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Guidelines for detection, monitoring and prevention of flow accelerated corrosion (FAC) in the pulp and paper mill

Scope

This Technical Information Paper provides guidelines for the detection, monitoring and prevention of flow accelerated corrosion (FAC) in the pulp and paper mill. FAC is a damage phenomenon that causes wall thinning of carbon steel piping, fittings, vessels and other equipment in systems that carry wet steam, high-quality boiler feedwater or condensate. FAC can occur under single- or two-phase flow conditions.

This TIP is a compendium of information about FAC. It is largely based on a paper by Petric and Ksiazek (1). With author permission, the compiling task group quotes the paper and has liberally inserted it into the TIP. Their goal is to review and update the original work with current information.

The power industry has found that the control of FAC requires corporate commitment, comprehensive implementation procedures, sound analysis and inspection programs, and a long-term strategy. This document addresses only the basic characteristics of FAC in the pulp and paper mill; the organizational focus on an FAC strategy is left to the individual company structure.

FAC wall thinning has resulted in catastrophic failures of high-energy piping systems for transport of water and steam/water mixtures. Based on research sponsored by the electric utility industry (2), the risk of FAC ruptures have been highlighted and the key parameters influencing FAC have been well identified. As a result, many of the nation's power plants have implemented organizational and technical procedures (sometimes assisted by computer-based modeling tools) to detect, monitor and hopefully prevent metal loss due to FAC. This approach uses FAC detection guidelines to inspect susceptible piping/process components for metal loss during scheduled outages. The results are then re-evaluated at regular inspection intervals to monitor the rate, if any, of FAC attack.

The piping and component systems of the pulp and paper mill are similar to those found in industrial power and steam plants. They include many of the same systems – boiler feedwater, condensate and extraction steam – which have been found to be susceptible to FAC in large power plants. Also, the pulp and paper mill has additional susceptible systems that are not found in electric utility plants. For instance, there are multiple boiler feedwater and condensate piping runs that are not isolated in the plant. Failure of these runs due to FAC related ruptures or leak-induced hot vapor/steam flashing hazards can lead to personnel exposure.

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This TIP describes the FAC mechanism, process conditions required for FAC to be active, and guidelines to assess FAC in the plant as part of a systematic procedure. The procedure includes detection (covering system evaluation, susceptible piping systems and process components, inspection and testing), evaluation of FAC thinning damage, FAC monitoring and preventative practices that also address repair/replacement options.

Risks to safety

Failures that result from FAC damage are often in the form of sudden pipe ruptures or leaks that release steam or water into the environment. Thus, there is a major safety concern if personnel are located in the vicinity of such a failure. Injuries have occurred in the pulp and paper industry and fatalities have occurred in the utility industry as a result of FAC. A reported incident at a pulp and paper mill that resulted in two fatalities in 1996 may also be due to FAC. A confirmed paper mill report stated that while investigating a leak on a recovery boiler, the economizer outlet piping failed from FAC, which resulted in an injury (3).

If a leak occurs in a piping system that has pressurized hot water or wet steam, an assessment should be made on the damage extent, location and pressure of the system. A small leak can increase in size and magnitude with no warnings. Industry standards and guidelines, such as the ASME and NBIC Codes, should be used to replace and/or repair pressure piping components and systems that are susceptible to or have been damaged by FAC.

Safety precautions

All parties involved in inspection and the monitoring of equipment must ensure that a safe work environment is maintained. Follow all mill safety procedures, work practices and personal protection equipment requirements. If radiography is selected as an inspection technique, comply with all appropriate regulatory agencies for radiation safety.

When trying to repair components that may have experienced FAC, a task safety evaluation should be conducted to ensure the safety of repair personnel. This evaluation should consider all proposed tasks, including depressurization of the system, so that hazards can be removed and repairs can be conducted safely.

If a leak is found, removing insulation or lagging to determine the extent of the leak while the component is under pressure can increase the hazard to personnel. There are companies that specialize in repairing leaks in higher pressure components while the pressure is maintained. The mill should consider using such a service if the pressure must be maintained on the component.

Background

FAC, sometimes also referred to as flow-assisted corrosion, is a common term that has been used in the electric utility industry for about 25 years. Other industries such as the pulp and paper industry, however, may not be as familiar with FAC, its potential consequences, the parameters which influence FAC, or the systems within steam plants and paper mills which are susceptible to FAC. While to-date, there have been few cases of identified FAC damage and injuries in the pulp and paper industry, this unfamiliarity could result in serious economic loss, personal injury or even fatalities. There has been extensive research performed in the area of FAC that can benefit the pulp and paper industry. The potential for FAC failures within the pulp and paper mill can be minimized by understanding FAC and establishing programs to detect and address FAC damage in the plant.

FAC is a damage mechanism that causes thinning of carbon steel piping, fittings and other equipment that carry saturated steam or water. The normally protective iron oxide layer (magnetite) on the component dissolves in single-phase or two-phase flow under certain conditions that influence the solubility of the iron oxide layer. The flow of the fluid across the surface carries away iron ions, promoting further dissolution that leads to an increase in wastage of the component. FAC occurs on the water contacting side of the component and, therefore, is more difficult to detect than exterior or weld-related types of metal loss. Depending on the conditions of the system, corrosion rates can be very high, such as 2.5 mm (0.100 in.) per year.

Flow of water or water/steam mixtures across metal surface can produce wastage by multiple mechanisms. Erosion-corrosion (EC) has been known as a common damage mechanism in the pulp and paper industry for a long time (4).

The visual examination of a component thinned due to EC may have an appearance very similar to an FAC-thinned component. However, there are fundamental differences between FAC and EC. EC is a damage mechanism where metal is thinned due to mechanical removal of the oxide. EC is often found in piping and equipment carrying/processing heavy, particulate-laden fluids such as pulping liquors and condensate streams containing hard oxide particles and/or depressed pH. In contrast, the FAC mechanism, operates by a dissolution process.

Appendix A presents a selection of FAC failure cases in the wood processing and pulp and paper industries.

Process conditions that can cause FAC

There are a number of process conditions that determine the rate of wastage of carbon steel components due to FAC. The conditions are related to factors that influence the solubility of the magnetite layer on the surface. FAC metal loss rates are a function of velocity of the fluid, component geometry (e.g., pipe size, location relative to flow disruptions, etc.), pH, dissolved oxygen, temperature and metallurgy.

Fluid velocity (mass transfer), including geometry effects

The velocity of the water or water/steam mixture affects the mass transfer of the iron oxide layer (magnetite) into the fluid stream. As the velocity increases, so does the rate of FAC. There is no minimum velocity threshold at which FAC will not occur; however, some researchers suggest that “bulk water velocities greater than 8 to 10 fps (2.4-3.0 mps) may create significant iron removal” (5).

The size and shape of a component have a significant effect on the rate of wastage due to FAC. While the overall velocity of the liquid may be within design limits, localized high velocities and turbulence, caused by component geometry, can result in locally increased wastage rates. For instance, FAC is more prevalent downstream of elbows, valves and tees. The turbulence at these locations increases dissolution rates of the oxide layer.

Steam/water quality

FAC can occur with exposure to either water or steam/water mixtures, typically referred to as single-phase or two-phase flow. The dissolution of the protective magnetite oxide requires the presence of liquid water with specific conditions that promote the solubility of the oxide.

FAC has been found to occur in the pH range from neutral to significantly alkaline (7 to 9.5) (6); this range is typical for power and recovery boiler operation within the paper industry. The wastage rate generally decreases as pH is increased through this range. Above pH values around 9.3 or 9.5, the potential for FAC is low.

The level of dissolved oxygen in the water affects the wastage rate due to FAC. The oxygen concentration range where FAC occurs (0 to 20 ppb) is where the solubility of magnetite (Fe_3O_4) is greater than hematite (Fe_2O_3) and the oxygen is so low the magnetite cannot oxidize to hematite (6) to help protect the steel.

For many years, paper mill boiler operators have wanted to reduce dissolved oxygen levels to as low as possible (such as 0 ppb) to minimize pitting in the economizer section of the boilers. The industry guideline limit for power and recovery boilers, with a well designed and functioning mechanical deaerator, has been 7 ppb (7). Research in the utility industry has shown that when dissolved oxygen levels are above 50 ppb, there is a substantial reduction in wastage due to FAC in carbon steel components. In some cases, known as oxygenated treatment, utility boiler operators remove virtually all the dissolved oxygen from the water and then add dissolved oxygen back in a controlled amount to help prevent FAC. This approach requires very high purity water to be effective. It is important to note that while further research is required to extrapolate these findings to lower pressure boiler applications, a more comprehensive review of boiler water chemistry parameters at pulp and paper mills may be warranted.

Temperature

The FAC dissolution of oxide is a function of temperature and typically has a bell-shaped curve. The temperatures where FAC is considered to operate range from about 100 to 250°C (212 to 482°F). The temperature where the maximum metal loss rate occurs depends on many factors. For instance, the temperature where wastage is a

maximum is generally higher for two-phase flow compared to single phase flow. The boiler feedwater for many power and recovery boilers is in the range of 140 to 160°C (284 to 320°F). In pulp and paper mills, the temperature must be maintained in this range because when the feedwater temperature is too low in power and recovery boilers, sulfur containing flue gases produce acid dew point corrosion in the economizer sections. Single-phase flows, having a temperatures of 95°C (200°F) or less, exhibit very little or no FAC damage. It is important to note that FAC failures have occurred at temperatures around 230°C (450°F).

Metallurgy

Most of the piping components in the low-pressure water, steam and condensate systems of the paper industry are made of plain carbon steel. The addition of chromium can greatly reduce FAC metal loss rates in steel components. Alloys containing chromium of at least 0.10% can reduce FAC rates. Low alloy steels that contain more than 1% chromium, effectively eliminate FAC susceptibility. Small amounts of molybdenum and copper can have a positive effect on reducing the rate of FAC, as well, although not as much as chromium.

Detecting FAC

FAC is a complex phenomenon which is influenced by the parameters mentioned above. Before inspecting systems for FAC, it is important to establish a structured, comprehensive and well-documented organizational and technical procedure that addresses locations and components susceptible to FAC. If wastage is found, the procedure can later be used to monitor the progression of FAC over time.

First, engineering evaluations of the systems (a systems review) should be performed to determine possible components susceptible to the conditions that allow for FAC. Special attention should be given to historic information if the plant has experienced leaks and/or ruptures to highlight locations to inspect for FAC damage.

As a product of the evaluation, an inspection protocol is developed, implemented and regularly practiced. Water treatment evaluation and monitoring is established or updated to address FAC water-side parameters and their impact on wastage rates.

On-going technical/engineering and organizational (management) reviews are necessary for the structure to be useful, economical to implement, and able to provide risk-controlled safe operation of the susceptible components.

Systems review

An engineering/technical evaluation of the systems in the mill must be an initial step. This evaluation will compare the mill's piping and component operating range to the FAC parameters mentioned above. If the number and complexity of the plant's susceptible components is large enough, there are computer software programs (8) available to assist with the evaluation of the system versus the occurrence of the FAC supporting parameters. Both the engineering evaluation and the computerized system evaluation programs will require piping and instrumentation diagrams (P&ID) and process information. In each case, the goal is to help determine where FAC is likely to occur, and to highlight locations in the system to inspect for FAC damage.

Eliminating unlikely locations

The system review should start by eliminating the piping and component locations where FAC will not be expected to occur. There are water and steam systems in a pulp and paper mill that will not be susceptible to FAC based on the parameters discussed above. The system characteristics that would typically not be susceptible to FAC, as determined by power industry research (1), are):

- Corrosion-resistant materials, such as stainless steel and low-alloy chromium containing steels with greater than 1% Cr (such as 1.25 or 2.25 Cr steels; e.g., P11, P22)
- Superheated steam (not including the attemperator or desuperheating stations as they have two-phase conditions present)
- Temperature less than 93°C (200°F), single-phase only
- No flow