Reprinted from
Encyclopedia of Material Science (Pergamon Press)

Corrosion in the Power Industry

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Corrosion is a leading cause of loss of availability in both fossil and nuclear power plants. The financial impact of corrosion to the power industry is on the order of billions of dollars per year. Corrosion occurs within the steam cycle of nuclear and fossil power plants and on the fire-side of fossil fired power plants. Steam cycle related corrosion has been the most troublesome causing failures to major components such as boilers, steam generators, turbines, feedwater heaters, condensers and the piping throughout the steam plant. Failures on the fire-side of fossil plants include; boiler tubes, superheaters, scrubbers and other pollution control equipment. Corrosion occurs throughout the steam cycle as illustrated in Figure 1 (a conventional fossil steam cycle). Multiple forms of corrosion can impact a given component in the system. This is illustrated in Figure 2 for a steam generator in a Pressurized Water Reactor (PWR) type nuclear plant.

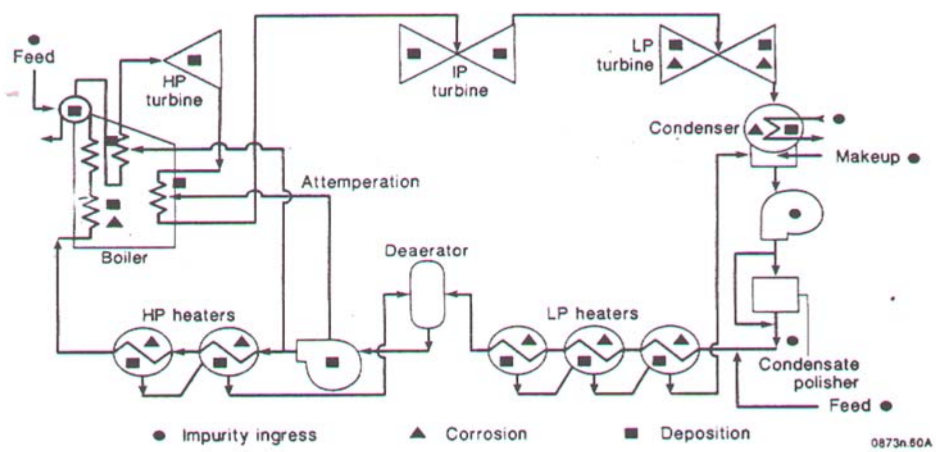

Figure 1. Typical drum boiler fossil plant cycle showing locations of impurity ingress, corrosion and deposition.

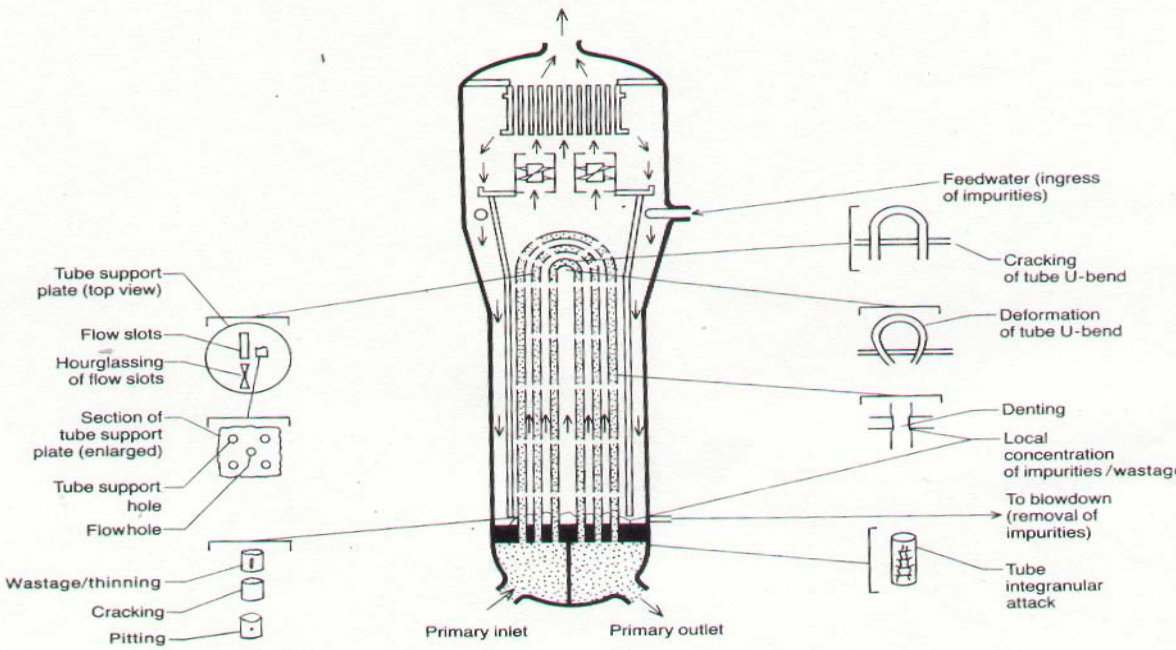

Figure 2-1. Sketch of Recirculating Steam Generator with Indicated Problems

1. Methods of Controlling Corrosion

Corrosion is pervasive in the power industry because of the high operating temperatures. Corrosion processes like other chemical or electrochemical processes generally occur faster at elevated temperatures. High temperatures are required to improve the thermodynamic efficiency of the steam cycle and therefore, limiting the temperature is not the preferred mitigation strategy. Four primary approaches are used to avoid or minimize corrosion in system components:

a) The use of corrosion resistant alloys. Stainless steels are used in reactor vessels and piping in nuclear plants as well as high temperature superheaters in fossil plants. Nickel alloys such as Inconel™ are widely used for specialized applications such as in the steam generators of PWRs and within sub-components of nuclear reactors. Other Nickel alloys are used for example in flue gas desulfurization systems. Titanium alloys are being used principally for condenser tubes where resistance to corrosion from salt water and good heat transfer properties are required. Copper/Nickel alloys are still widely used because of their excellent heat transfer properties for heat exchange application such as feedwater heating, but due to the deleterious corrosive effects of copper released from these components on other system components their use is decreasing. Carbon steel is widely used for boiler tubes in fossil plants and for piping throughout the steam cycle. Carbon steels with low levels of chromium or other additives are specified for specific corrosion issues such as flow accelerated corrosion of piping materials.

b) Specialized heat treatments. Much of the corrosion in power plants, especially of alloys is localized at grain boundaries. Sensitization of stainless steels and other alloys can be controlled by specialized heat treatments. Heat treatments must be designed to optimize the physical properties of the structural materials with its corrosion resistance.

c) Design Features. Stress Corrosion Cracking (SCC) and crevice corrosion are two of the most serious corrosion problems in the power industry. Reduction of the local and applied stresses both during manufacture and subsequent heat treatment as well as in-situ stress reduction techniques are important mitigation strategies for SCC. Likewise, designers are careful to eliminate crevices in steam generators , large turbines and other components. Often crevices are sites where impurities can accumulate by local boiling and electrochemical mechanisms. Concentrated impurities can lead to accelerated corrosion. The crevices between tube support plates and the thousands of heat exchanger tubes in PWR Steam Generators is one of the most serious corrosion problems facing the nuclear power industry.

d) Controlling the environment. In today's conventional nuclear and fossil power plants, ultrapure water is used as the working fluid for producing electricity by the Rankine cycle. The water is purified using ion exchange, filtration and other processes to remove the impurities before the water is added to the steam cycle. Local crevices and other occluded regions however, can lead to the accumulation of trace levels of impurities resulting in aggressive environments. Operators of power plants must be diligent in controlling the water chemistry to insure that any problems that degrade water quality are corrected quickly. Organic and in-organic additives are used to provide further corrosion protection. Oxygen is one of the main corrosion agents in the steam cycle. Adding an oxygen scavenger, such as hydrazine directly to the condensate water can be used to remove residual oxygen. Ammonia and other organic amines are added to the feedwater to control the pH. Maintaining alkaline conditions throughout the steam cycle can minimize the general corrosion rate of carbon steels that are widely used in piping systems. Corrosion inhibitors, dispersants and other chemicals are also used in some power plants to control corrosion and to minimize fouling of heat transfer surfaces. Sodium phosphate was once used in most nuclear plants and is currently used in many fossil plants to buffer the pH due to impurity ingress excursions.

2. Commonly Encountered Forms of Corrosion

In fossil plants, boiler tube failures and turbine blade or disk failures are the most serious problems. At least twenty-eight mechanisms have been identified for boiler tube failure, most of which are related to corrosion. Some of the corrosion related mechanisms include; caustic gouging, hydrogen damage, pitting, fireside oxidation, corrosion fatigue, and stress corrosion cracking. Turbine availability losses are generally attributed to blade failures by corrosion fatigue and stress corrosion cracking mechanisms.

Nuclear plants have experienced capacity losses due to corrosion damage to a number of components the most serious of which are stress corrosion cracking of Boiling Water Reactor (BWR) coolant piping and reactor internals and PWR steam generator tubes. Other corrosion problems include, erosion-corrosion of carbon steel steam-system piping, particularly turbine cross-around piping and extraction lines. In the reactor, nuclear fuel cladding failures in BWRs and PWRs can lead to increased O&M costs, investment losses, reduced cycle efficiency and increased inspection and reconstitution costs as well as to operational restrictions and outage duration increases. Crud induced localized corrosion (CILC) in BWRs, was a major problem in the mid-70's has been controlled by reducing copper transport. PWR cladding failures have generally been associated with debris or are due to hydriding. Irradiation-assisted stress corrosion cracking (IASCC) of core internals is becoming of increasing importance as plants age.

In both fossil and nuclear plants, problems with service water systems have included fouling, sedimentation and various forms of corrosion (including microbial induced corrosion). These corrosion issues have had a significant impact on maintenance costs at some plants.

2. Economic Considerations

Power plants are large capital investments. The plants are designed to operate nearly continuously for 40+ years. Throughout the world, the demand for reliable inexpensive power has increased the need to operate these systems at full capacity and at as low a cost as possible. Most of the important corrosion issues are due to chronic as opposed to acute causes and may take years or decades to manifest themselves. Operators of power plants must control short-term costs without compromising the long-term integrity of these systems. Replacement of major components is cost prohibitive in many cases. In nuclear plants, the contamination of components with radioactive isotopes increases maintenance costs significantly. The industry is committing significant resources towards eliminating or mitigating corrosion in an effort to reduce the cost of power to both the consumer and to industry.