Boiler tube failures (BTFs) in natural circulation high pressure drum boiler of a power station

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Received 18 July 2007; revised 13 October 2008; accepted 25 November 2008

This paper assesses boiler tube failures (BTFs), especially in boiler water wall tubes (BWWTs) for a natural circulation high-pressure fossil (natural gas) drum boiler unit (TIME-COB-206, Russia). Metallographic (micro and macrostructural) examinations of BWWTs materials (carbon steel, Russia) were carried out extensively. Analyses of carbon (mild) steels (0.22% C) revealed distinctive changes in ferrite-pearlite distribution, might be due to decarburization. Huge pits, few grooves followed by flow lines were observed on internal surfaces of BWWTs with respect to length of power plant operation. Corrosions or scaling in BWWTs depicted one of the major causes of BTFs in fossil units with drum boilers usually treated by coordinated phosphates.

Keywords: BTFs, Boiler, Hydrogen damage, Regime, Water wall tubes

Introduction

Boiler tube failures (BTFs), due to corrosion, scale formation and materials degradations, are major problems in thermal power plants. Dooley¹,² investigated tubes failures in conventional fossil fired boiler as well as in combined cycle power plant, besides BFTs in all volatile teread (AVT) fossil drum boiler unit. Bursik³ found that under-deposit mechanism continue unabated with hydrogen damage occurring in drum boiler unit (60%) due to deficiencies in cycle chemistry. Hirano⁴ investigated corrosion behavior of boiler materials during long-term lay up of a fossil unit. Kohler⁵ studied corrosion damage in copper alloyed power cycle components of thermal power plant. Hickling⁶ identified environmentally assisted cracking (EAC) of carbon steel and low-alloy steels pressure vessels and pipelines for steam generating system of nuclear power plants. Prisyazhniuk⁷ simplified a technique for calculating index of corrosion and scale forming properties of boiler water.

This study presents cause failures in boiler water wall tubes (BWWTs) materials (carbon steel, st.- 20, Russia) for a natural circulation water wall tubes high pressure (158 kgf cm⁻²) drum boiler unit (TIME-COB-206, Russia), at unit No.4 Ghorasal Thermal Power Station (GTPS), Bangladesh.

Experimental Procedure

Using a Metallurgical Microscope (Japan), micro and macro structural investigations of BWWTs materials were carried out. During analyses of microstructures, hydrochloric acid, nitric acid and water were employed for etching of sample materials. Analyses of the composition of BWWTs materials, deposits attained and operational chemical parameters of boiler water were carried out by using an Atomic Absorption Spectrophotometer (AAS), model: AA6650, Shimadzu (Japan) and a Photo-electric colorimeter, model: KFK-2 (Russia).

Measurement of Deposits

Quantity of deposits on inside surface of BWWTs at different period of time was determined⁸ by rubbing out deposits from a definite surface area (3 cm × 3 cm) of WWTs followed by weighing. Composition of deposits (as oxide) was determined by gravimetric⁹, titrimetric, AAS and colourimetric⁸⁻¹⁰ techniques.

Results and Discussion

Coordinated phosphate treated natural circulation water wall tubes high pressure drum boiler unit No.4, at GTPS, Bangladesh, is operated with maintaining chemical
Table 1—Supplied (Russian) parameters for natural circulation high-pressure (158 kg cm\(^{-2}\)) drum boiler unit

<table>
<thead>
<tr>
<th>Parameters</th>
<th>(pH)</th>
<th>EC* (µS cm(^{-1}))</th>
<th>Alk. p/m</th>
<th>(H_2)</th>
<th>SiO(_2)</th>
<th>N(_2)H(_4)</th>
<th>NH(_3)</th>
<th>Cl</th>
<th>Cu</th>
<th>Fe</th>
<th>DO</th>
<th>Na</th>
<th>P(_4)(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demi Water</td>
<td>6.5-6.8</td>
<td>0.3-1.5</td>
<td>00</td>
<td>0.02-0.1</td>
<td>0.02-0.1</td>
<td>0.02</td>
<td>0.002</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.002</td>
</tr>
<tr>
<td>Feedwater</td>
<td>9.1±0.1</td>
<td>0.8-4.0</td>
<td>0.50-1.0</td>
<td>0.02-0.04</td>
<td>0.02-0.04</td>
<td>0.5-1.0</td>
<td>0.004</td>
<td>0.005</td>
<td>0.02</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensate</td>
<td>9.1±0.1</td>
<td>0.8-4.0</td>
<td>0.50-1.0</td>
<td>0.02-0.04</td>
<td>Trace</td>
<td>0.5-1.0</td>
<td>0.004</td>
<td>0.005</td>
<td>0.02</td>
<td>0.020</td>
<td>≤0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler drum (clean)</td>
<td>9.3</td>
<td>4.0-8.0</td>
<td>1.5-2.0</td>
<td>0.50-1.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.040</td>
<td></td>
<td></td>
<td>3.0-6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt section (blow down)</td>
<td>9.5</td>
<td>Up to 40</td>
<td>1.5-2.5</td>
<td>0.1-0.2</td>
<td>2.0-6.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.60</td>
<td></td>
<td>Up to 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>9.1±0.1</td>
<td>0.50-1.0</td>
<td>0.0-0.015</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EC*—µS cm\(^{-1}\), Other units—mg l\(^{-1}\)

Chemical analyses of BWWTs materials (carbon steel, st-20, Russia) collected from boiler unit No.4 revealed slight changes in constituents in BWWTs. The steel BWWTs contained (average values): C, 0.22; Si, 0.21; Mn, 0.47; S, 0.02; and P, 0.015%.

During last overhaul of unit, hard, irregular, dark brown to black, tenacious deposits have covered internal surfaces of BWWTs after 96000 h of boiler operation. Microstructure images of internal BWWTs materials (carbon steel, st-20, Russia) of unit No.4 after 43800 h (Fig. 1) and 96000 h (Fig. 2) of power plant operation depicted distinctive changes (spreading trends) in ferrite (white) and pearlite (lamellar, black, i.e. \(\gamma \rightarrow \alpha + Fe_3C\)) distributions with respect to plant operating period. Microstructural change in carbon mild steel also indicates decarburization, initially around pearlite and then gradually spreading, may be due to long term high rate of heat input through BWWTs. Microstructural images of internal BWWTs materials of unit No.4 after 96000 h of operation revealed large pits and very few numbers of grooves (Fig. 3) and while irregular parallel flow lines were observed on inside surfaces of BWWTs at longitudinal direction (Fig. 4). Oxygen pitting was present along waterline throughout internal surfaces of BWWTs due to improper hydrazine dosing. While grooves might be resulted from accumulation of highly concentrated NaOH in BWWTs as well as erosion loss due to long time high rated circulation of water-steam system as well as excessive boiler blow down. Close macrostructure images show finely spaced, wave lines, parallel undulation on eroded internal surfaces of BWWTs, essentially due to excessive deposition on BWWTs, essentially due to excessive deposition on BWWTs, especially at high metal temperature. Maximum deposition was observed on fireside internal surface (388 g m\(^{-2}\)) and on insulation side of internal surfaces (290 g m\(^{-2}\)). Excessively immaculate chemical compositions (as oxides) of deposits collected (by rubbing out) from internal surfaces of BWWTs after three different periods (21900 h, 43800 h, and 96000 h) contained maximum (%): Al\(_2\)O\(_3\), CaO, MgO, P\(_2\)O\(_5\), CuO, Fe\(_2\)O\(_3\), and Fe\(_3\)C. The amount of Fe\(_2\)O\(_3\) followed by SiO\(_2\) amount of Fe\(_2\)O\(_3\) followed by SiO\(_2\) and Fe\(_3\)C, increases with respect to plant operating period. Maximum deposition were observed on fireside internal surface (388 g m\(^{-2}\)) and on insulation side of internal surfaces (290 g m\(^{-2}\)). Parameters as supplied by the Russian Plant manufacturers (Table 1).
Fig. 1—Microstructure of ∅ 60 × 6 Carbon Steel, Water Wall tube showing ferrite and pearlite × 600 (after 43800 h)

Fig. 2—Microstructure of ∅ 60 × 6 Carbon Steel, Water Wall tube) unit No. 4 showing ferrite and pearlite × 600 (after 96000 h)

Fig. 3—Macrostructure of (∅ 60 × 6 Carbon Steel, Water Wall tube, internal) unit No. 4, showing etch pits, × 60, in the transverse section (after 96000 h)

Fig. 4—Macrostructure of (∅ 60 × 6 Carbon Steel, Water Wall tube) unit No. 4, showing flow lines in the longitudinal directions, × 60 (after 96000 h)

Fig. 5—Macrostructure of (∅ 60 × 6 Carbon Steel, Water Wall tube, external fire side) unit No. 4, showing flow lines and groove in the longitudinal directions, × 60, (after 96000 h).

Fig. 6—Amount of deposit (gm²) built up on boiler water wall tubes of 158 and 100 kgf cm² boilers with respect to operating period.
fireside external surfaces of boiler WWTs followed by distinctive hemispherical pits adjacent to a distinct groove after 96000 h of plant operation (Fig. 5). It happened possible due to erosion of tube materials by highly heated fuel flow containing trace amount of sulphur in the fuel. Corroded regions of fireside boiler WWTs were covered with a thin but soft layer of brown corrosion product, which contained: iron, 93.4; silica, 3.3; carbonates, 1.7; and sulphur, 1.1%.

Scale layer thickness as well as deposits quantity (gM⁻²) in BWWTs increases with increase in boiler pressure followed by length of plant operation (Fig. 6). Moreover, burner position and excessive steam production contributed significantly to deposition and eventual overheating. So far, in one of the fireside tube (No.10, panel No.13), slight rupture and fissuring, might be caused by very long-term expose of metal to high temperature. Deposits contained high level of silica (10.7% SiO₂) in its constituent. Therefore, silica-containing deposits have very low¹² thermal conductively (0.2-0.6 Kcal.m⁻¹.h.°C). Even a relatively small amount of such a type of deposit can cause rise in wall temperatures considerably, and hence results in boiler tube overheating followed by bulging, rupture, and bursting of BWWTs.

Grooving on internal surfaces of boiler, WWTs might be resulted from caustic accumulation from excessive phosphates dosing into BWCR. Phosphates dosing parameters in BWCR of such a high-pressure drum boiler is found to be very high in comparison to Japanese¹³ practices of similar capacity. Actually, phosphates in BWCR produce NaOH and apparently concentrated to corrosive level beneath porous iron oxide deposits. Presence of hard magnetite deposits indicates exposure to concentrated NaOH¹⁴ administration in BWCR, which may finally cause in hydrogen damage that is almost always associated with BWWTs metal gouging followed by thick-walled ruptures. Robin¹⁵ depicted that employing steel alloy 600 (USA) tubes in re-circulating steam generators (RSGs), which chemically treated with phosphates, produces excessive corrosive thinning (waste) followed by stress corrosion cracking (SCC) on internal tubes materials.

After completion of overhauling the unit No.4, boiler was acid cleaned carefully and boiler chemical parameters were re-evaluated, especially phosphates parameter has been minimized. Now, unit has been operated at or slight below the designed loads and ensuring that all boiler components are working effectively. Procedure has minimized solid deposition on internal surfaces of BWWTs tube.

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Table 2—Chemical composition (%) of boiler WWTs (158 kg.cm⁻² boiler) materials (carbon steel, st.-20, Russia) with respect to operating period

<table>
<thead>
<tr>
<th>Location</th>
<th>Operating period, h</th>
<th>Carbon</th>
<th>Silicon</th>
<th>Manganese</th>
<th>Sulphur</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right wall</td>
<td>0</td>
<td>0.24</td>
<td>0.18</td>
<td>0.55</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Left wall</td>
<td>21900</td>
<td>0.22</td>
<td>0.21</td>
<td>0.50</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Front wall</td>
<td>43800</td>
<td>0.21</td>
<td>0.22</td>
<td>0.48</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Back wall</td>
<td>96000</td>
<td>0.18</td>
<td>0.23</td>
<td>0.44</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table-3—Chemical composition (average) of deposits attained on internal surfaces of boiler WWTs (158 kg.cm⁻² boiler) as a function of plant operation at GTPS, Bangladesh (maintaining chemical parameters as Table 1)

<table>
<thead>
<tr>
<th>Operating period, h</th>
<th>Fe₂O₃</th>
<th>SiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>P₂O₅</th>
<th>CuO</th>
</tr>
</thead>
<tbody>
<tr>
<td>21900</td>
<td>82.4</td>
<td>6.20</td>
<td>3.88</td>
<td>2.27</td>
<td>0.71</td>
<td>2.90</td>
<td>0.82</td>
</tr>
<tr>
<td>43800</td>
<td>72.3</td>
<td>8.2</td>
<td>6.20</td>
<td>3.80</td>
<td>1.9</td>
<td>4.8</td>
<td>1.02</td>
</tr>
<tr>
<td>96000</td>
<td>63.2</td>
<td>10.7</td>
<td>8.38</td>
<td>5.84</td>
<td>2.8</td>
<td>5.6</td>
<td>1.78</td>
</tr>
</tbody>
</table>
Conclusions
Administration of contaminated feed water (due to condenser leakage), excessive dosing of phosphates in BWCR, non-uniform practices of boiler blow down as well as over firing during startup are major causes of hard deposition on BWWTs, in such a type of high pressure drum boiler with respect to length of plant operation. Long term overheating of BWWTs caused distinctive microstructure changes in BWWTs materials (carbon steel, st.-20, Russia) due to carburization, initially around pearlite and then gradually spreading and causing micro fissuring, leading to inter-granular cracking followed by hydrogen damages. Thermal stresses during startup, shutdown, load changes as well as faulty boiler firing and fuel adjustment may also be reason for scaling followed by metallographic change in BWWTs materials.

Acknowledgement
Authors thank Head, Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering Technology (BUET), Dhaka 1000, Bangladesh for help in micro and macro examination.

References
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