Control Erosion-Corrosion of Steels in Water and Wet Steam

The combined phenomenon reduces the integrity of piping and major cycle components, and is a prime contributor to sludge and crud buildup in both drum boilers and nuclear steam systems.

By Otakar Jonas, P.E., Jonas Inc

Erosion/corrosion of carbon steel exposed to wet steam in both nuclear and fossil-fueled powerplants has long been a matter of concern. It is most pronounced in carbon steel components with high-velocity, turbulent flow of low-pH moisture containing a high concentration of CO₂ (or other acid-forming anions). The phenomenon is also associated with high-velocity water under similar hydraulic and chemical conditions.

Known for decades to exist in condensate-return lines, erosion/corrosion is now recognized as the cause of a new set of problems. It has reduced pipe-wall thickness in several pressurized-water reactors (PWRs)—to perforation, in at least one case—and has been responsible for partial or complete disappearance of moisture-separator chevrons after several years of operation. It is identified with the accumulation of large quantities of oxides in boiling-water reactors (BWRs) and PWR steam generators, causing additional corrosion and contamination problems. Erosion/corrosion is also frequently observed in feedwater heaters, vertical deaerators, BWR steam separators, and wet regions of steam turbines.

The term erosion/corrosion is applied to the interaction of mechanical wear and corrosion, with corrosive action initiated by erosion of the protective metal-oxide layer from a metal surface. Without this protective layer—mostly magnetite (Fe₃O₄)—carbon steel is vulnerable to general corrosion/dissolution, even in weakly acidic water. The acids most likely to be present are carbonic, short-chain organic—acetic, formic, etc—and possibly hydrochloric, hydrofluoric, and sulfuric.

Carbonic acid forms from reaction of water with CO₂. The latter enters the steam cycle with inleaking air, or results from decomposition of carbonate and organic impurities. Organic (and certain inorganic) acids can be generated by decomposition of organic impurities, chelants and polymers used in boiler-water treatment, and ion-exchange resins.

Aggressiveness of a moisture film depends on its velocity, turbulence, and

![Graph of material wear rate vs. pH and temperature](image)

1. Wear rate of various materials from erosion/corrosion in 350°F water moving at 65.6 ft/sec, 580 psig, is shown for three typical pH/oxygen combinations.

2. Temperature effect on erosion/corrosion is greatest in 266-366°F range. Conditions: 580 psig, 115 ft/sec, pH = 7, O₂ < 40 mg/kg, exposure time = 200 hr.
chemical composition. For each material and temperature, there seems to be a critical velocity below which erosion/corrosion is negligible. At higher velocities, damage occurs in regions of turbulence—such as tub e ends in heat exchangers, flow obstacles present in pipes, and points where the flow changes direction (such as at moisture-separator chevrons). Under the indicated conditions, the rate of wear depends on the material's composition—with the presence of chromium providing a beneficial effect—as well as temperature, flow velocity, and chemical composition of the water in contact with the surface involved; oxygen concentration and pH also have pronounced effects.

Material-wear rates are shown in Fig 1 for nine steels and two platted carbon steels. Water moving at 65.6 ft/sec, with 366°F temperature and three typical pH/oxidation combinations, was used. The highest erosion/corrosion rates were observed on 0.5% molybdenum and carbon steels in natural water with low oxygen content. For many environment combinations, the highest rates occurred at temperatures between 266°F and 366°F, as seen in Fig 2. Moreover, the effect increases exponentially with flow velocity (Fig 3). Under constant flow velocity and chemistry, the rate is almost constant with time. (Note: All figures are from Reference 2.)

Independent of oxygen content, erosion/corrosion rates drop sharply at pH levels above 9.2 (Fig 4). To provide an operating margin, therefore, a pH of 9.6 or higher is recommended for all-volatile treatment (AVT) systems. An O, concentration above 100 ppb is apparently beneficial for neutral water, since this improves the repassivation of carbon and low-alloy steels (Fig 5).

Iron oxides removed by erosion are transported and deposited in various parts of the cycle. In PWRs, moisture-separator drains are pumped forward to the steam generators. As a result, much of the iron oxides produced and released reach the steam generators, where they usually deposit on the lower tubesheets and form crud and sludge.

Soluble impurities, such as chlorides, caustic, and phosphate, can concentrate in the sludge pile, often resulting in stress corrosion, thinning, and pitting of steam-generator tubes.

Transport of these oxides into PWR steam generators and boiling-water reactors can be reduced by magnetic filtration of moisture-separator drains or feedwater, or by rerouting the drains to the condenser. Oxides produced by erosion/corrosion of piping can also lead to solid-particle erosion (cutting) of both turbine control-stage blades and valves.

Sufficient data and knowledge are now available to mitigate these problems. The following remedies may be applied:

- Increasing the moisture pH.
- Reducing flow velocity below the critical level.
- Changing the material of construction from carbon steel to a steel with higher chromium content.
- Lowering the moisture content of wet steam.

All of these approaches have been tested in operating units. In ferrous PWR systems using AVT chemistry, increasing pH to about 9.6 and controlling air leakage to reduce CO₂ represents the easiest remedy. It offers the added benefits of improved corrosion protection of feedwater heaters, steam generators, and turbines. It can also be applied to units having condensate polishers incorporating cation resins operated in the ammonia form.

Occurrence of erosion/corrosion can be detected by monitoring pipe-wall thickness—either manually or automatically, with the unit on-line—and by periodic inspection of moisture-separator reheaters and other components. These techniques can be supplemented by examination of chemical data and review of steam-generator sludge-accumulation history. A cycle chemical-transport study with a material balance can reliably identify locations where the rate of erosion/corrosion is excessive.

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References
4. J Marcone, Erosion/corrosion of wet steam—design choices, sizing, materials, manufacturing, EdF/ADERP symposium (see Ref 3)
6. P Berge et al, Effects of chemistry on erosion-corrosion of steel in water and wet steam, 1980 British Nuclear Energy Society meeting (see Ref 3)

3. Flowing water increases material-loss rate exponentially with flow velocity.

Conditions: 580 psig, 356°F, pH = 7, 0₆ < 5 μg/kg, exposure time = 200 hr

4. Increasing pH reduces material wear, particularly above pH = 9.2

5. Oxygen content above 100 ppb gives maximum steel protection in neutral water