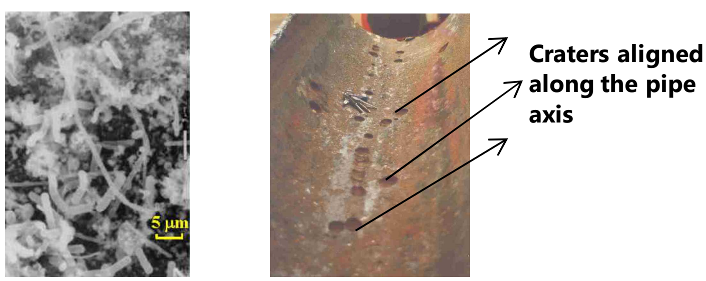
Let us speak about Corrosion

What is corrosion?

Corrosion is a physico-chemical deterioration process due to the interaction of a material with its surrounding environment. Corrosion can be concentrated locally to form a pit or crack but it can also extend across a wide area to produce macroscopic failure. Although most alloys corrode, some metals are more intrinsically resistant to corrosion than others, either due to their fundamental atomic nature or due to the way in which reaction products form. Some dedicated metals such as zinc, magnesium, and cadmium have naturally slow reaction kinetics. Gold nuggets do not corrode, even on a geological time scale. The corrosion process can be strongly affected by exposure to certain substances such as acids (including acid gases), bases, halogen salts and some organic materials such as phenol ("carbolic acid"). Sea water which has a high NaCl content is a highly corrosive fluid. The most common corrosion process (known as "rust") is the weakening of iron by oxidation, but there are many other types of corrosion, the most important of which are:

- Galvanic corrosion occurs when two different metals immersed in an electrolyte (i.e. sea water) electrically contact each other. In the galvanic couple, the more active metal corrodes at an accelerated rate and the more noble metal corrodes at a retarded rate. Factors such as the relative size of the anode (smaller is generally less desirable), the surface area ratio between the anode and the cathode, the types of metal used, and the operating conditions (temperature, humidity, salinity) will affect the galvanic corrosion rate. Galvanic corrosion is often used in "sacrificial anodes" to protect offshore steel such as jackets or immersed pipes (see later).

- Microbial or bacterial corrosion is caused or promoted by microorganisms. It can apply to both metals and nonmetallic materials. In the absence of oxygen, sulphate-reducing bacteria produce hydrogen sulphide causing stress cracking and microcraters along the pipe axis (**Figure 1**). In the presence of oxygen, some bacteria directly oxidise iron to iron oxides and hydroxides, other bacteria oxidise sulphur and produce sulphuric acid.



Sulphur bacteria **Microbial corrosion**

Figure 1 – Sulphur bacteria
Example of pipe severely damaged by microbial corrosion

- High temperature corrosion is a deterioration process occurring in very high temperature conditions. This form of corrosion occurs when a metal is subjected to a high temperature atmosphere containing oxygen, sulphur or other compounds capable of oxidising (or assisting the oxidation of) the material concerned. For example, the materials used in aerospace, power generation and even in car engines have to resist sustained periods at high temperature during which they may be exposed to an atmosphere containing potentially highly corrosive combustion products.

Examples

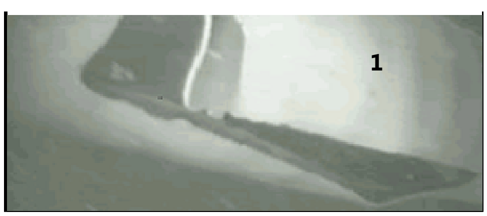
Air corrosion of mature surface installations

The most obvious effect of maturity when visiting mature installations is the corrosion of the surface installations. Both topsides (tanks, flowlines, railings, gratings) and jackets very often have a heavily corroded appearance as can be clearly observed in **Figure 2**. These corrosion problems are reinforced by sea level washing systems (sea water is a highly corrosive fluid). For jackets, both air and galvanic corrosion can play a role since the metal is alternatively immersed and emerged.

Figure 2 – Corrosion of mature installations
Tubing corroded by CO_2 - Surface valve - Corroded structure- Hole in a railing

Harmful internal corrosion of a subsea injection pipe

Due to the nature of the effluent (sea water is much more corrosive than oil), the injection pipes are much more sensitive to internal corrosion than the production pipe. For this simple reason, the injection pipe requires a specific internal coating to reduce internal corrosion and avoid early deterioration.



1. **Subsea failure identification**
2. **Macroscopic longitudinal fracture**
3. **"6 hours" heavy reduction in thickness**

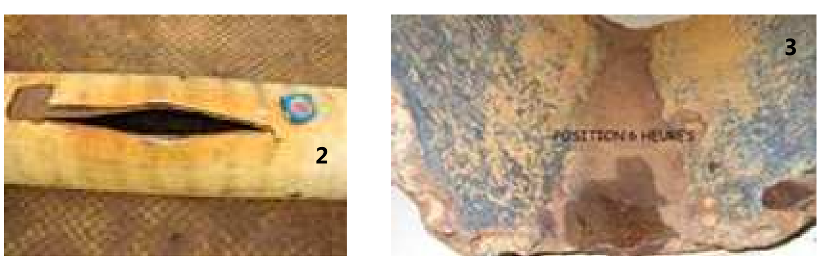


Figure 3 – Hole in a subsea oil production pipe converted into an injection pipe

The example presented in **Figure 3** results in the conversion of an oil pipe into a water injection pipe without an initial coating. The rupture was observed following a total pressure drop in the injection system. The location of the damaged zone was identified using a ROV system (picture 1), then the damaged part was removed and temporarily replaced by a new section of safe pipe. The observation of the damaged zone after removal indicates a macroscopic longitudinal fracture 30 cm in length (picture 2) as well as a dramatic reduction in thickness (70% - picture 3 in the six o'clock position).

2.1.1 Hot corrosion of gas turbines

Hot corrosion generally results in the coupling between the high temperature and the contamination of the driving fluids.

Figure 4 refers to the failure of a gas lift compressor installed in 1999 in the Middle East. Severe hot corrosion was identified in 2004 with extensive damage and cracking in the combustion liner and first stage nozzles. The primary cause was the presence of H_2S in the fuel gas and SO_2 in the air/combustion gases aggravated by salts in the air and "liquids" in the fuel gas. Therefore a fuel gas sweetening unit was installed to remove the H_2S and the SO_2 from the air.

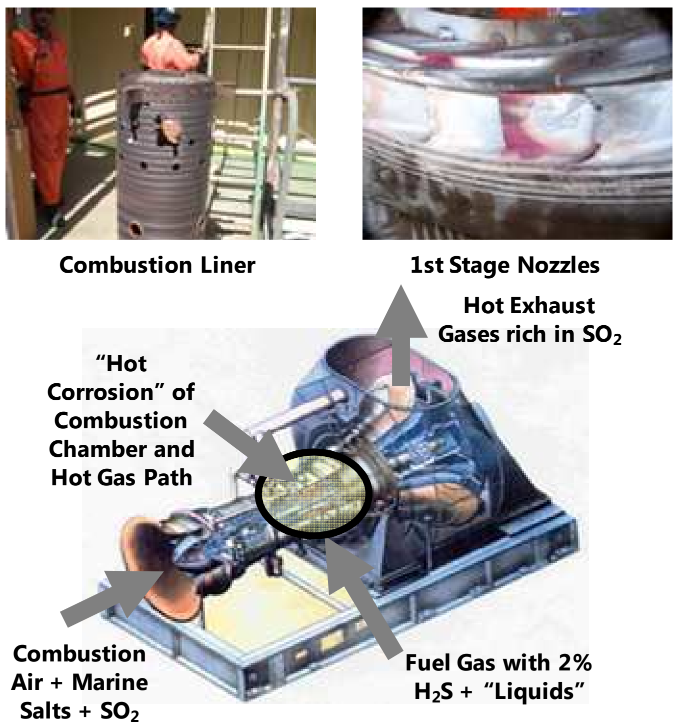


Figure 4– Hot corrosion in a gas lift compressor (Middle East)

2.1.2 Subsea corrosion of an FSO hull

Ships are subjected both to galvanic corrosion (when immersed) and air corrosion (when emerged). This applies particularly to the hulls of fixed tankers (FSO, FPSO) for which the period between full maintenance operations (which require a dry dock) is regularly ten years. The corroded FSO (Gulf of Guinea) presented on Figure 5 highlights corrosion spots which were reported after a microwave inspection. Although the global loss of material remains moderate, the loss of material is as high as 80% at some weak spots. It is possible to cure such corrosion spots offshore but it generally requires production to be stopped so that the corroded parts remain emerged during the maintenance work.

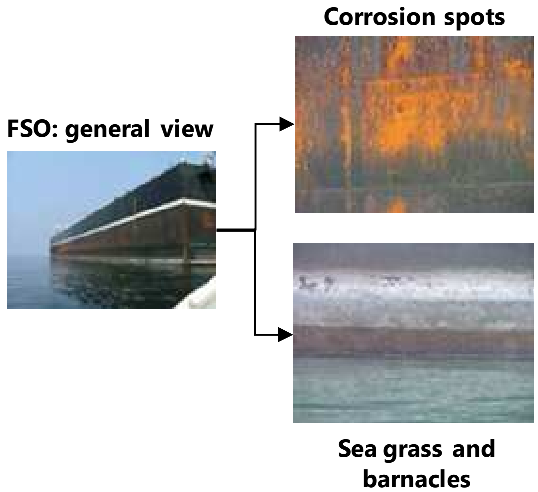


Figure 5 - Corrosion of an FSO (Floating Storage Offloading unit) in the Gulf of Guinea. Sea grass, barnacles and heavy corrosion spots.

Mitigation

The main mitigation techniques to protect materials against corrosion are passivation, surface treatments, corrosion inhibitors and cathodic protection which are briefly described below.

- Passivation is a natural mitigation technique which consists of a thin corroded film (sometimes less than one micron) which forms on a metal's surface and acts as a barrier to further oxidation.

- Surface treatments consist of providing a corrosion-resistant barrier to the damaging environment. Plating using zinc or cadmium and painting are the most common anticorrosion treatments. Corrosion inhibitors is a temporary surface treatment forming an electrically insulating and/or chemically impermeable coating inhibiting electrochemical reactions on exposed metal surfaces. Other dedicated treatments can also inhibit bacteria and protect against microbial corrosion. Most corrosion inhibitors are chromates, phosphates as well as a wide range of surfactants.

- Cathodic protection is a technique which uses galvanic corrosion to protect a metal structure by coupling that structure (working as a cathode) with a "sacrificial anode" which will corrode according to the electrochemical potential difference.