Flow Accelerated Corrosion Failures in Gas to Liquids Plant (Methane Gas Reforming Plant)

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Introduction to Flow-Accelerated Corrosion

• Flow-accelerated corrosion (FAC) is a corrosion process that degrades carbon steel material.

• FAC normally occurs above room temperature under specific chemistry conditions normally found in Power and Nuclear plants.

• FAC requires that flowing water or water/steam mixtures be in contact with the steel surface.

• FAC is normally related to turbulence especially near fittings, e.g., elbows, orifices, valves.
Why is FAC detrimental?

- FAC Damage and Catastrophic failures result in safety risks to plant personnel due steam leaks, Piping and equipment replacements, serious injuries, fatalities, and unplanned shutdowns.
- Rates up to 3 mm/Yr Have been observed In Power & Nuclear Plants.
- If piping or vessel walls become too thin, wall failure can occur via stress rupture (Pressure & Other Applied Loads)
- FAC caused failures can be sudden and catastrophic!
- Transients incidents (e.g. Pump Trip) can induce the “Last Straw” Leading To rupture
International Major Industry FAC Failures: Incidents Surry Unit 2

- An 18 inch elbow in a condensate line ruptured catastrophically in 1986
- Four fatalities and several injuries resulted

Flow was from left to right

Source: EPRI guideline
FAC Training
Mihama Unit 3

• A 22 inch condensate line downstream of an orifice ruptured catastrophically in 2004.

• Five fatalities and several injuries resulted.

Flow from right to left. Note orifice flange is at right edge of photo.

Source: EPRI guideline
FAC Training
FAC Industry Knowledge

• FAC mechanism and its preventative measures are relatively well understood in power and nuclear plants after research by The Electric Power Research Institute (EPRI).
• Gas to Liquids (GTL) plant, Petrochemical plants and Refineries often misdiagnosed FAC for simple erosion or erosion corrosion!
• Consequently inappropriate and ineffective cures are implemented in absence of proper metallurgical failure analysis to correctly identify the failure mechanism.
• Porous Oxide (Magnetite) Layer Formed At Surface
• Oxide Dissolves In Water
• Dissolved Species Removed By Flowing Water
• Oxide Formation/ Dissolution Cycle Is Continuous
Description of Damage

- This results in a Progressive wall thinning or global attack (i.e. widespread thinning) rather than local attack (i.e., pitting or cracking)
- Damage rates caused by FAC are dependent on the water chemistry indicating that FAC is a corrosion process – not mechanical in nature
Critical Parameters Influencing FAC

- **Water Chemistry**
  - Oxidizing/Reducing Potential (Oxygen + Reducing Agents)
  - pH
  - Temperature

- **Hydrodynamics**
  - Flow
  - Component Geometry & Upstream Influences
  - Steam Quality
  - Mass Transfer

- **Pipe/Vessel Material Composition**
  - Chromium
  - Copper
  - Molybdenum

Note: Carbon Steel Does Not Have A Required Level Of Cr
FAC Appearance (Single Phase)

Chevrons Show Flow Directions

Magnetite Layer Missing From Affected Surface
Typical appearances of FAC failures

Black/shiny

Single-phase (i.e. water only) conditions, the damaged surface displays a “scalloped” or **Orange Peel**

Single-Phase FAC

Under high quality, two-phase conditions, the surface may show a pattern of dark and light areas known **Tiger-Striping**

Source: EPRI guideline
FAC Training
FAC In LP Evaporator
Single- & Two-Phase Damage

Source: EPRI guideline
FAC Training
Background on GTL plant FAC failures

• Historically, several failures were reported on the boiler feed water systems and steam/condensate services, after 10 years of operation.

• A project was initiated to investigate perceived problem relating to the failure of steam/condensate lines at the GTL plant (PetroSA) in Mossel Bay in October 2005.

• Unfortunately Metallurgical failure analysis was not carried out consistently as failures were thought or misdiagnosed to be simple erosion or erosion-corrosion.
Methane Gas Reforming Plant: Single Phase FAC Failure cases

Photograph showing general appearance of Condensate return line 06-CMR-0004-N-4” in the as-received condition. Note window failure and mechanical damage for accelerating draining process during repairs.

To date this pipeline had experienced about reported 9 failures in total in the form of bursts and pinhole leaks mostly on reducers, bends and Tee pieces since April 2004.
Close-up photograph showing internal surface of the longitudinally sectioned spool piece. Note window failure area, severe localised wall loss like “paper thin”, “pit like” are chevron markings with tip pointing in the direction of the flow where wall loss is minimal, orange peel appearance typical of single phase (water phase only) flow accelerated corrosion damage.
Micrograph showing very little patches of protective magnetite layer, most of the surface magnetite layer is missing on inner surface. [Etched in 5% Nital, 50X Magnification]
## Component Details

<table>
<thead>
<tr>
<th>Piping System</th>
<th>Unit 06 Condensate return line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Failures</td>
<td>9 at different locations with repeats since 2003</td>
</tr>
<tr>
<td>Design Pressure</td>
<td>1000kPa</td>
</tr>
<tr>
<td>Operating Pressure</td>
<td>800kPa</td>
</tr>
<tr>
<td>Design Temperature</td>
<td>200°C</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>176°C</td>
</tr>
<tr>
<td>Material specification</td>
<td>ASTM A 106 Grade B XXS (Carbon Steel)</td>
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</tbody>
</table>
Methane Gas Reforming Plant: Steam condensate blow down FAC Failure

General appearance of ruptured steam condensate common line

Pinhole on Steam condensate blow down line (Internally)

Design and operating conditions
Material: Carbon Steel

<table>
<thead>
<tr>
<th>Equipment name</th>
<th>Design Pressure (KPa)</th>
<th>Operating Pressure (KPa)</th>
<th>Design Temp (°C)</th>
<th>Operating Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>1000</td>
<td>800</td>
<td>200</td>
<td>176</td>
</tr>
</tbody>
</table>
Magnetite protective layer was completely removed at the point of failure. Note sound typical pearlite –ferritic microstructure. [Etched by 5%Nital at 200x magnification]
History Of Failures History On The Blow Down Line

The figure below is the graph showing the number of failure that has occurred since (2003 to 2014). In total the line has failed 27 times at different locations.

 Frequency of failures on this common line since 06-DBD-0005-N-3” (2003-2014) at different sections.
**FAC Affected Units or Equipment**

Piping, Small bore piping systems & Vessels are susceptible to FAC if:

- Carbon steel & C-Mn steel (Cr >0.1% reduce rates significantly)
- There is water or wet steam flowing in the pipes
- The water is deoxygenated (i.e., service water systems do not experience FAC)
- Mostly 100 - 250ºC
- Higher & Turbulent flow (geometry) areas – valves, T-pieces, bends, etc.
- Lowest O-levels & PH levels
- Steam pipes
  - 2 phase flow like drain lines
- Similar areas to water pipes & vessels
FAC Inspection and Monitoring Program

FAC Examination/ detection Methods:

- Ultrasonic Examination (UT)
  - Most Commonly Used, UT with grids
- Radiography (RT)
  - Through Insulation
  - New Direct Digital Technology
- Endoscope, camera, visual on inside component Survey For Two-Phase Damage In Vessels
- Pulsed Eddy Current (PEC)
  - Through Insulation, Survey Technique
- Guided-Wave UT
  - Survey Lines For Wall-Loss Damage
FAC Management Program

Plant FAC Management Program was developed and being implemented. It included:

- Review of plant design, materials & construction
- Identify susceptible systems and pipe lines.
- Conduct periodic FAC inspections to include both visual examinations and wall thickness measurements by RT & UT during turnarounds
- Replace selected susceptible areas with higher chromium material and design change i.e. use of long radius bends where possible and increasing pipe diameter to reduce condensate velocity in severly affected areas.
- Two phase flow best addressed with =>1.25% chromium material metallurgy upgrade.

- Optimise feedwater treatment and chemistry

The key parameters are pH, Oxygen and Cation Conductivity, Oxygen, Hydrazine, Oxidizing reducing potential Performance, Current & Past Practices
FAC Management Program Cont.

• Train everyone to recognize FAC e.g. chemistry, maintenance, Process engineering personnel

• If FAC Damage found and taking into account risk ranking:
  
  - Piping below 75% of design minimum wall thickness to be replaced at next convenient opportunity

  - Piping below 50% design minimum wall thickness will be replaced immediately
Conclusions

• Have a formal FAC preventative program with management support and other engineering disciples.
• FAC related failures require metallurgical investigation to confirm failure mechanism and root cause, i.e. this cannot be left to the inspector
• Our Industries such as Gas to Liquids plants, Refineries and Petrochemical plants must follow Electric Power Research Institute FAC preventative /management program guideline and computer FAC modeling technology in boiler feed water, condensate, blowdown, and deaerator systems.

• Utility industry FAC incidents have to be prevented or else we will learn by serious injuries or even fatalities!
REFERENCES

- EPRI Guidelines For Controlling FAC In Fossil & Combined Cycle Plants (1008082)
- Chakraborty P.L and Bhave M.L, Flow accelerated corrosion failures in refineries Hydrocarbon Asia Journal, July-Sept 2012, pg 40-46
THE END

THANK YOU FOR YOUR ATTENTION!