APRIL CHAPTER MEETING SEMINAR

Oxygen Corrosion of Carbon Steel Boiler Tubes

Presented by Dwight Sheppard, Capitol Boiler Works

Dwight Sheppard of Capitol Boiler Works (CBW) presented a case study of a condominium complex that experienced oxygen corrosion of their carbon steel hot water boiler tubes during the NAPE April Chapter meeting seminar. The case study follows below.

Background

The condominium has two identical horizontally oriented hot water boilers, connected in parallel, for providing heat to the residences. As CBW understands, only one of the boilers (typically #1, set at 150°F) is normally used to provide heat; the other boiler (typically #2, set at 120°F) is kept warm to act as a backup in the event #1 boiler goes out of service. The boilers are connected in parallel with two chillers, which are themselves connected in parallel; therefore, the same water circuit is used for both heating and cooling.

Nameplate information indicates that each boiler was manufactured 32 years ago. For each boiler, the maximum working pressure for use in hot water heating is shown as 100 lbs. Each boiler is comprised of a cylindrical central firebox surrounded by a tube-in-shell heat exchanger. Each boiler is fitted with 194 carbon steel tubes. The tubes are 2.5-inch outside diameter (OD) 0.135-inch wall thickness and are 13-feet, 10-inches long. The boiler #1 was completely re-tubed eleven years ago while boiler #2 was re-tubed ten years ago. The boiler tubes are rolled and welded into the return pass tube sheet (where the failures occur), but are only rolled into the tube sheet at the other end (where the burner is located). The boiler tubes are unsupported between the two tube sheets.

For the past three years, one to three shutdowns have occurred each season to replace failed tubes. This season, nine shutdowns have occurred on #1 boiler and four shutdowns on #2 boiler. Reportedly, the tube failures have been identical: A waterside groove developed in the failed tubes at the return pass tube sheet, followed by through-wall cracking of the tubes. All failures have occurred in the lower quadrant of the heat exchanger, and most failures have typically occurred between the 10 and 2 o'clock position on the tubes.

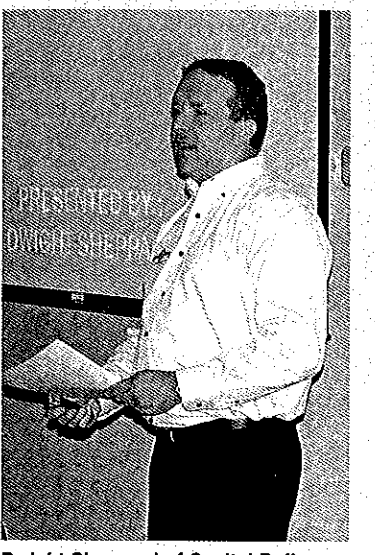
This heating season a heating riser piping replacement project has been underway which has necessitated draining and refilling parts of the heating/cooling circuit. In addition, the records of the firm that handles water treatment indicate that a recirculating pump was leaking, though the magnitude of the leak was not described.

NAPE Members attend the April Chapter meeting seminar presented by Dwight Sheppard of Capitol Boiler Works. Photo by Richard McGalem.

Analysis

Ten (10), approximately 2-inch long, failed tube ends were provided for examination. Also provided was one (1) approximately 6-inch long tube end from the burner end of boiler (where no failures had occurred.) Each tube end was a partial circumferential section, part of each tube having been cut away to facilitate removal from the boiler.

Each of the failed tube ends displayed the groove and crack failure features, described above, immediately adjacent to the ½-inch wide band where the tube had been rolled into the tube sheet. On each tube the groove was approximately 1.5-inches long, extending only part way around the circumference. In each case, the groove appeared to be the result of corrosion, mainly due to its irregular surface, rather than mechanical deformation.



Dwight Sheppard of Capitol Boiler Works presents the April Chapter meeting seminar. Photo by Richard McGalem.

Six (6) boiler tubes that had failed were available for examination at the condominium. It was noted that the general appearance of the tubes fell into two categories: Tubes that had a red, rusty appearance and tubes that had a black, shiny appearance. Closer examination of a rusty tube revealed the presence of significant pitting, accompanied by rust-colored mounds (known as "tubercles") along its length.

Metallurgy

One of the failed tube ends supplied was sectioned longitudinally through the groove and crack for metallographic examination. The presence of thick black oxide on the groove and parts of the crack surface, as well as lack of deformation in the microstructure, confirmed that corrosion was the cause of the grooving. There were no indications of overheating of the tube.

Water Treatment Records

CBW was provided with the records of eight (8) service calls made to the condominium by the water treatment provider within the last six months. The following items were noted:

- A steady drop in nitrite inhibitor levels from 840 ppm to approximately 300 ppm within 6 months.
- The addition of molybdate inhibitor to the water treatment regimen, presumably to combat tuberculation.
- The notes of a "recirculating pump" leak thought to be responsible for a drop in nitrite inhibitor levels.

The note of lower-than-expected nitrite levels possibly being the result of "water loss or oxygen in the system that is 'eating-up' the chemical."

Results of Water Sample

A sample of water was obtained from #1 boiler during the CBW visit. The sample was analyzed for dissolved oxygen, which had a concentration of 5ppm.

Problem #1: Condensation

Every water boiler manufacturer lists its standard for the minimum return water temperature. This is usually between 140-160° F. The reason is because the colder the water temperature, the colder the boiler tubes will become. In boilers, when the tube temperature becomes at or below the dew point temperature, there will be condensation. As moisture increases, the ignition equipment and flame sensors get wet and fail creating an emergency situation that needs to be resolved.

Problem #2: Oxygen Corrosion

The boiler tube failures were caused by oxygen corrosion of the tubes produced by dissolved oxygen in the boiler water. This was based on the rusty appearance of most of the failed tubes, the presence of pits and tubercles (classic oxygen corrosion features) along the lengths of some of the failed tubes, and the thick oxide present on the metallographically prepared failure site. Oxygen corrosion of the tubes at the failure locations led to the grooving described earlier. The groove reduced the tube wall thickness and subsequently acted as a stress-raiser during normal thermal cycling of the boiler. Stresses from thermal cycling eventually produced the final failure of the tubes by cracking.

"The boiler tube failures were caused by oxygen corrosion of the tubes produced by dissolved oxygen in the boiler water."

The reason the failures occurred at the return end of the boiler was that the tube sheet and tubes were hottest at this end, which produced localized boiling of the oxygen-laden water. Boiling of the water produced a scouring effect on protective oxide films, which led to localized grooving. (It cannot be ruled out that tubes outside this quadrant could also be damaged, although the corrosion may have been occurring at a slower rate. It is fairly certain, however, that other boiler tubes, besides the ones that failed, have suffered pitting and may have the groove damage.)

It is possible that occluded cell (crevice) corrosion played a role in the grooving. In this scenario, a differential aeration cell is set up between the tube adjacent to the return end tube sheet and the tube just under the edge of the tube sheet (assuming leakage of boiler water under the tube sheet.) This cell will lead to corrosion of the tube just under the tube sheet, which accounts for the observed grooving.

Chemical Analysis

Under normal (ideal) operating conditions boiler water is de-aerated (i.e., less than 1 ppm). Under such conditions, low residual oxygen produces a layer of black iron oxide (magnetite), which protects steel tubing. Thermal cycling can fracture the magnetite layer, which exposes underlying bare steel to the boiler water. In the presence of excessive dissolved oxygen (greater than 2 ppm) in the boiler water, accelerated corrosion of the steel tubes occurs. CBW analysis shows that the boiler water contained dissolved oxygen at levels greater than 5 ppm.

Engineering Practice

Under the current situation, aeration of the boiler water occurred through the frequent additions of make-up water to the system after drain-downs for the riser replacement project and repairs to the boiler after tube failures, and as a result of the recirculating pump leakage noted in the water treatment records. The steady drop in nitrite inhibitor over the last 3 months without a simultaneous rise in nitrate levels (as indicated by CBW water tests) provides support for this assertion. [If no make-up water had been added to the system, nitrate (oxidized nitrite) levels would be expected to be much higher than measured.]

The Final Answer

The current water treatment regimen is inadequate to prevent oxygen corrosion; boiler tube failures will continue to occur as long as dissolved oxygen is present in the boiler water. ■

April Chapter Meeting & Seminar

By *Bulletin* Staff

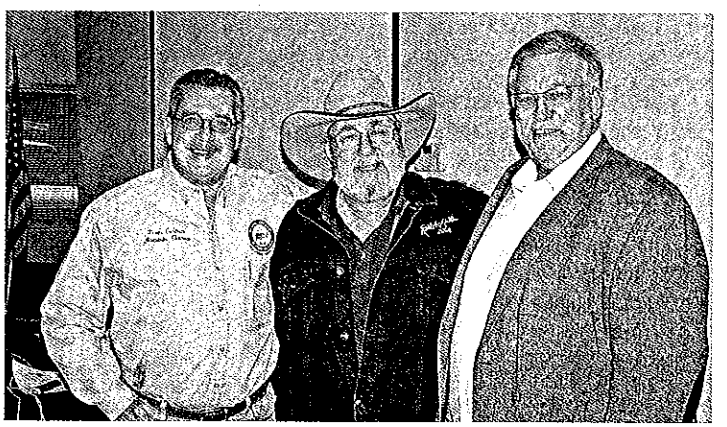
NAPE would like to thank Dwight Sheppard of Capitol Boiler Works, Inc. for presenting a seminar on Oxygen Corrosion of Carbon Steel Boiler Tubes prior to the April Chapter Meeting. The informative seminar was well attended. NAPE members enjoyed a wonderful dinner along with the seminar presentation.

The nominations for Board of Directors were announced and will be voted in at the next Chapter meeting. Also, a drawing for one of the openings on the spring fishing Chapter boat was held. Tyrone Bryan was the lucky winner. There was also a drawing for attendees at the seminar to get a chance at winning a seat on the boat. Three names were pulled and they are: Don Laverty, Ray Hayes & Miquel Castillo. Remember there are still two more seats to fill and the drawing is coming soon so see Donnie Childress for a raffle ticket.

The next chapter meeting will be held on Wednesday, May 6, 2009. Justin Liberto of Bopat Electric will be speaking about electrical preventive maintenance. Make a note on your calendar and plan to attend. ■

Donnie Childress organizing the 50/50 contest at the April Chapter meeting.

Left to Right: Dale Treadway, Dave Grinder, Ted Ross, and Curt Struchtemeyer at the April Chapter meeting.



Board Members: Donnie Childress, Martin Blake, Ted Ross.

Photos by Richard McGalem.