapes and coatings)
- Active protection (cathodic protection)
- Environment modification (adding the inhibitors, Ph modification)

One of the major methods well know in industries is the Cathodic Protection (see next slide).

CATHODIC PROTECTION

Two methods are used in plants:

Impressed Current and ***Sacrificial Anods***

COMPARISON OF TWO MAIN METHODS

IMPRESSED CURRENT	**SACRIFICIAL ANODES**
DISADVANTAGES Need of an e.m.f. source Difficulties to obtain a good current distribution Higher maintenance costs	**DISADVANTAGES** Limited flexibility of service conditions High cost of anodes Relevant mechanical stress transmitted to the structures
ADVANTAGES The current output can be modified easily The output current cost is lower	**ADVANTAGES** Reliability Good distribution of the protective current. Less control and maintenance problems

CORROSION MONITORING

- ✓ A corrosion measurement, inspection and maintenance program will incorporate the measurement elements provided by the combinations of on-line/off-line, direct / indirect measurements.
- ✓ Exposure and examination of corrosion coupons
- ✓ Corrosion evaluation using electrical resistance or linear polarization methods (or other more sophisticated electrochemical techniques).
- ✓ Ultrasonic Testing (UT) of materials thickness or cracks
- ✓ Hydrogen Probes (in hydrogen sulphide or other hydrogenating environments)

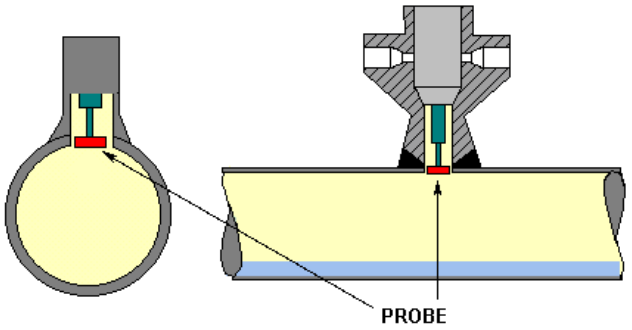
See next slides for further information of some of above techniques

CORROSION COUPONS

These are weighed samples (probes, coupons) of the metal or alloy metal pieces inserted into a system and left exposed for a dedicated time interval. The coupon is removed, cleaned of all corrosion product and re-weighed. The weight loss is converted to a corrosion rate (CR) or metal loss (ML), as follows:

$$\text{Corrosion Rate (CR)} = \frac{\text{Weight loss (g)} * K}{\text{Alloy Density (g/cm}^3\text{)} * \text{Exposed Area (A)} * \text{Exposure Time (hr)}}$$

$$\text{Metal Loss (ML)} = \frac{\text{Weight loss (g)} * K}{\text{Alloy Density (g/cm}^3\text{)} * \text{Exposed Area (A)}}$$

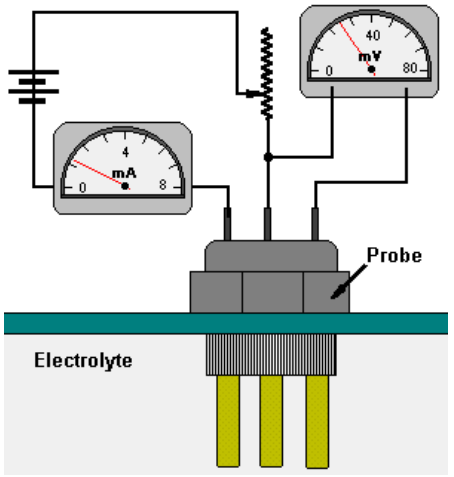


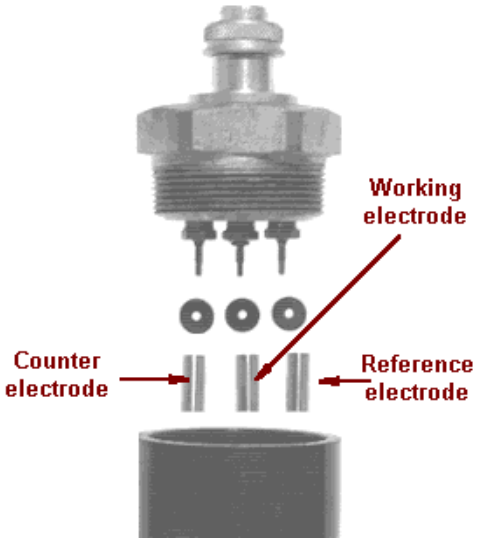
LINEAR POLARISATION PROBES

Linear polarisation is an electro-chemical technique used to measure the corrosion rate.

If electrodes are corroding at a high rate, metal ions are passing easily into the solution and a small potential applied to the electrodes will produce a high corrosion current.

Similarly, if electrodes are corroding at a low rate with ions passing slowly into the solution, a small potential applied to the electrodes will produce a small current.





ELECTRIC RESISTANCE PROBES

This technique is based on the increase of the resistance of a metallic element due to the reduction of its cross-section as a consequence of corrosion.

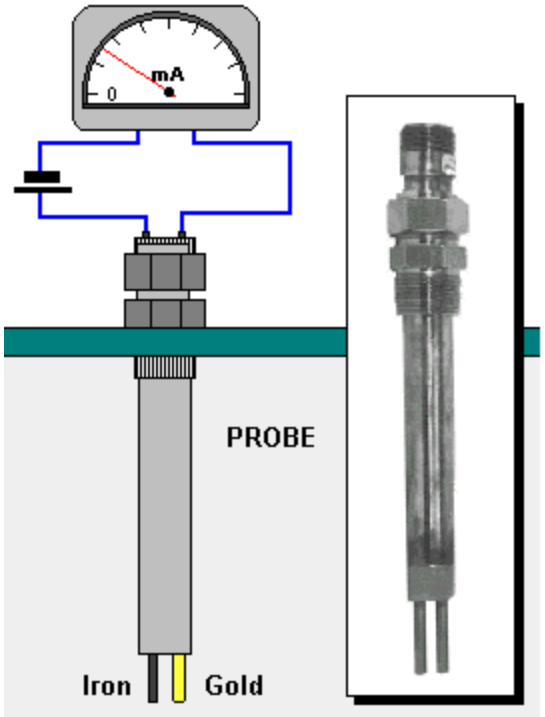
The measurement consists in measuring the ratio between the resistance of a certain element exposed to the aggressive environment and that of an element, made of the same material, but unexposed

MEASURING DISSOLVED OXYGEN

They are used in water to measure the content of dissolved oxygen.

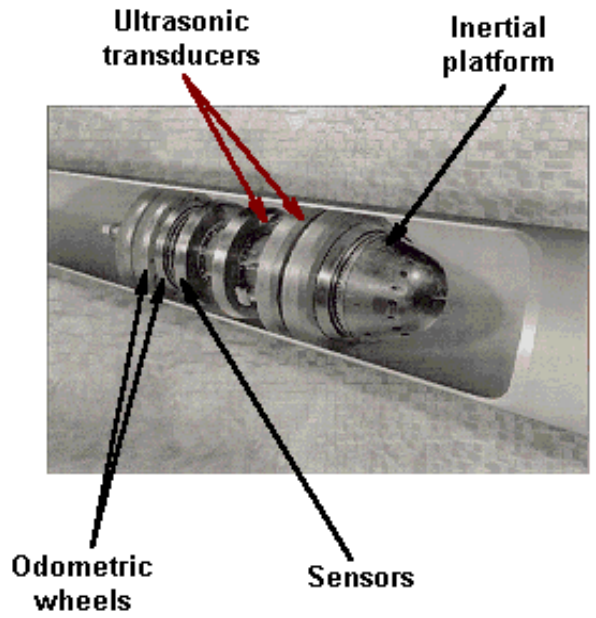
The probe is composed of two different metallic elements (for instance iron and gold) that are exposed to water.

The short circuit current between the two elements is measured, and its intensity is directly proportional to the concentration of dissolved oxygen.



INTERNAL INSPECTIONS WITH INTELLIGENT PIGS

Intelligent pigs are instrument that travel in the pipelines, propelled by the pressure difference between upstream and downstream zones, to monitor and record information about the pipeline conditions including wall thickness.



GLOSSARY

Inspection: the inspection maintenance is the equipments and machinery check. This maintenance typology involves an inspectorial analysis and the issue of a certification from the surveillance authority.

Maintenance: It is the combination of all the technical and administrative actions including the supervision actions aiming at maintaining or putting back an object so as it can carry out the requested function.

NDT: Non-Destructive Testing, is a means of testing material and components without changing or destroying their usefulness.

On Condition maintenance: is the preventive maintenance subordinated to the achievement of a predetermined limit value through the monitoring and interpretation of the data. They indicate the decay condition of the object analysed.

GLOSSARY

Dry corrosion: this is generated by a direct chemical attack, at a high temperature, in environments having a gaseous atmosphere (in absence of condensate aqueous liquid phases).

Wet corrosion (or electrochemical corrosion): this occurs when a metal is in contact with an environment containing condensate water. It is the result of two concurrent half-reactions (oxidation-reduction reaction, also known as redox).

Anodic reaction: which leads to the metal oxidation.

Cathodic reaction: which leads to the reduction of the aggressive species.

GLOSSARY

Planned maintenance: is the category of preventive maintenance carried out at pre-arranged time intervals.

Predictive maintenance: is the typology of preventive maintenance carried out when the trend of some parameters presages incipient troubles.

Preventive maintenance: carried out at pre-arranged intervals or in accordance with fixed criteria. Its aim is to reduce any possible fault or the working degradation of an element, an entity or a good. The planned, cyclic and predictive maintenance belong to the preventive maintenance.