Boiler Tube Life Management

D.J. Marks, P.J. James & C.J. Davis
Materials & Corrosion Team, Uniper Technologies Limited
Fuel & Energy Research Forum – Sheffield – 11th April 2018
We are Uniper

Our operations:
- Power Generation
- Global commodities
- Energy Storage
- Energy Sales
- Energy Services

Where we operate:
50 countries around the world

Main activities:
- Gas fired plants
- Coal fired plants
- Hydroelectric plants
- Energy storage
- Gas fields
- Gas pipelines & infrastructure
- Trading
- Energy sales (small to large customers, electricity & gas)
- Services
- Regasification

Generation:
- Net capacity by fuel type (GW)
- Electricity production (TWh)
- Employees: 13,000

Energy storage
- Gas 9bn m³
- Windgas ?? m³
- Battery ?? MW
Expertise built on engineering excellence and owner operator asset experience

We are a one-stop shop offering a broad range of services that work closely together, reducing complexity and risk for customers.

Our background as an asset owner/operator gives us deep understanding of the energy industry and our customers’ needs.

We are independent of equipment and component suppliers, giving us freedom to choose the best solution for customers.

Expertise based on experience

- Hibernia AG mining company
- UK Central Electricity Generating Board
- PLE Pipeline Engineering GmbH
- e.on
- uniper
- ruhrgas
- VEB Kraftwerke Ruhr AG
- Powergen UK Power Technologies
Boiler Evolution

250 years
# Modern Boiler Diversity

<table>
<thead>
<tr>
<th>Boiler Designs</th>
<th>Fuel</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Pass (Tower)</td>
<td>Coal (black &amp; brown)</td>
<td>Carbon Steel</td>
</tr>
<tr>
<td>Two Pass</td>
<td></td>
<td>T13Mo</td>
</tr>
<tr>
<td>Multiple Pass</td>
<td></td>
<td>T10Mo</td>
</tr>
<tr>
<td>D-Boiler</td>
<td></td>
<td>T23/T24</td>
</tr>
<tr>
<td>HRSG</td>
<td></td>
<td>T91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X29</td>
</tr>
<tr>
<td>Pulverised Fuel</td>
<td>Oil</td>
<td>T909/910/929/937</td>
</tr>
<tr>
<td>CFB</td>
<td>Orimulsion</td>
<td>T911/914/916</td>
</tr>
<tr>
<td>Bubbling Bed</td>
<td>Gas</td>
<td>Alloy625</td>
</tr>
<tr>
<td>Grate</td>
<td></td>
<td>Misc Coatings</td>
</tr>
<tr>
<td>Drum &amp; Once Through (Benson)</td>
<td>Waste</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biomass</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Boiler Designs**: Single Pass, Two Pass, Multiple Pass, D-Boiler, HRSG
- **Fuel**: Coal (black & brown), Oil, Orimulsion, Gas, Orimulsion

- **Temperature**: 80°C - 650°C
- **Pressure**: <1MPa - 35MPa
- **Load**: Stand-by → Cyclic → Seasonal → Base-load
Influence of Boiler Design on Failure Location

- Economiser
- Final Stage Superheater
- Evaporator / Superheater Panels
Boiler Tube Failures

- Boiler tube failures responsible for 2% – 5% loss of plant availability worldwide
  - This represents the majority of forced outages on plant
- Thermal boiler plant offers a wide range of tube damage mechanisms (at least 15 different failure modes)
- Plant design and operation can strongly influence the potential for tube failure

- Conventional fossil plant (Coal, Gas, and to some extent Biomass)
  - Many of these failures are influenced by commercial requirement for power generation
  - 2-shifting and low load operation of plant in response to market demands
  - High final steam temperatures to maximise efficiency

- Waste to Energy plant (and some Biomass plant) driven by alternative commercial model
  - Economic disposal of waste is primary concern
  - Failures due to aggressive nature of fuel represents primary issue
  - Reliable plant operation between planned outages is critical
  - Final steam temperatures limited (typically to ~400°C) due to corrosion concerns
Cost of Boiler Tube Failures

- Boiler Tube Failures are not generally a safety issue (although there are notable exceptions to this)
- Any preventative measures will be justified on commercial basis
- Major costs of tube failure are typically associated with lack of asset availability i.e. No Power Generation (e.g. Conventional Fossil) or No Fuel Consumption (e.g. Waste to Energy)
- The actual costs of tube repair are typically relatively minor
  - Scaffolding for access (where required)
  - Boiler Engineer to identify failure location and mechanism – Essential to plan appropriate repair strategy
  - Non-Destructive Testing – Damage to local tubes (thickness loss, crack detection, post-repair quality assurance)
  - Replacement tubing
  - Welding
**Tube Refurbishment Strategies**

- Extent of tube repair / refurbishment during planned outages will be dependent on market drivers
  - Conventional Plant
    - Refurbishment will be undertaken when stages become life expired. However, downward pressure on costs means prioritisation of replacement – unlikely all work will be undertaken.
    - During operational campaigns, repairs may be undertaken on an opportune basis, dependent on the prevailing operational practice (driven by the Electricity Market needs). Balance between investment and operational income.
  - Waste to Energy plant (and some biomass plant)
    - Aim to achieve uninterrupted operation (no tube failures) between planned outages – More regular replacement, and deployment of high grade materials to prevent failures
Pressure Parts Failure; Mechanistic Causes

- Mechanical
- Thermal
- Environmental
- Quality Control

- Fatigue
- Overheating/Creep
- Corrosion
- Erosion
Pressure Parts Failure; Mechanistic Causes

- Pressure Parts Failures
  - Mechanical
  - Thermal
  - Environmental
  - Quality Control

- Fatigue
- Overheating/Ckelp
- Corrosion
- Erosion

- Thermal
- Mechanical
- Corrosion
Fatigue

• Typically a start related damage mechanism, however:

• Fuel based issues can have an impact primarily due to propensity for fouling, and strategies utilised to removed fouling. Particularly significant for Waste to Energy and Biomass plants.

• Fatigue typically restricted to issues with:
  • Gas flow resulting in tube vibrations
  • Soot management strategies - Potentially long term issues associated with tube cleaning (rapping systems etc.)
Fatigue

- Gas pass tube vibrations can result in both fretting damage, and fatigue to tubes if the support structure is not optimised for the gas flow.
- Can be influenced through fouling and gas laning within the stage.
Pressure Parts Failure; Mechanistic Causes

- Mechanical
- Thermal
- Environmental
- Quality Control

- Fatigue
- Overheating/Creep
- Corrosion
- Erosion

- Aqueous
- Molten Salt
- Gaseous
- Fireside
- Steam/Water
- Oxidation
- Aqueous
Fireside Corrosion

- Active species determined by tube metal temperature and fuel chemistry – S, Cl, Alkali Metals, Heavy Metals.
- Monitored through visual/tactile surveys and strategic tube wall thickness checks.
- Refractory also employed to protect tubing, although this can sustain unacceptably high temperatures in flue gas at later stages.
Fireside Corrosion (Coal)

- Furnace wall (combustion zone)
- Gaseous mechanism
- Reducing (low $O_2$) environment a necessary pre-requisite (often associated with flame impingement)
- Fuel sulphur and chlorine worsen wastage rate where low $O_2$ persists
- Temperature and heat flux important parameters
Fireside Corrosion

- High temperature (steam tubing)
  - Associated with molten sulphatic phases (K/Na) from ash deposit
    - Scale fluxing
    - Enhanced sulphidation
  - Influence of fuel chemistry recognised (i.e. sulphur & chlorine)
    - Alkali metals (when tied into clays in coal) are relatively inert
    - However, Chlorine promotes release of Alkali Metals
  - Influence of temperature (>570°C) and incident heat flux
  - Mathematical relationship for austenitic tubing:
    \[ r = A \times B \left( \frac{T_f}{G} \right)^m \left( \frac{T_m - C}{M} \right)^n \left( \%Cl - D \right) \]

- Biomass / Waste to Energy – potential for corrosion intensification
- Reactive alkali metal and heavy metals, e.g. Zn, Pb, Sn, As and often higher Chlorine content
Fireside Corrosion

- Evaluation of candidate materials through site specific probe studies and/or installation of ‘rainbow’ tubes.
- Example; Attack by alkali chlorides when firing a biomass fuel.
- Marked effect of operating temperature.
- Benefit of IN625 weld overlay over plain T22.
- Weld overlays still not fit and forget!
Fireside Corrosion

Corrosion of IN625 weld overlay
Fireside Corrosion

Mitigation:

• Tube life extension through alternative materials – monobloc, overlay or thermally sprayed

• Quality Control applied during manufacture / installation can strongly influence the longevity of materials within the boiler. This is particularly true of products applied in-situ
Dew Point Corrosion

- Temperature control issues towards the boiler exit can lead to issues with dew point corrosion
- Boiler control systems should automatically compensate for low temperatures at economiser BUT systems are not always perfect
- If gas exit temperatures not managed properly, then rapid corrosion can occur, necessitating stage replacement
Pressure Parts Failure; Mechanistic Causes

Pressure Parts Failures
- Mechanical
- Thermal
- Environmental
- Quality Control

Mechanical
- Fatigue
- Overheating/Creep

Environmental
- Corrosion

Quality Control
- Erosion

Erosion/Corrosion
- Erosion
- Fly Ash
- Soot Management
Erosion-Corrosion

- Tubes developing mechanically weak/defective corrosion scales can experience enhanced wastage through the synergistic action of corrosion and erosion.
- Chlorine is almost invariably the active corrosion species.
- Sootblower erosion and/or local increases in flue gas velocity (fouling/blockages) can exacerbate metal loss.
- Corrective measures usually involve upgrade to more corrosion resistant material.

Good scale (protective) 13CrMo44
Poor scale (un-protective) 15Mo3
Erosion-Corrosion

- Fuel composition can significantly influence the propensity for fouling of tubing within the gas pass – Alkali metals and iron sulphide can promote fouling.
- This is typically associated with an increase in flue gas temperature later in gas pass due to fouled stages not extracting heat.
- Soot cleaning then required to remove deposits and maintain the desired temperature distribution within the boiler.
- Soot cleaning strategies are important.
- If system not optimised, and operators trigger a clean too regularly, can cause significant erosion damage to tubing.
- Intelligent control systems available.
- Mid-life changes in fuel supply can strongly influence fouling characteristics – need to re-evaluate soot cleaning strategy following such changes.
Soot Cleaning Systems
Pressure Parts Failure; Mechanistic Causes

- Mechanical
- Thermal
- Environmental
- Quality Control

- Fatigue
- Overheating/Creep
- Corrosion
- Erosion
Quality Control

• Quality control - critical to avoid premature tube failures
• Weld overlay
  • Excessive dilution – compromise corrosion performance
  • Weld defects – In worst case scenario, through thickness cracking of weld deposit will act as pathway for corrosive species to attack substrate, allowing coating to be undermined
• Tube Manipulation
  • Non-code compliant tube bending can introduce defects, such as unacceptable deformation (ovality), and increased hardness rendering the tube susceptible to premature failure (Stress Corrosion Cracking, Low temperature creep).
Tube Failure Management

- **Renew tubes wholesale** – typically at planned outage on basis of known wastage rate to optimise maintenance strategy for reliability.

- **Improve design of tube stage** – Inevitably plant built to a cost, therefore optimisation of stage design (and materials employed) versus the original installation can potentially reduce maintenance burden.

- **Selective tube renewal** – Lead tubing inevitably encounters more severe conditions compared to more sheltered tubing within the bank, replacement of lead tubing can economically extend lifetime of stage prior to full replacement.

- **Local repair** – Typically undertaken in response to forced outages. Critical to select correct repair procedure (overlay, tube insert) for failure mechanism and tube location.

- **Improvement in repair quality** – Ensure appropriate NDT applied to avoid early life failures. Critical when undertaking stage replacement to minimise ‘bathtub’ failures.

- **Change operational procedures** – e.g. appropriate management of soot cleaning systems or gas exit temperatures.
Thank you for your attention