Aging Related Failure Modes in Heat Recovery Steam Generators

1. Introduction

Heat Recovery Steam Generators (HRSGs) are essential in combined-cycle power plants, converting waste heat into steam for additional power generation. In this document we have summarized what we have learned about aging related HRSG failure mechanisms from the literature review. We have identified 3 main failures mechanisms.

- Flow Accelerated corrosion (FAC)
- Under deposit corrosion (UDC)
- Thermal transients

2. Common Failure Modes in Heat Recovery Steam Generators

2.1 Flow-accelerated corrosion (FAC)

Introduction	FAC occurs when the protective oxide layer (magnetite) on carbon steel dissolves due to water flow, causing metal loss and thinning.
Impact on HRSG Components	- Single-phase: LP Feedwater piping, around Deaerator, boiler feed pumps & boiler feed pumps, attemperator piping. - Two-phase: LP & HP heater drains, shells, reheater & SH attemperators.
Factors Contributing to FAC	- Cycle Chemistry: Low oxygen and mildly alkaline pH levels. - Flow Dynamics: High flow velocity and turbulence. - Material Composition: Low chromium carbon steel. - Temperature: FAC peaks at 140 ºC and vary with temperature.
Detection and Monitoring	- Ultrasonic testing, radiographic, Positive Metal Indication (PMI), Pulsed Eddy Current (PEC), Visual and Borescopic (Fibre Optics) - Visual inspection: Wave like depressions on metal surface (scalloping effect)
Prevention Strategies	Cycle chemistry aspect: - An oxidizing treatment AVT(O) or OT must be used to prevent single phase FAC. No reducing agent should be used during operation or shutdown. - Elevated pH with a volatile amine is needed to control two phase FAC. - The total iron corrosion products should be monitored. - Phosphate Treatment (PT): Adding tri-sodium phosphate

	- Caustic Treatment (CT): In HRSG drum type boilers to reduce the risk of FAC where all-volatile treatment has proved ineffective. Should be carefully done. - Film Forming Substances (FFS): A physical barrier at the molecular level between the water/ water-steam and the surface. (hydrophobic effect) Cannot defend two phase FAC.

2.2 Under Deposit Corrosion (UDC)

Localized corrosion develops beneath deposits on a metal. These corrosion products are mostly formed due to FAC in the low temp parts of the system.

There are 3 main UDC mechanisms.

2.2.1 Caustic Gouging

Introduction	Caustic gouging is a type of Under Deposit Corrosion in boiler and HRSG tubes, caused by excessive deposits of corrosion products and concentrated sodium hydroxide.
Impact on HRSG Components	It leads to material loss in tubes, characterized by distinct depressions filled with thick deposits, but does not cause microstructural changes in the tube material.
Factors Contributing to FAC	Poor feedwater treatment, excessive sodium hydroxide, flow disruptions, adverse fireside conditions, ineffective chemical cleaning, and inadequate instrumentation.
Detection and Monitoring	Ultrasonic testing for tube thinning and tube sampling to assess deposits. Immediate actions include reducing sodium hydroxide levels and possibly shutting down the boiler.
Prevention Strategies	Minimizing deposit buildup, optimizing boiler water chemistry, using reliable monitoring, and preventing upsets in makeup water systems.

2.2.2 Hydrogen Damage

Introduction	Due to the acidic environment at the base of the deposits, atomic H develop at the tube wall. It penetrates into the carbon steel structure and react with the Carbon. This will form micro-cracks in the structure. This will reduce strength. Mainly effect HP evaporator.
Causes	- Poor water treatment cause high corrosion product levels (iron, copper oxides) generated due to FAC. They get deposited on the HP/LP evaporator tubes. - Flow disruptions in the tubes contributes to increased deposition. - Ineffective chemical cleaning - Inadequate instrumentation
Solutions	- Minimize FAC in LP circuits. - Remove geometrical flow disrupters (pad welds)

2.3 Thermal Transients

Introduction	Thermal transients during plant startup and shutdown cause thermal stresses in components, leading to cracks and eventual failure.
Factors Affecting Thermal Transients	- Rapid temperature fluctuations. - Material properties. - Thermal gradients in components.
Identified Failures	- Attemperator spray water leakage: Causes temperature difference at the top and bottom of the pipe, leading to thermal stresses. - Attemperator overspray: Insufficient steam flow to evaporate sprayed water leads to pipe erosion. - Ineffective HP SH draining during startup: Condensate accumulation can cause damage to tube lines. - HP drum damage due to high ramp rates: Cracking of the oxide layer due to excessive ramp rates. - Forced Cooling: Rapid cooling of GT and HRSG post-shutdown, involving HRSG depressurization, can cause high ramp rates in the HP drum.

	- Economizer Quenching: Failures in LP economizer tube/header welds due to sudden cooling (quenching).
Prevention Strategies	- Attemperator overspray: Repair and ensure the control system's capability to maintain steam temperature within limits, Prohibit manual operation. - Ineffective HP SH draining during startup: Calculate the maximum rate of condensate formation and size the drain pipes accordingly, Automatic drain control. - HP drum and header damages due to high ramp rates: Maintain ramp rates under the rates given by OEM, or evaluated values.

3. References

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