Team 7's Case Study
Glycol Desalination Plant
Agenda

- Overview of the Desalination Plant and Case Study
- Mechanical and Operational Root Cause Analysis
- Identified Root Causes
- Corrosion Risk Assessment
- Mitigation Plans
- Concluding Remarks
Team 7 - Members

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Wood Plc

Rachael Milne
BP

Jorge Garcia
SGN

Onieeb Khan
Subsea7

Agenda
Team 7's Case Study
Glycol Desalination Plant
Case Study Background

- Overview of the Desalination Plant
- Leak Locations and Details
- Spool Piping Branch Details: Material and Design Operating Parameters
Desalination Plant Overview

- MEG used for hydrates and corrosion control of gas pipelines from three offshore fields.

- Desalination plant removes calcium ions and other salts from the MEG for reuse.

- Incoming MEG has sodium carbonate added to aid calcium carbonate precipitation for salt removal.

- Rich MEG fed into the evaporator.

- **NO LEAK POLICY.**
Desalination Plant Schematic
**Desalination Plant Overview**

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Case Study Background

- Overview of the Desalination Plant
- Leak Locations and Details
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Desalination Plant Overview
Leak Locations and Details
Spool Piping Branch Details
Leak Locations and Details

- Two leaks occurred in the Evaporator (V-5607) section:
  - **LEAK A**: drain off-take from the Calandria to the S-5602 Centrifuge.
  - **LEAK B**: recycle line from V-5607 to the E-5601 Calandria.

- Both leaks occurred at perpendicular branch piping welded onto the main piping.

- 1mm diameter holes occurred approximately 5mm from the toe of the branch piping welds.
Case Study Background

- Overview of the Desalination Plant
- Leak Locations and Details
- Spool Piping Branch Details: Material and Design Operating Parameters
Spool Piping Branch Details: Material and Design Operating Parameters

- Titanium Grade 12 piping was selected for enhanced corrosion resistance.
- Insulated piping (Nilflame & Ulvashield).
- Operating temperature approximately 120°C (max. 135°C).
- MEG containing sodium chloride <25%.wt.
- Piping diameters: Leak A Ø33.4mm - Leak B Ø28.5mm.
- Piping thickness: 1.65mm.
- Both leaks occurred 15 years into service.
Case Study Background

- Overview of the Desalination Plant
- Leak Locations and Details
- Spool Piping Branch Details: Material and Design Operating Parameters
Team 7's Case Study
Glycol Desalination Plant
Materials Issue

Can we confirm piping is Titanium 12?

Evidence Requested

- Material Specification
- Chemical composition
- PMI
- Material Certifications

Evidence Response

- Chemical composition

Proved that material was
Titanium 12 as per ASTM B861
Table 4

Titanium 12 within design
parameters for the purposes
Materials Issue

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  Titanium 12 within design
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Considered and Discounted

Evidence Response

- Chemical composition

Proved that material was Titanium 12 as per ASTM B861 Table 4

Titanium 12 within design parameters for the purposes
Manufacturing Defect

Confirm exact location of the damage internally

Evidence Requested
- Section of the failed pipe

Considered and discounted

Conclusions
- Pits seen uniformly across the pipe
- Most severe damage at the HAZ of the branch weld and the seam weld
Conclusions

- Pits seen uniformly across the pipe
- Most severe damage at the HAZ of the branch weld and the seam weld
Welding Issue

Potential Issues:
- Incorrect welding procedure (WPS)
- Poor weld quality

Evidence Request
- Copy of original WPS
- Copy of original welder qualifications
- NDT reports from original manufacture

Evidence Response
- No original weld details available
- Advised to assume that this was good and to standard

Considered and discounted
Design Issue

Potential Issues
- Wall thickness incorrect
- Why did the pipework leak but not the vessel

Evidence Requested
- Fabrication Drawings

Evidence Response & Conclusions
- Pipe thickness ok as per ASME B31.3 design code

Considered and discounted
**Possible Issues**
- Change in process medium, temperature, pressure... could mean that titanium 12 is no longer suitable

**Evidence Requested**
- Operating information (PI data)
- Sample information

**Evidence Response & Conclusions**
- Sample info provided from 1995/1996 - no recent sample info available
- Oxygen in the evaporator as Vacuum unable to be maintained for 1 year
- Corrosive organic acids present (acetic acid, formic acid, glycolic acid)

Potential Root Cause - Corrosive Acids now present
Change in Process Conditions
Excess Solids in the System
Turbulent Flow
Potential for solid particles to cause erosion at the branch location

Possible Issues
- Increased solids in the system
- Filters not functioning correctly

Evidence Requested
- Sample information
- Maintenance/Inspection history for the filters

Potential Root Cause
Possible Issues

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Evidence Requested

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Potential Root Cause
Change in Process Conditions
Excess Solids in the System
Turbulent Flow
Possible Issues
- Turbulent flow around the branch connections
- Cavitation

Research & Conclusions
- Cavitation can occur where bubbles implode on the material to create the pits
Change in Process Conditions

Excess Solids in the System

Turbulent Flow
Damage Initiated by Erosion

Corrosion - Presence of Organic Acids

Identified Main Root Cause For Titanium 12: Stress Corrosion Cracking

Transgranular Susceptibility

Residual Stress
Erosion caused by

Cavitation

Solid Particles
Surrounding liquid

Increased static pressure

Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.
Erosion caused by

Cavitation

Solid Particles
Identified Main Root Cause For Titanium 12: Stress Corrosion Cracking

- Damage Initiated by Erosion
- Corrosion - Presence of Organic Acids
- Transgranular Susceptibility
- Residual Stress
Titanium 12 & Organic Acids

Calculated concentration of acids in sample:

<table>
<thead>
<tr>
<th>Acid</th>
<th>Concentration</th>
<th>%</th>
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<tbody>
<tr>
<td>Acetic acid</td>
<td>700ppm</td>
<td>53.4%</td>
</tr>
<tr>
<td>Formic Acid</td>
<td>500ppm</td>
<td>38.2%</td>
</tr>
<tr>
<td>Propanic Acid</td>
<td>100ppm</td>
<td>7.6%</td>
</tr>
<tr>
<td>Glycolic Acid</td>
<td>&lt;5ppm</td>
<td>0.4%</td>
</tr>
<tr>
<td>Oxalic Acid</td>
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Corrosion rates for Titanium 12 alloy:

<table>
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<tr>
<th>Concentration</th>
<th>Temperature °F(°C)</th>
<th>Corrosion rate mpy (mm/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formic acid,</td>
<td>10</td>
<td>212 (100)</td>
</tr>
<tr>
<td>non-aerated</td>
<td>25</td>
<td>212 (100)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>Boiling</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>212 (100)</td>
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# Titanium 12 & Organic Acids

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<td>Formic acid, non-aerated</td>
<td>10</td>
<td>212 (100)</td>
<td>&gt;50 (&gt;1.27)</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>212 (100)</td>
<td>96 (2.44)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>Boiling</td>
<td>126 (3.20)</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>212 (100)</td>
<td>118 (3.00)</td>
</tr>
</tbody>
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Identified Main Root Cause For Titanium 12: Stress Corrosion Cracking

- Damage Initiated by Erosion
- Corrosion - Presence of Organic Acids
- Transgranular Susceptibility
- Residual Stress
Macrostructure & Cleavage Cracking
Martensitic

Equiaxed Grains
Macrostructure & Cleavage Cracking

HAZ  Parent metal

Weld
Cleavage Cracking

- Increases at lower temperature and higher strain rate
- Could be accelerated by operational cyclic stresses
Macrostructure & Cleavage Cracking

HAZ      Parent metal

[Images of macrostructure and cleavage cracks]
Identified Main Root Cause For Titanium 12: Stress Corrosion Cracking

- Damage Initiated by Erosion
- Corrosion - Presence of Organic Acids
- Transgranular Susceptibility
- Residual Stress
• Residual stress might remain
• Operational cyclic stresses
  + Residual stresses = Work hardening of weld area
Identified Main Root Cause For Titanium 12: Stress Corrosion Cracking

- Damage Initiated by Erosion
- Corrosion - Presence of Organic Acids
- Transgranular Susceptibility
- Residual Stress
Team 7's Case Study
Glycol Desalination Plant

Root Cause Analysis
Identified Root Causes
Corrosion Risk Assessment
Mitigation
Conclusion
Introduction
Case Study Background
Susceptible areas

S

High aerosol content
Slightly combustible
Swallowing
Ingestion
Irritation to eyes
Skin
Respiratory problems
Acids
High temperature

P

Plant shutdown
Efficiency
Optimization
Economic losses

E

Aquatic organism
Terrestrial organism
Pollution
Corrosion Risk Assessment

1. Identify Susceptible Areas
2. Risk Assessment
3. Risk Mitigation
### RISK = Impact x Likelihood

<table>
<thead>
<tr>
<th>Class of Impact</th>
<th>Safety</th>
<th>Production</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible – 1</td>
<td>No (or very slight injury)</td>
<td>No disruption</td>
<td>No residual impact</td>
</tr>
<tr>
<td>Minimal – 2</td>
<td>Minor Injury</td>
<td>Brief disruption to production</td>
<td>Minor impact</td>
</tr>
<tr>
<td>Medium – 3</td>
<td>Major Injury</td>
<td>Partial short-term shutdown</td>
<td>Localised but major impact</td>
</tr>
<tr>
<td>High – 4</td>
<td>1 fatality</td>
<td>Undefined shutdown</td>
<td>Sever impact</td>
</tr>
<tr>
<td>Major – 5</td>
<td>&gt;1 fatality</td>
<td>Substantial plant loss</td>
<td>Extreme impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Generic Qualitative</th>
<th>Energy Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare – 1</td>
<td>Never heard of in the industry</td>
<td>&gt;20 years</td>
</tr>
<tr>
<td>Unlikely – 2</td>
<td>Known possibility</td>
<td>10-20 years</td>
</tr>
<tr>
<td>Possible – 3</td>
<td>Has happened in the organisation or more than once per year in the industry</td>
<td>5-10 years</td>
</tr>
<tr>
<td>Likely – 4</td>
<td>Has happened at the location or more than once per year in the Organisation</td>
<td>2 to 5 years</td>
</tr>
<tr>
<td>Highly Likely – 5</td>
<td>Has happened more than once at the location</td>
<td>&lt; 2 years</td>
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1. Identify Susceptible Areas

2. Risk Assessment

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Corrosion Risk Assessment
Corrosion Risk Assessment

1. Identify Susceptible Areas

2. Risk Assessment

3. Risk Mitigation
Team 7's Case Study
Glycol Desalination Plant

Root Cause Analysis
Identified Root Causes
Corrosion Risk Assessment
Mitigation
Conclusion
Introduction
Case Study Background
Mitigation Plan

Short Term

Medium Term

Long Term
Short Term

Follow the non-leaking policy
Partial shutdown at off-peak time
Fully replace pieces (like per like)
Investigation of spools
Filters
Operational rounds
  • Specify the use of correct PPE
Investigation and identify more susceptible areas
Mitigation Plan

Short Term

Medium Term

Long Term
Medium term

Create new policies/procedures
Set up a proactive approach
Data collection
Samples
NDTs (Pitting - UT)
Installation of titanium coupons
Repair more susceptible areas
Mitigation Plan

Short Term

Medium Term

Long Term
Long term

Bypasses for maintenance
Oxygen scavengers
Installation of corrosion inhibitors
Corrosion probes
Alternative manufacturing method like forged tees
- Microstructure/grain
- Thickness
- Titanium 12
- Documentation (WPSs, NDTs, Design, life expectancy)
Mitigation Plan

Short Term

Medium Term

Long Term
Team 7's Case Study
Glycol Desalination Plant
Conclusion

- Loss of protective titanium oxide layer at the branches.
- Corrosion of the exposed material due to organic acids.
- Grain boundaries within the HAZ susceptible to chemical corrosion attack.
- Crack propagation at the grain boundaries.
Conclusion Continued

To mitigate against the root causes of the leaks:

- Investigate, maintain and improve the filter design.
- Investigate the loss of the vacuum.
- Re-design at-risk pipework sections in the evaporator spools.

SAFE, RELIABLE AND COMPLIANT PLANT OPERATION
Conclusion Continued

To mitigate against the root causes of the leaks:

- Investigate, maintain and improve the filter design.

- Investigate the loss of the vacuum.

- Re-design at-risk pipework sections in the evaporator spools.
Any Questions?
Conclusion Continued

To mitigate against the root causes of the leaks:

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SAFE, RELIABLE AND COMPLIANT PLANT OPERATION
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