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

SCALE EFFECTS

Steam or water reacts with steel to form an iron-oxide scale on the inside surface of waterwall (WW) and superheater/reheater (SH/RH) tubes. The formation of these oxides is necessary and beneficial. They form protective barriers against further oxidation, and corrosion.

$$4H_2O+3Fe = Fe_3O_4+4H_2 \qquad (1)$$

For the high-temperature components, the scale forms exclusively at the steam/metal interface, and is referred to as formed-in-place oxide. Figure 1 shows a metallographic cross section through the steam-side scale from a T-22 tube.

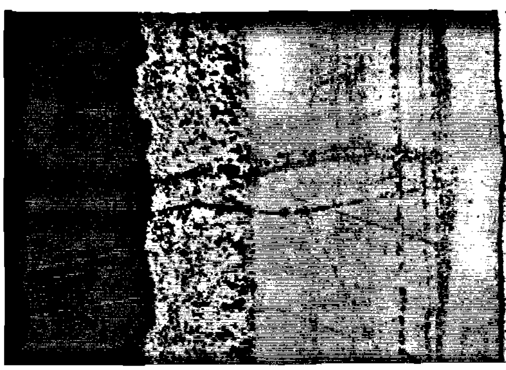

Figure 1

In addition to the formed-in-place oxide, there is iron oxide that forms elsewhere in the boiler, usually the economizer, and deposits on the water-filled tubes. Incorporated in this deposit are chemicals intentionally added to the boiler water (for example, phosphates for pH control), contaminants as a result of improper water treatment, and corrosion debris from the feedwater heater and condenser. These water-side deposits will usually contain small amounts of silica, calcium-magnesium carbonate, and corrosion products from the pre-boiler circuits. Copper, nickel, and zinc are often present, too. When metallic copper appears, it forms by reaction of copper ion with iron as shown in (2).

$$Cu^{++}+Fe = Fe^{++}+Cu \qquad (2)$$

The difference in appearance between a SH and WW scale is obvious. The superheater tube has a denser and thicker scale. WW tubes have a more porous and rougher metal/scale interface as a comparison of Figures 1 and 2 will show.

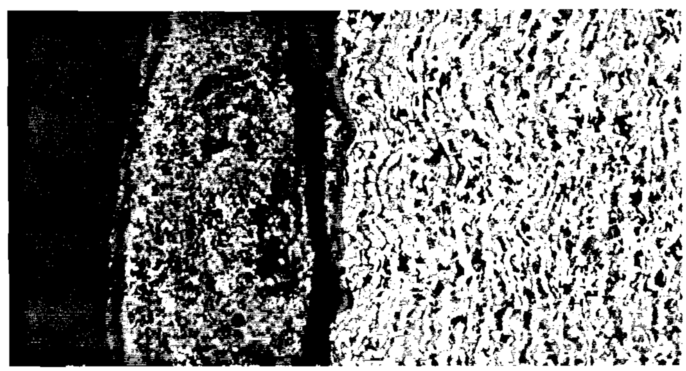

Figure 2

The most serious effect of these ID scales and deposits is the thermal barrier they present to heat-transfer. Since the deposits have a thermal conductivity about 5% that of the steel; these oxides form effective insulating layers. The net effect of a thermal resistance on the inside of the tube is to raise tube-metal temperatures. An estimate of just how big this effect may be is calculated from simple steady-state heat-transfer equations. The heat-flux is equal to the temperature gradient divided by a thermal resistance, as shown in (3).

$$Q/A = \Delta T/R \qquad (3)$$

where Q/A = Heat-flux BTU/hr-ft^2
ΔT = Temperature gradient, °F
R = Thermal resistance, hr-ft^2-°F/BTU

The thermal resistance of the scale is, in effect, the thickness of the insulating layer divided by its thermal conductivity, corrected for the curvature and size of the tube.

$$R_s = \frac{r_3 \ln r_2/r_1}{k_s} \tag{4}$$

R_s is thermal resistance of scale
r_3 is half the OD, in.
r_2 is half the ID, in.
r_1 is actual inside radius, in.
r_2-r_1 is the scale thickness, in.
k_s is scale thermal conductivity.

As a first approximation, we can set the temperature gradient through the deposit as numerically equal to the temperature increase in the steel tube as a result of the deposit. This is a reasonable approach, as the steam temperature does not change appreciably in a SH (old SH has same outlet temperature as new) and not at all in a WW tube. The saturation temperature in a WW is unaffected by heat-transfer conditions. The amount of steam generated may vary slightly but not the temperature. Thus, Eqs. 3 and 4 indicate the temperature increase due to the fluid-side deposit is equal to the heat-flux times the thermal resistance of the deposit.

For a RH tube, say 2.5" OD with an actual wall thickness of 0.200", and using the scale thickness shown in Figure 1 at 25 mils, the estimated tube-metal increase varies from 25°-67°F, as shown in Table I.

TABLE I
REHEAT EXAMPLE

Q/A	ΔT
15,000	25
25,000	42
40,000	67

For a T-22 superheater tube with a diameter of 1.75" and an actual wall thickness of 0.380" and the same 25 mils of scale, the temperature increase varies from 38°-101°F, as shown in Table II.

TABLE II
SUPERHEAT EXAMPLE

Q/A	ΔT
15,000	38
25,000	63
40,000	101

In the case of a WW tube with a 2.5" diameter and an actual wall thickness of 0.250", the condition is even more severe. Heat fluxes in the furnace vary from about 75,000 to 140,000 BTU/hr/ft². Thus using the scale thickness shown in Figure 2 at just under 10 mils, the temperature increase due to the water-side deposit varies from 67°-112°F, see Table III.

TABLE III
WATERWALL EXAMPLE

Q/A	ΔT
75,000	67
100,000	90
125,000	112

The increases in metal temperatures lead to increased fire-side corrosion rates in the SH and RH as well as the earlier failures due to high-temperature creep. In the case of the WW, the increase in tube-metal temperature can lead to under-deposit corrosion, hydrogen damage, and in the extreme, microstructural changes of spheroidization, graphitization, and ultimately creep failure.

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