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A VIEW FROM THE PENTHOUSE: USEFUL INFORMATION FOR THE WORLD OF BOILERS

SOME METALLURGICAL PROBLEMS WITH HRSGs

For the past many years the installation of choice for new electric-generating capacity has been a natural gas-fueled combustion turbine. On the back end is a heat-recovery steam generator (HRSG) to capture the sensible heat in the turbine exhaust and improve overall thermal efficiency. These HRSG units are a series of heat exchangers that are designed to heat water in the feedwater heater or economizer, boil water in the evaporator, and superheat steam in the superheater section. There is usually more than one operating pressure for economizers and evaporators as well. The HRSG will increase the output by more than 35%. The principal advantage of this combination is the favorable heat rate, perhaps as low as 7,500 btu/megawatt of electricity generated.

A second important feature is the use of natural gas as the primary fuel. Oil is the back-up fuel. Natural gas is inherently less polluting than either coal or oil-fired boilers. Since methane (or natural gas) is one atom of carbon to four atoms of hydrogen, a significant portion of the heat (more than 50%) comes from combustion of hydrogen to water vapor which limits the amount of greenhouse gas (carbon dioxide) emitted per megawatt generated. For all of the thermodynamic advantages, however, these HRSG devices come with some important, potential, metallurgical problems.

Natural gas is colorless and odorless. For safety reasons, a small quantity of an odorant, a sulfur compound, is added. Gas leaks may then be detected by the smell. Enough odorant is added that some sulfur dioxide and sulfur trioxide are part of the combustion turbine exhaust. To prevent dew-point corrosion by sulfurous and sulfuric acids, the feedwater heaters have been fabricated of 304 or 304L austenitic stainless steel. These alloys are also chosen to minimize the oxygen-pitting corrosion problems on the water side of the tubes. The water inlet temperature to the feedwater heater is between 70° and 100°F, well blow the dew-point of sulfuric acid. The exact dew-point depends on the concentration of sulfur trioxide in the exhaust but is around 280°F. The dew-point of sulfurous acid (sulfur dioxide and water) is lower, around 230°F.

Unexpected, however, were the failures of the feedwater heaters by chloride-induced, stress-corrosion cracking that initiated on the outside or gas side. A combustion turbine is, in effect, a very large vacuum cleaner that ingests all of the atmospheric contaminants along with the combustion air. Cooling towers use chlorine or chlorine compounds as a biocide and contribute chlorine and chlorides to the environment. When the wind is in the "wrong" direction, cooling-tower spray becomes a part of the turbine inlet air. Other sources of chlorides are seawater and perhaps road deicing salt, as well as industrial smog. Whatever the source, chlorine compounds then find their way into the combustion exhaust. The feedwater-heater inlet temperature is around 70-100°F, well below the hydrochloric-acid dew point of around 130°F. Inevitably the coldest portion of the inlet to the feedwater heaters is below the hydrochloric-acid dew-point. When the conditions are just right (or wrong, depending on your perspective), hydrochloric acid (and perhaps other chloride species) condenses on the feedwater heater. Failures have occurred in the austenitic stainless steel by chloride-induced stress-corrosion cracking. The cracks initiated on the outside or gas side of the tubes.

In order to conserve space and reduce manufacturing costs, some feedwater heaters or economizers have a flow pattern through a split inlet header, with up-flow and down-flow in the same module. Water enters the lower header from one end, rises to the upper header, across the header, and flows back down the other half of the heat exchanger. The water absorbs heat on both the up-leg and down-leg parts of the flow path. The result is the temperature is higher in half the heat exchanger. A baffle at the mid-point of the lower header assures the proper flow pattern. Thus there is an inherent temperature difference between the two halves of the heat exchanger. This temperature difference leads to a thermally induced strain. The hotter tubes are longer than the cooler tubes, and the strain between the two creates thermal-fatigue cracks usually at the toe of the tube-to-header weld at the mid-point of the headers. The cracks often develop in any under-cut left in the socket or attachment weld. Over a fairly short time, leaks will develop caused by the temperature difference between the up-leg and down-legs.

A third unexpected problem has been the oxygen pitting noted in some special locations of the feedwater heater or economizer. The design of these heat exchangers may contain a pair of tubes with a slight bend just below or above the header to permit a radial entry of the tube. While the bends may only be 30°, or less, they are made to a very tight radius. The extrados or outside of the bend is left with a residual stress equal to the yield stress. The cold work associated with these tight-bend radii lead to preferential locations for corrosion, both oxygen pitting and general attack.

Oxygen pitting may be viewed as a localized solution of the steel by the oxygen-contaminated water. The more highly stressed or the more severely cold worked the steel is, the easier it is to dissolve. Thus preferential attack will occur in those regions of most severe deformation. This form of attack is sometimes called stress-enhanced or stress-assisted corrosion. In cycling units, it has been referred to as corrosion fatigue. Any highly strained site is an open invitation to corrosion. It does not matter whether the strain is from an applied load (at a weld attachment for example) or residual strain from cold bending.

During start-up, the pH may not always be stabilized within the control range. The pH is adjusted to minimize the corrosion rate; and any deviation, either up toward more basic, or down toward more acidic, will temporarily increase corrosion. As with oxygen attack, general corrosion is more rapid at regions of higher localized stress.

These close-radius bends, especially at the inlet, are a favored spot. This problem may be prevented by a stress-relief anneal after cold bending. For ferritic steels, a temperature in the range of 1100°-1350°F, depending on the alloy, is satisfactory.

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