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

WALL THINNING AND TUBE FAILURES

In the normal operation of a boiler, tube wastage or wall thinning occurs. Oxidation by reaction of steam with steel on the inside of the tubes, and oxidation by reaction of the excess oxygen within the flame on the outside are expected. Wastage is exacerbated fly-ash erosion, soot-blower erosion, water-side corrosion, and fuel-ash corrosion. These wastage processes lead to uniform wall-thickness reduction. Oxygen pitting and thermal or corrosion fatigue will lead to local, non-uniform thinning. In general, guidelines need to be developed to identify wall thicknesses at which continued safe, trouble-free operation may be jeopardized. Guidelines for tube replacement in waterwall or economizer tubes may be developed from the simple hoop stress equation. These components operate well below the creep range so the wall thickness at failure may be estimated quite simply. The principal stress in a cylinder with internal steam pressure is the hoop stress, S psi, and is given by Equation 1:

$$S = \frac{P(Dm)}{2W} \quad (EQ1)$$

where: P is the steam pressure, psi
Dm is the mean tube diameter, inch
W is the wall thickness, inch.

EQ 1 gives a reasonably good estimate of the hoop stress, provided the stress calculated is below the yield strength of the material. Thus the strains are all elastic without the complications of plastic deformation. For fire-side wastage, it is better to use the ID which makes Dm = Di+W; for water-side corrosion it is better to use the OD which makes Dm=Do-W. To a first approximation, EQ 1 may be rearranged and the wall thickness at failure estimated from EQ 2 for fire-side corrosion and EQ 3 for water-side wastage.

$$W = \frac{PDi}{2S - P} \quad (EQ2)$$

$$W = \frac{PDo}{2S + P} \quad (EQ3)$$

Failure may be expected when the calculated hoop stress as a result of the internal steam pressure equals the yield strength of the material at the operating temperature. Plastic deformation would occur, and a rupture may be expected. Thus the wall thickness at failure may be estimated from EQ 2 with the hoop stress set equal to the yield strength. Table I below is a truncated tabulation of the yield strength for carbon steels similar to SA210 A-1 as a function of temperature.

Test Temperature °F	Yield Strength Psi
80	36,000
500	27,800
700	25,400
900	21,500
1100	16,300
1300	7,700

Since waterwall tubes and economizer tubes operate in the neighborhood of 500-700°F, the use of 25,000 psi as the yield strength at 700°F will provide an estimate of the wall thickness at failure. As an example, a 2600-pound boiler may have a waterwall tube of 2.75 in. OD x 0.290 inch MWT, of SA210 A-1 material. Using EQ 2 with the pressure equal to 2600 psi, the tube ID equal to 2.11 in., and the yield strength at 700°F of 25,000 psi gives a wall thickness at failure of 0.116 in.

The above calculations assume the fire-side wall-thickness reduction is smooth and leaves the circular ID cross-section the same. Figure 1 shows such a wastage pattern. Since the desirable condition is to prevent failures, the wall thickness needs to be greater than calculated in EQ 2.

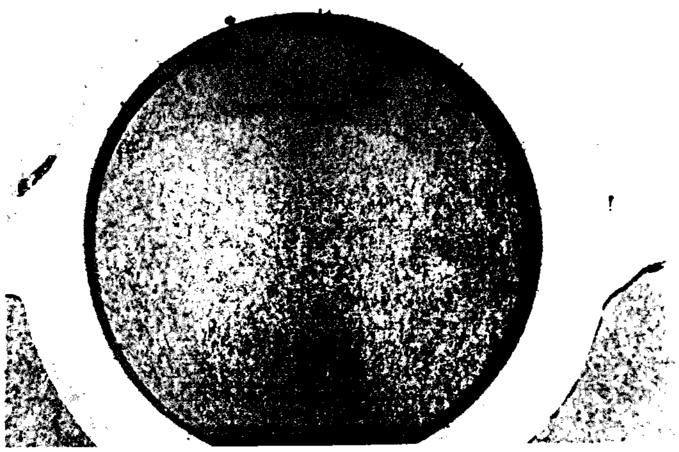

Figure 1.

Thus the recommendation would be to use not the yield strength in EQ 2, but say 75% of the yield strength. When 75% of the yield strength is used, the wall thickness at replacement is found to be 0.157 in. in our example.

When there is substantial water-side pitting as a result of control problems with the boiler-water chemistry, the stress at the tip of a deep pit may be estimated from EQ 4.

$$S = \frac{PD}{4W} \quad (EQ4)$$

Where: S is the hoop stress in a sphere, psi
D is the diameter of the pit, in
W is the thickness at the tip of the pit, in.

EQ 4 is the hoop stress in a thin-walled sphere. As the pit depth increases, the thickness of steel at the tip obviously decreases, and failure would be expected at some wall thickness that may be estimated from EQ 4, if the tip of an isolated pit is assumed to be a sphere. Figure 2 shows a water-side pit. Generally the tip of a pit may be assumed to be a sphere and from Figure 2 the diameter is 0.04 in.

Figure 2. (25x)

Again, for our 2600-pound boiler, failure would be expected when the calculated hoop stress at the tip of the pit is equal to the yield strength, and that occurs at a wall thickness of about 0.001 in. or a pit depth of virtually the full wall.

That isolated pits do not lead to steam leaks until the pit depth is nearly equal to the wall may be illustrated by the following. Often following the chemical cleaning of boilers that suffer severe pitting, several leaks upon restart may appear. What happens is the oxide that fills the pits is removed, the "plug" is gone, and failures then develop when the unit is repressurized.

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