By Otakar Jonas

Flow-Accelerated Corrosion & Cavitation

Recommendations and control strategies for dealing with problems related to FAC and cavitation

ARTICLE SUMMARY

Challenge: Flow-accelerated corrosion and cavitation can wreak havoc on water systems and cause fatal accidents.

Solution: Having the proper software as well as skillful knowledge of water chemistry can help prevent FAC and cavitation.

Conclusion: OEMs, plant managers and engineers must have a good FAC control program and know proper inspection procedures to ensure the best prevention.

WEBresources>>>

Related search terms from www.waterinfolink.com: corrosion, erosion-corrosion, cavitation

For more information related to this article, visit www.wwdmag.com/lm.cfm/wd010906

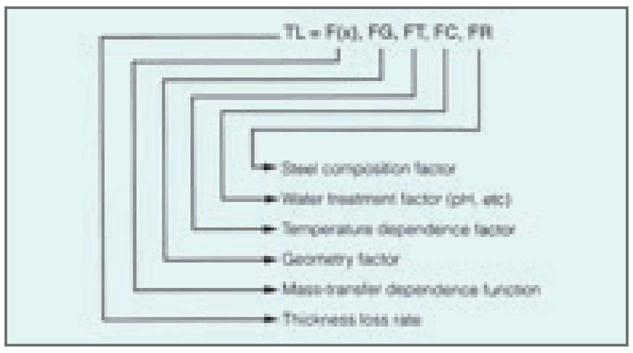
Flow-accelerated corrosion (FAC)—also called erosion-corrosion (E-C)—and cavitation are significant and costly damage mechanisms common to all types of utility and industrial steam and hot water cycles. There has been an increased emphasis on correcting these problems due to fatal accidents that occurred in 1986, 1995, 1996 and 2004.

The slow FAC damage can lead to a catastrophic "break-before-leak" situation with steam expanding and hot water flashing into steam. Carbon steel pipe thinning typically occurs in the feedwater, return condensate and wet steam parts of the cycle. It is estimated that more than 50% of units experience FAC. Sufficient knowledge exists to predict and prevent these two types of damage.

Flow-Accelerated Corrosion

FAC results in thinning of carbon and low-alloy steel components, mostly of carbon steel piping and tubing. It is a mass transfer process in which the protective oxide (mostly magnetite) is removed from the steel surface into the flowing water. The material wear rate depends on the steel composition, temperature, flow velocity and turbulence—and on water and water droplet pH and oxygen and oxygen scavenger concentration.

Figure 1. The parameters influencing FAC material wear rate.



These complex relationships are shown in Figure 1.

Most of the above factors have a very strong, exponential effect on the material wear rate.

The FAC problem is most pronounced in carbon steels. In these steels, even small concentrations of chromium, molybdenum and copper can improve the FAC resistance. A survey of 38 heats of carbon steel found that depending on the scrap composition, there could be up to 0.3% Cr, which can improve the FAC resistance up to 100 times. Where FAC problems cannot be resolved by changing water chemistry, carbon steels are often replaced by low-alloy steels, such as P11 and P22, or a weld deposited overlay is used.

Temperature has a pronounced effect on the FAC wear rate (see Figure 2), and when a system is inspected, components in the 250˚F to 400˚F range should be of the highest priority. Flow velocity (see Figure 3) has a strong effect, which makes wet steam systems very susceptible to FAC because the steam flow velocity is usually much higher than the water flow velocity.

Water Chemistry

Water chemistry effects are strong and often not well understood. The pH of feedwater and steam droplets needs to be kept above the 9.5 threshold, which depends on the pH agent used (see Figure 4) and on temperature. For ammonia and amines, their effect on droplet pH diminishes with temperature. The effects of oxygen and oxygen scavengers are often misunderstood. Oxygen is good at preventing FAC. It has been shown that 5 ppb of oxygen in feedwater can practically stop FAC, while excessive concentration of oxygen scavengers accelerates it. It has been shown that in most cycles that do not have copper alloy tubing, oxygen concentrations can be as high as 20 ppb without causing any problems.

FAC Experience

FAC control programs have been implemented in all nuclear plants in the U.S., France and elsewhere, and in many utility and industrial plants—yet major damage is still occurring.[1-5] This is particularly the case for combined cycle units. It is estimated that more than 50% of these units have FAC (mostly in heat-recovery steam generators, but also elsewhere in the cycle).

There are three main reasons for FAC: 1) Marginal management and insufficient knowledge (chemistry, flow velocity) by original equipment manufacturers (OEMs), architect engineers and owners/operators; 2) Imperfect technical tools (software): effects of temperature, oxygen scavengers and cavitation chemistry; and 3) Misrepresentation of the water chemistry history and material composition, leading to gross errors in FAC assessment.

Systems Typically Susceptible to FAC

Any carbon and low-alloy steel piping system and other components may experience FAC. The following are examples of the systems that have experienced FAC:

- Steam generators/boilers;
- Feedwater piping (Figure 5 is an example of a catastrophic failure of an 18-in. carbon steel pipe where, during 13 years of service, pipe thinning caused by FAC weakened the system. During an unrelated trip, the static pressure increased by about 50% and the pipe ruptured, killing four workers nearby.);
- Steam piping in heating systems;
- Deaerators;
- Condensers;
- Return condensate;
- Feedwater and other heaters, tubes, vessels, internals and heater drains;
- Downstream of flowmeters;
- Downstream of control valves; and
- Thermowells, sampling nozzles and injection quills.

Control of FAC

An effective FAC control program should include the assessment of the propensity of different plant systems and components to FAC, the use of available software with water and steam chemistry corrections and periodic inspections. Monitoring of iron concentration around the steam cycle is also useful; elevated concentrations may indicate ongoing damage in a specific subsystem.

FAC and cavitation evaluation procedures used by this

Figure 2. Temperature effect on FAC is greatest in 250 to 370˚F range – (Conditions: 580 psig, 115 ft/sec, pH = 7, 02<40 ppb, Exposure time = 200 hours).

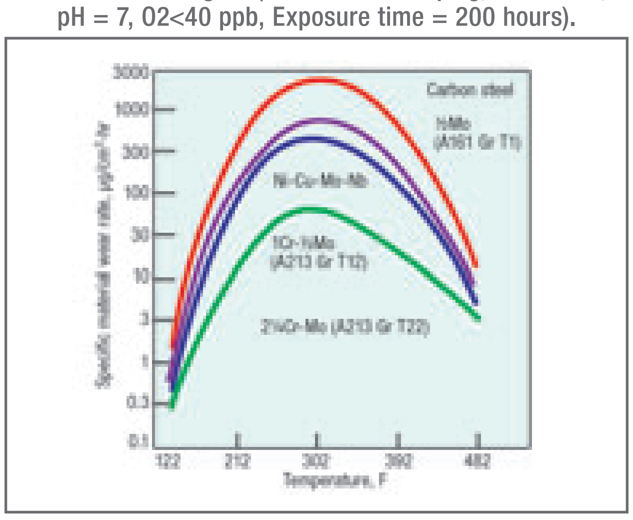


Figure 3. Flowing water increases material loss rate exponentially with flow velocity (Conditions: 580 psig, 356˚F, pH = 7, 02 < 5 ppb, Exposure time = 200 hours).

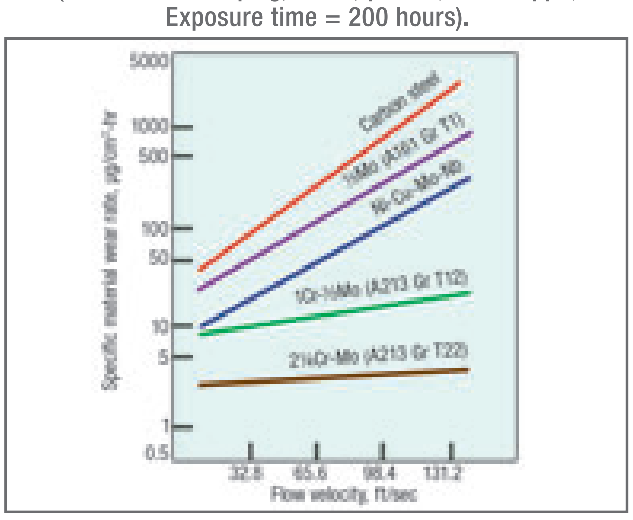
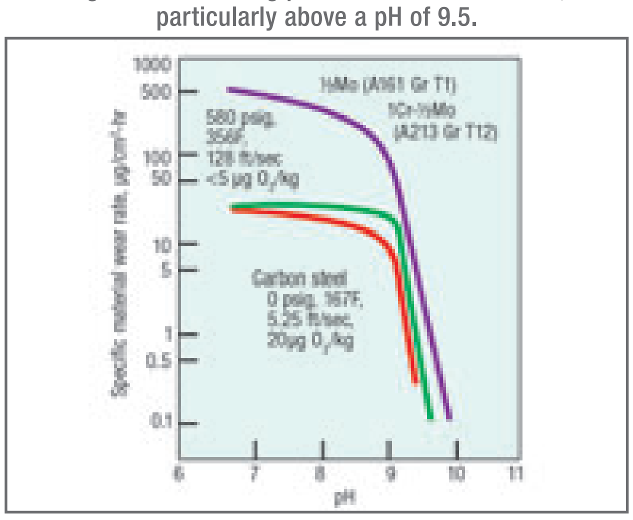


Figure 4. Increasing pH reduces material wear, particularly above a pH of 9.5.



author include the combined effects of:

- Component geometry;
- Flow velocity;
- Water and steam parameters;
- Material composition;
- Water chemistry (pH, oxygen, oxygen scavenger, CO_2, organics); and
- Operating experience.

Inspection and NDT

After a theoretical evaluation of the whole system for propensity to FAC and cavitation, the most susceptible components should be selected for inspection. The nondestructive (NDT) methods typically used include: ultrasonic wall thickness measurement, radiography of smaller sections with geometries that can cause turbulence and INCO test. Inspection grids have been developed for UI wall thickness measurements for typical geometrical elements. Often neglected are piping areas downstream of flowmeters, thermowells and injection quills. Both FAC and cavitation can be active downstream of these components, where vortices generated by the flow obstruction can travel for many feet. It is important to establish permanent critical locations for long-time monitoring of wall thickness.

Hydrotest

When there is urgency for safety or other reasons and the system cannot be shut down for inspection, a hydrotest of at least 50% overpressure can provide a temporary degree of safety. Many components can be inspected during operation using X-ray techniques.

FAC Software

Three groups of software packages have been developed for assessment of wall thinning caused by FAC; by EPRI, EdF and Siemens/KWU. Results of predictions of FAC with the use of the software have been mixed, some realistic and some very wrong. The main reasons for the wrong predictions include poor representation of water chemistry in the software (at temperature pH, concentration of oxygen scavenger, concentration of oxygen and chemistry of water droplets), oversimplification of the water chemistry history by the user and not using the actual steel composition.

Cavitation

Cavitation (or cavitaton/erosion) is the name given to the repeated growth and collapse of bubbles (or cavities) in a liquid because of local static pressure fluctuations, usually caused by changes in flow velocity. If the pressure in a flowing liquid decreases to below its vapor pressure because of, for example, significant increases to the local flow velocity, then vapor bubbles are nucleated. These bubbles are transported downstream from this flow disturbance. When they reach a region of higher pressure, they collapse suddenly and may erode any solid material in their vicinity.

Any liquid water handling system that can operate near the saturation conditions is susceptible to cavitation damage. The low-pressure part of the system, such as the suction of booster pumps and boiler feed pumps, can be close to the saturation conditions. This proximity to saturation can be locally increased by increased flow velocity around obstacles and in regions of turbulence where the static pressure of the water is reduced or by an increase in water temperature.

Cavitation is most often caused by the collapse of steam bubbles, but it can also be caused by gases (nitrogen and oxygen) and

Figure 5. Feedwater pipe elbow damaged by FAC and ruptured due to unexpected increase of static pressure caused by a reactor trip.

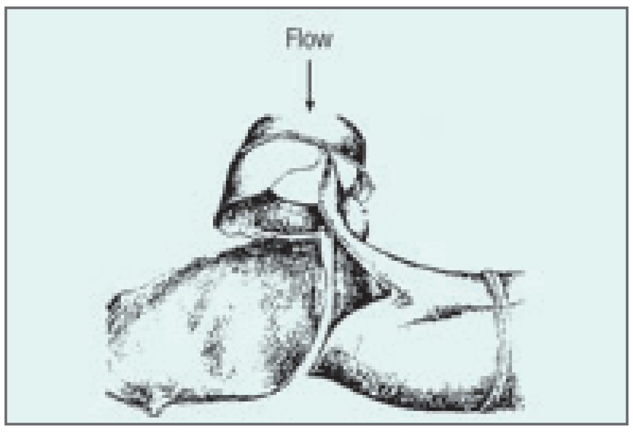
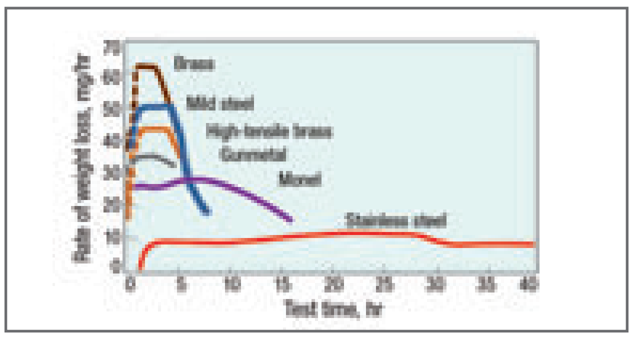


Figure 6. Cavitation susceptibility of various materials.



volatile chemicals coming out of the solution in water and subsequently redissolving.

Cavitation Behavior of Materials

Unlike FAC, all materials used in steam cycle water systems are susceptible to cavitation damage (see Figure 6). The material property that correlates best with the susceptibility to cavitation is the fatigue limit. However, it is not clear whether, for various aqueous environments, the cavitation correlates with air fatigue or corrosion fatigue properties.

Recommendations

Every steam and water plant should have a formal program for prevention of FAC and cavitation, starting with an early design review. The design review should include all the parameters influencing FAC (see Figure 1).

In cases where organic water treatment chemicals such as amines, dispersants and oxygen scavengers are used, their effects and the effects of their decomposition products should be considered.

When using any FAC software, special attention needs to be paid to the representation of at-temperature pH_T, pH of water droplets, concentration of the oxygen scavenger and concentration of oxygen.

Piping should be inspected after all orifices, thermowells, sampling nozzles and chemical injection quills, and leaking valves. In addition, boiler blowdowns, downcomers, headers, drum liners, saturated steam pipes, steam separation systems, turbine extraction pipes and extraction valves, feedwater heater drain valves and shells, feedwater piping, condensate return piping, condensers and boiler feed pump recirculation lines should be inspected.

The inspection methods for wall thinning used today include ultrasonic wall thickness measurements, X-ray of piping and other components, pulsed Eddy Current technique and a magnetostrictive sensor technique.

Cavitation can also be detected online by listening to the noise produced by the collapsing steam or gas bubbles. This can be done by listening to acoustic noises or using acoustic microphones and by the use of acoustic emission techniques.

It is important to establish critical locations for periodic long-time monitoring. Instrumental techniques for continuous in-line monitoring are also available. WWD

References

For a full list of references, visit www.wwdmag.com/lm.cfm/wd010906.

Otakar Jonas, P.E., is president of Jonas, Inc. Jonas can be reached at 302.478.1375 or by e-mail at jonasinc@steamcycle.com.

For more information, write in 1106 on this issue's Reader Service Card.