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

DENTS AND DINGS

There are occasions during operation when a boiler tube becomes partially collapsed. The most obvious cause of these dents is a slag fall onto the hopper slope. However, superheater and reheater tubes can be damaged by a violent rupture in the neighborhood. The flailing of a severed tube end can do considerable damage to its neighbors. The question always is "how big a dent and how much of a reduction in cross-sectional area or steam or fluid flow is tolerable?" Some thoughts.

The operation of a boiler is a dynamic balance between heat flow and either steam generation in the waterwalls or steam superheating in a superheater or reheater. Any upset in this balance will lead to increased tube-metal temperatures. That is, reduced cooling by a reduced fluid flow leads to increased metal temperatures and premature creep or stress-rupture failures. A reduction in the cross-sectional flow area will obviously lead to reduced cooling by reducing fluid flow. In the extreme, a slag fall may virtually close off a waterwall tube. In this case, a tube failure may occur almost immediately, usually by a wide-open, high-temperature burst at the high heat-flux zones of the furnace (See VOL.IV, No. 4 of this Newsletter). The second effect is to change the stress distribution within the tube which may lead to a localized stress increase and premature failures.

Figures 1, 2 and 3 show typical dents. The photographs are cross-sectional views taken through the minimum diameter of the dent. Fig. 1 is from a damaged roof tube dented by the rupture of a superheater tube in the vicinity. Fig. 2 is a cross section through a reheater tube dented by a shotgun pellet used for de-slagging. Fig. 3 is a dent caused by an improper lift during installation. For comparison purposes, the correct circular cross section is presented.

A comparison of the ring sections in each photo indicates the flow restriction or reduction in cross-sectional area at the dent. In order to measure the flow restriction, a photocopy of the photograph was made and the ID of each tube carefully cut with a pair of scissors.

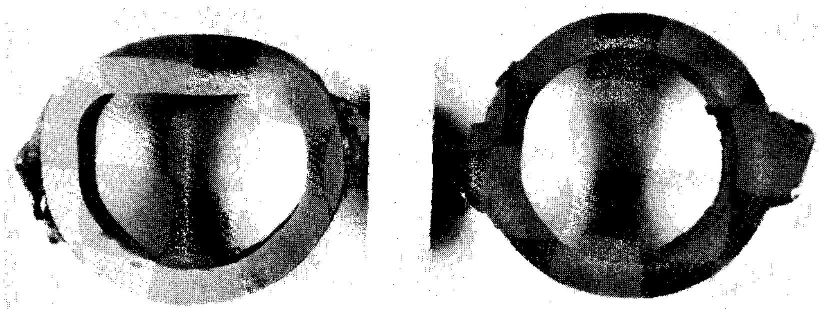

Fig. 1. Roof tube damaged by flailing tube.

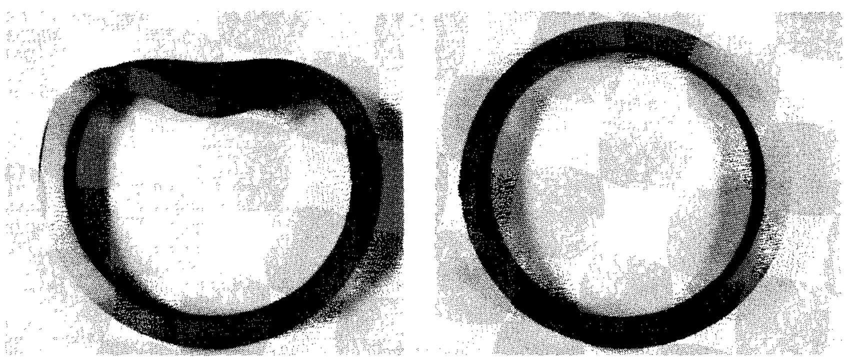

Fig. 2. Shotgun pellet damage.

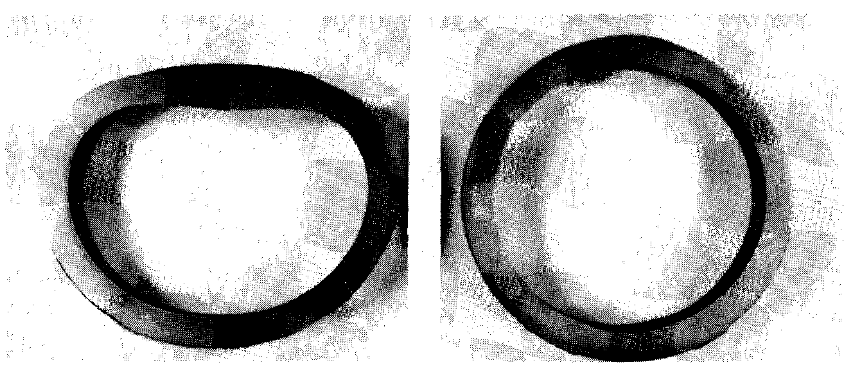

Fig. 3. Dent from improper lift.

The shapes of the paper cut-outs accurately reflect the cross sectional areas at the end of the tube and through the dent. These two cut-outs are weighed to 4 decimal places. The relative weights give the relative areas of the two paper cut-outs. By this technique the dents were shown to reduce the steam-flow area by 4-13%. The dented tube from the improper lift, Fig. 3, has an area reduction of less than 4%. The damaged roof tube from a guillotine rupture of a superheater tube, which then hammered the roof tube, had an area-reduction of 7 1/2%; and the shotgun-pellet dent, Fig. 2, has the largest area reduction, 13%.

There are two concerns with this type of tube damage:

1. The reduction in cross-sectional area will lead to a flow restriction. A reduced cross-sectional area increases the resistance to fluid flow which reduces the fluid flow. With reduced fluid flow there is less cooling and high-temperature creep or stress-rupture failures are possible.

2. The deformation leads to a redistribution of stress. The localized stress at the dent may be slightly higher than designed for, which again increases the chance of failure. Clearly this higher stress is of greater concern in high-temperature components that operate within the creep range. For waterwall tubes or economizer tubes that operate below the creep range, this higher stress is unlikely to cause any concern at all, see VOL. II, NO. 3 of this newsletter. There are two minor concerns for dents made by shotgun pellets, used for de-slagging of superheaters and reheaters. One is grain-boundary penetration of the steel by molten lead. While this phenomenon is rare, it has been observed and has led to failures. When the molten lead coats the grain boundaries, there is a dramatic weakening of the steel which leads to steam leaks. The other is an impact failure in thin reheater tubes of stainless steel. For tubes in service long enough to form sigma phase within the microstructure, ashotgun pellet may have sufficient impact to rupture the tube. Sigma phase reduces the impact strength and ductility of austenitic stainless steels. While these two failure mechanisms are rare, failures from these causes are known.

In order to assess the size of a dent that would be too small to adversely affect flow, two fabrication techniques are relative. When a backing ring or chill ring is used for tube-to-tube butt welds, an area reduction of up to 20% is possible, depending on the style of chill ring. In one extreme case the ID at a well-placed backing ring was 1.346", while the tube bore was 1.545". These lead to relative areas of 1.42 and 1.87 square inches, or an area reduction of 24%.

One other area of tubing manufacture that leads to flow restrictions is close-radius bends. A 10% flattening of the tube at the bend will lead to an area reduction of something greater than that, perhaps 14 or 15% due to the thickening of the tube walls along the inside of the bend.

Thus, it seems reasonable to suggest that for dents caused by operational problems in boiler tubing that restrict the flow by less than 15% would be quite safe for long-term operation. The drawback, of course, is how to define 15% flow restriction by measuring the shape of the OD of the tube. For tubes that are slightly flattened, as for example, Figs. 2 and 3, a flattening of approximately 1/4" has led to flow restrictions less than 10%. The 1/4" flattening in Fig. 2 represents a 16% reduction in diameter, and the flattening in Fig. 3 represents a 13% reduction in diameter. Thus, a flattening of perhaps 20% on the diameter would lead to a flow restriction of something less than that and would be unlikely to lead to long-term problems.

There once was a boiler named Thor
Whose superheater erupted with a roar.
Was it fly-ash erosion?
Or coal-ash corrosion?
Call Dave French, he'll tell you the score!

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