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

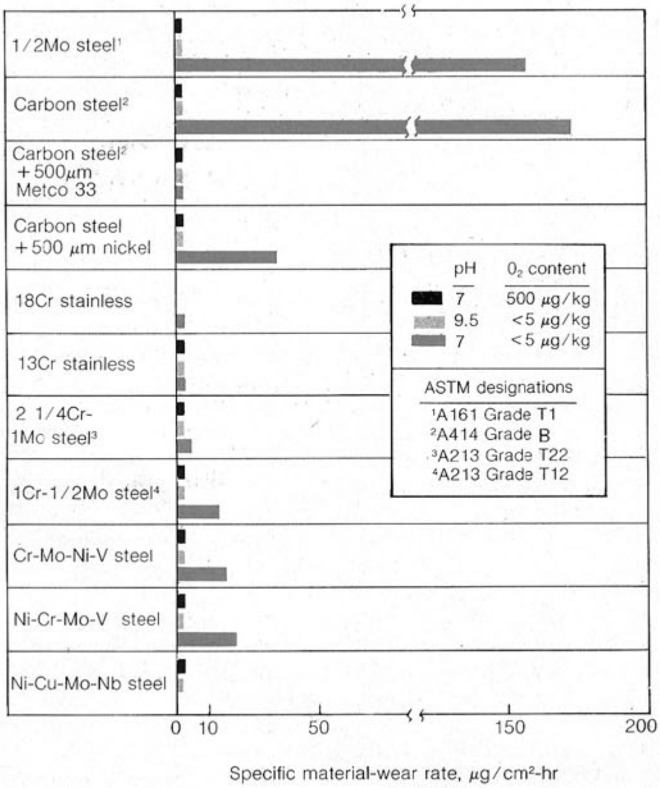
Erosion/corrosion of carbon steel exposed to wet steam in both nuclear and fossil-fueled powerplants has long been a matter of concern. It is most pronounced in carbon steel components with high-velocity, turbulent flow of low-pH moisture containing a high concentration of CO_2 (or other acid-forming anions).[1-8] 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.

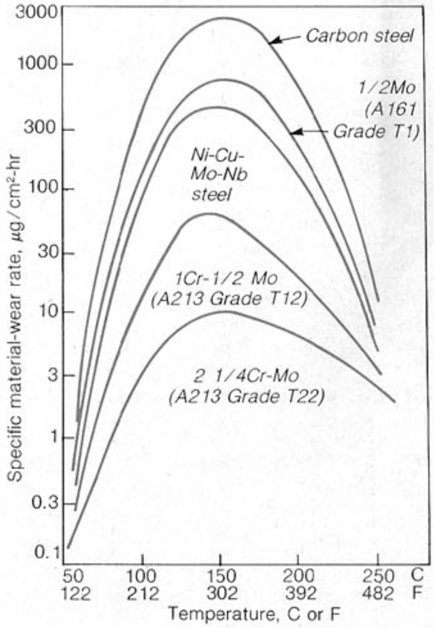
The term erosion/corrosion is applied to the interaction of mechanical wear and corrosion, with corrosive action initiated by erosion of the protective metal-oxide layer from a metal surface. Without this protective layer—mostly magnetite (Fe_3O_4)—carbon steel is vulnerable to general corrosion/dissolution, 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 CO_2. 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



1. Wear rate of various materials from erosion/corrosion in 356F 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 266-366F range. Conditions: 580 psig, 115 ft/sec, pH = 7, $O_2 < 40$ μg/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 tube 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 plated carbon steels. Water moving at 65.6 ft/sec, with 366F temperature and three typical pH/oxygen combinations, was used.[2] The highest erosion/corrosion rates were observed on 0.5%-molybdenum and carbon steels in neutral water with low oxygen content. For many environment combinations, the highest rates occurred at temperatures between 266F and 366F, 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_2 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.[9] 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 valving.

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 inleakage to reduce CO_2 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.

Edited by Sheldon D Strauss

References

1 H G Heitmann and P Schub, Initial experience gained with a high pH value in the secondary system of pressurized-water reactors, 1983 British Nuclear Energy Society Conference, Water Chemistry III, Bournemouth, England

2 H G Heitmann and W Kastner, Erosion-corrosion in water-steam circuits—causes and countermeasures, *VGB-Kraftwerkstechnik,* Vol. 57, No. 6, p 211, 1982

3 J P Cerdan et al, Erosion/corrosion in wet steam—impacts of variables and possible remedies, EdF/ADERP symposium on water chemistry and corrosion in the steam/water loops of nuclear power stations, Seillac, France, March 1980

4 J Marceau, Erosion/corrosion of wet steam—design choices, sizing, materials, manufacturing, EdF/ADERP symposium (see Ref 3)

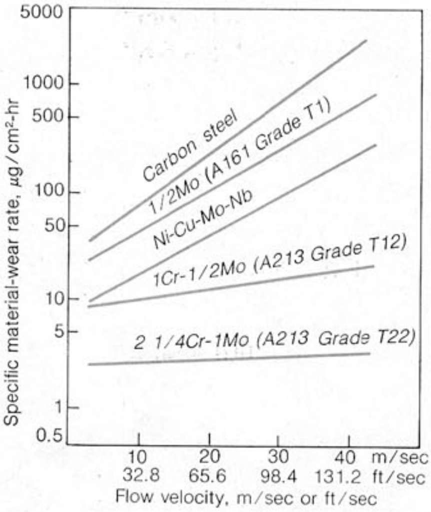
5 G J Bignold, Erosion-corrosion in nuclear steam generators, 1980 British Nuclear Energy Society Conference, Water Chemistry II, Bournemouth, England

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 5)

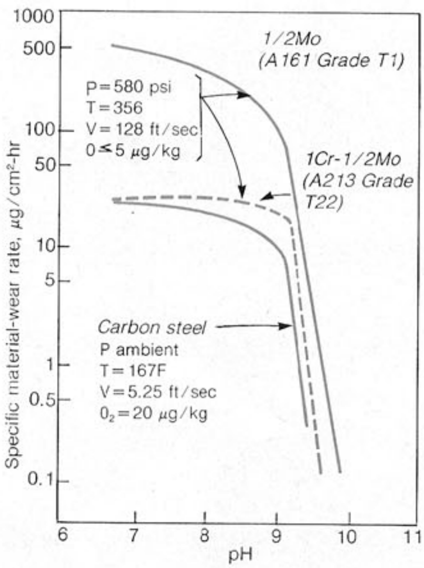
7 R Svoboda and G Faber, Corrosion in power-generating equipment, p 269, Plenum Publishing Co, 1984

8 F L Archibald, J W Purssell Jr, and F G Straub, Prevention of metal losses in the wet-steam areas of steam turbines, American Power Conference, Chicago, April 1953

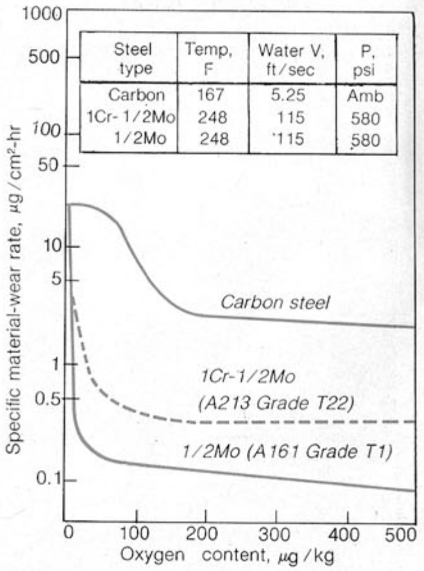
9 O Jonas, Increase of impurity concentrations in once-through units with forward-pumped moisture drains, *Combustion,* August 1977, p 20



3. Flowing water increases material-loss rate exponentially with flow velocity. Conditions: 580 psig, 356F, pH = 7, O_2 < 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