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

TUBE WASTAGE/WALL THINNING

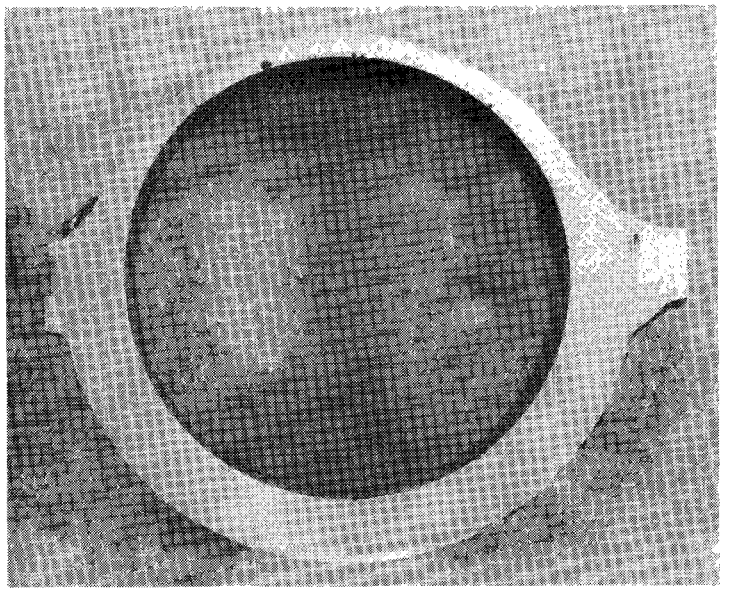

Figure 1

During normal boiler operations, a certain amount of tube wastage or wall thinning will occur. Such wastage may be caused by: erosion by fly ash, coal particles or soot blowers, corrosion by fuel ash or oxidation. In most cases the metal loss cannot be prevented. Guidelines are needed for tube replacement, criteria for the extent of wall thinning that can be accepted without failures and forced outages.

As an example, Figure 1 displays a cross section of a waterwall tube with severe metal loss. The boiler has an operating drum pressure of about 2600 psig and the waterwall tubes are specified as 2 3/4" OD x 0.290" MWT, SA-210 A-1 material. This sample has an actual wall thickness of 0.093", and contains no failure! Tube wastage is caused by molten ash in a wet bottom coal fired boiler. This example has lost 2/3 of its specified minimum wall thickness (MWT) without failure.

An understanding for developing guidelines for tube replacement begins with a simple stress analysis. The circumferential or hoop stress, S, psi, in a tube of outside diameter, D, inch; wall thickness, W, inch; and internal pressure P, psi, is:

$$S = \frac{PD_M}{2W} \qquad \text{EQ 1}$$

where D_M is the mean diameter and equal to:

$$D_M = D - W \qquad \text{EQ 2}$$

Substituting EQ 2 in EQ 1 and rearranging to solve for W, gives:

$$W = \frac{PD}{2S + P} \qquad \text{EQ 3}$$

EQ 3 is close to the ASME Boiler and Pressure Vessel Code, Section I equation PG 27.2 for calculating the minimum tube wall thickness. A small "factor of ignorance" is added to EQ 3 to give the Code equation for W_{MIN} for welded construction:

$$W_{MIN} = \frac{PD}{2S + P} + 0.005D \qquad \text{EQ PG 27.2}$$

All of the symbols have the same meanings as previously noted except S is the Code allowable stress given in Table PG 23.1 of the B & PV Code, Section I. For waterwalls, economizers, low temperature superheaters and reheaters where metal temperature is below the creep range, the Code allowable stress is the tensile strength at the operating temperature divided by a safety factor of four (4). In using EQ PG 27.2 the design pressure, usually about 10% larger than the operating pressure, is used for P.

Let us calculate a MWT from EQ PG 27.2 and a wall thickness at which replacement should be made. Boiler conditions are:

1. Design pressure: 2900 psig
2. Tube OD: 2 3/4"
3. Metal temperature: 750°F (allowable stress from Code Table PG 23.1 is 13,000 psi for SA-210 A-1)

$$W_{MIN} = \frac{(2900)(2\ 3/4)}{2(13{,}000) + 2900} + 0.005(2\ 3/4)$$

$$= 0.290 \text{ inch}$$

Thus our example is 2 3/4" OD x 0.290" MWT, SA-210 A-1.

When tube metal wastage occurs from the

outside of the tube, both the diameter and wall thickness change. There is a redistribution of hoop stress within the wall. Since the stress that will cause failure is in the thinnest section at an unknown diameter, it is more convenient to use the inside radius, R_I, and mean radius R_M. EQ 1 and EQ 2 are altered to reflect this change from diameters to radii:

$$S = \frac{PR_M}{W} \quad \text{as } D_M = 2R_M \qquad \text{EQ 4}$$

and: $$R_M = R_I + \frac{W}{2} \qquad \text{EQ 5}$$

The inside radius R_I is given by:

$$R_I = \frac{D-2W}{2} \qquad \text{EQ 6}$$

Since failures are not intended to occur, R_I remains essentially constant as the wall thickness and outside diameter are reduced.

EQ 4 and EQ 5 are combined:

$$W = \frac{PR_I}{S - \frac{P}{2}} \qquad \text{EQ 7}$$

EQ 7 is solved for the minimum wall thickness necessary for replacement.

In order to calculate W in EQ 7, values for the pressure, P, and the safe stress, S, must be assigned. The Code uses design pressure for all stress related calculations. However, boilers actually operate at a lower pressure. Therefore it is appropriate to use operating drum pressure, about 10% less than design pressure, for P. The Code allowable stress below the creep range is the tensile strength at a given temperature, divided by a safety factor of 4. For waterwalls and economizers at metal temperatures below about 750°F, the actual tensile strength at 750°F is close to the Code specified minimum tensile strength at room temperature. For SA-210 A-1, this specified minimum strength is 60,000 psi. Boiler tubes show considerable thinning before failures occur. In the example given in Figure 1, wall thickness was reduced by 2/3. It seems reasonable to use a safety factor of $2\frac{1}{2}$, rather than 4, therefore.

In our example:

$$R_I = \frac{2.75 - 2(.290)}{2} = 1.085$$

P = 2600 psig
S = 60,000/2.5 = 24,000 psi

Solving EQ 7

$$W = \frac{(2600)(1.085)}{24{,}000 - \frac{2600}{2}} = 0.124"$$

The wall thickness when replacement is necessary is 43% of the original specified minimum thickness. No failure occurred in the sample shown in Figure 1 at 1/3 of the original wall.

Thus for boiler tubes operating below the creep range it is quite safe to allow tube wastage to reduce the wall to about 40% of the original.

The next time you have a boiler tube failure due to erosion or corrosion induced wall thinning, calculate the stress at failure from EQ 4. I'd be interested in knowing the conditions when the tubes ruptured. Please fill in the chart below and send it to me.

ORIGINAL DIMENSIONS, OD & WALL:

MATERIAL:

DRUM PRESSURE:

AGE OR OPERATING HOURS AT FAILURE:

FINAL DIMENSIONS, OD & WALL:

LOCATION:

BOILER FUEL:

CAUSE OF WALL THINNING:

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