Erosion Corrosion

Erosion corrosion arises from the combined action of chemical attack and mechanical abrasion or wear as a consequence of fluid motion.

Virtually all metal alloys, to one degree or another, are susceptible to erosion–corrosion. It is especially harmful to alloys that passivate by forming a protective surface film; the abrasive action may erode away the film, leaving exposed a bare metal surface. If the coating is not capable of continuously and rapidly reforming as a protective barrier, corrosion may be severe. Relatively soft metals such as copper and lead are also sensitive to this form of attack Reasonably, the corrosion form is typical at relatively high velocities between the material surface and the fluid, and it is particularly intensive in cases of two-phase or multiphase flow, i.e. liquid–gas and liquid–solid particle flow. Components often liable to erosion corrosion are propellers, pumps, turbine parts, valves, heat exchanger tubes, nozzles, bends, and equipment exposed to liquid sputter or jets.

Types and Mechanisms

The three types may overlap each other and partly occur simultaneously in the same system:

1-Impingement corrosion, often occurring in systems with two-phase or multiphase flow, particularly where the flow is forced to change direction. Numerous impacts from liquid drops in a gas stream, or particles or gas bubbles in a liquid flow lead to pits with a direction pattern as shown in Figure -1. In cases with solid particles, the situation can be illustrated as in Figure -2, where corrosion products are removed and the surface locally activated.

Figure 1: Impingement
Figure 2: Impact from solid particle in liquid flow causing removal of corrosion products from surface.

2- Turbulence corrosion, which occurs in areas with particularly strong turbulence such as the inlet end of heat exchanger tubes figure -3

Figure – 3 turbulence corrosion

Single-phase flow, a) Developed laminar flow showing parabolic velocity profile b) Developed turbulent flow showing logarithmic velocity profile with large gradients near the wall c) Disturbed turbulent flow with separation, recirculation and reattachment showing complex velocity field.
3- Increased corrosion due to removal of corrosion products by wear due to particles moving along and in contact with the corroding surface, or by wear between components in moving contacts with each other.

*Erosion and erosion corrosion in liquid flow with solid particles*

Erosion corrosion will be particularly intensive when the flowing medium contains solid particles. At relatively low velocities, we may have the situation illustrated in Figure 2. The particles hit the surface with a velocity \( v \) at an angle \( \beta \). Corrosion products are removed from the surface, which is activated, and the corrosion rate on the activated spots may increase strongly. With increasing velocity the impact energy increases as well, and above a certain level not only the corrosion products, but also small particles of the material itself will be removed.

For the pure erosion rate can be expressed by the following formula:

\[
W (\text{mm/year}) = K_{\text{mat}} K_{\text{envr}} c V^n f(\beta)
\]

where \( K_{\text{mat}} \) is a material factor depending in a complex manner on (among other properties) hardness and ductility of the substrate; \( K_{\text{envr}} \) is an environmental factor that includes the effects of size, shape (sharpness), density and hardness of the particles; \( c \) is the concentration of particles, \( n \) is the so-called velocity exponent, \( v \) is the particle velocity, and \( \beta \) the impact angle shown in Figure -2.

*Control*

1- Suitable selection of materials.
2- Appropriate design. Numerous examples of good design of flow systems and other equipment. Pipe dimensions and flow cross sections are to be chosen with the aim of keeping the flow velocity below the critical level. It should be noticed that disturbing local geometrical elements still may cause local turbulence and subsequent local attack. Therefore, such elements should be avoided as far as possible, and any change of cross section or flow direction should be sufficiently smooth and streamlined (Figure 4 a). Turbulence should be avoided. Particularly in the most critical parts of the system, e.g. by positioning bends.
sufficiently far from turbulence-producing elements (Figure 4 b). If possible, regions where corrosion is difficult to avoid should be positioned such that the attack does not cause any harm, e.g. by extending outlet pipe ends into the tank, as shown in Figure 4 c.

3-Change of environment, e.g. as shown in Figure 5: filtration or precipitation of solid particles (a), precipitation of water droplets from air, gases or steam (b), and removal of air or other gases from liquid flow (c). In all these cases it is important to have the separation as early in the process as possible. Upstream to the separation point, the pipe diameter should be large (low velocity) or resistant/replaceable parts should be used. Furthermore, it is important to 1) reduce the temperature, and 2) keep the pressure high to avoid gas in liquid systems. Use of inhibitors and removal of air may be effective but not always economical methods.
4-Application of corrosion-resistant coatings, e.g. metallic coatings by welding, metallic, metallic–ceramic and ceramic coatings by thermal spraying, concrete or rubber/polymer coatings.

5- Cathodic protection. A problem with this is that very high current density is usually needed because the cathodic reaction occurs very efficiently under conditions of high flow velocities. Sacrificial anodes in the form of zinc or steel plates have been used to protect the inlet part of heat exchanger tubes. Sacrificial anodes may also be applied as plugs in pump housings and other components.

Cavitation Corrosion

This corrosion form is closely related to erosion corrosion, but the appearance of the attack (Figures 6 and 7) differs from the erosion corrosion attacks described in the last section. While the latter has a pattern reflecting the flow direction, cavitation attacks are deep pits grown perpendicularly to the surface. The pits are often localized close to each other or grown together over smaller or larger areas, making a rough, spongy surface.

Cavitation corrosion occurs at high flow velocities and fluid dynamic conditions causing large pressure variations, as often is the case for water turbines, propellers, pump rotors and the external surface of wet cylinder linings in diesel engines. Vapour bubbles formed in low-pressure zones, or at moments of low pressure at the actual positions, collapse very rapidly when they suddenly enter a high-pressure zone or high-pressure moment. When this happens close to the metal surface, the bubble collapse causes a concentrated and intense impact against the metal, with the induction of high local stress and possibly local plastic deformation of the material. Parts of any protecting film are removed. Repeated impacts may lead to microscopic fatigue and crack formation, and subsequent removal of particles from the material itself. During this process the material is strongly activated at the attacked points, and high local corrosion rates are possible. In some cases, however, the corrosion contribution is small and the deterioration form is more correctly called cavitation erosion.
Figure 6: External cavitation corrosion on a cast iron cylinder lining in a diesel engine.

Figure 7: a) Cavitation corrosion on the propeller of a high-speed passenger ship, b) Close up of the damages
Fretting Corrosion (Fretting Oxidation)

Fretting wear occurs at the interface between two closely fitting components when they are subject to repeated slight relative motion (slip). The relative motion may vary from less than a nanometre to several micrometres in amplitude. Vulnerable objects are shrink fits, press fits, bolted joints, and other assemblies where the interface is under load. A critical position is at the end of a collar, as shown in Figure 8. Sometimes the attack is serious, particularly because it may lead to macroscopic motion between the parts, or fatigue cracks may develop in the shaft.

![Diagram of fretting wear](image)

The mechanical contribution to fretting damage may include elements of adhesive wear, microscopic fatigue crack development and delamination that result in removal of small particles from the metal lattice. The particles form a debris, which may partly adhere to the fretting surfaces and be trapped between these, and may partly escape from the fretting area.

Thank you