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The Society is grateful to those companies that allow their professionals to serve as lecturers

Additional support provided by AIME

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl
The Science and Engineering of Internal Corrosion Control in the Upstream Petroleum Industry

… mainly about managing water …

Mohsen Achour
ConocoPhillips
Why Corrosion is Important

$276 Billion

The United States Cost of Corrosion Study

Project funded by DOT in 1998
Corrosion Consequences

Aug. 19, 2000 - New Mexico
- Pipeline ruptured
- Natural gas ignited
- 12 people killed
- $1MM property damage

Dec. 12, 2012 - West Virginia
- External corrosion
- 15-mile stretch fire
- 4 homes destroyed
- No casualties
2006 - Prudhoe Bay oilfield: Infield line leaked 200,000 gallons of oil into tundra

*Incident impactful to the operator liability/reputation*

Operator was subject to severe fines both at the federal and state levels
2000 – 2010 Statistics

Incidents of Offshore Pipelines/Risers Gulf of Mexico
(Total 1842)

Number of Incidents

<table>
<thead>
<tr>
<th>Failure Cause</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion (Internal)</td>
<td>601</td>
</tr>
<tr>
<td>Corrosion (External)</td>
<td>322</td>
</tr>
<tr>
<td>Impact</td>
<td>218</td>
</tr>
<tr>
<td>Unknown</td>
<td>210</td>
</tr>
<tr>
<td>Structural (Design)</td>
<td>153</td>
</tr>
<tr>
<td>Material Defect</td>
<td>137</td>
</tr>
<tr>
<td>Line</td>
<td>67</td>
</tr>
<tr>
<td>Pluggage</td>
<td>65</td>
</tr>
<tr>
<td>Anchoring</td>
<td>42</td>
</tr>
<tr>
<td>Construction</td>
<td>17</td>
</tr>
<tr>
<td>Erosion</td>
<td>10</td>
</tr>
</tbody>
</table>
… Mainly About Managing Water …

“Water is the driving force in nature”

Leonardo da Vinci: painter, sculptor, architect, musician, scientist, mathematician, engineer, inventor, anatomist, geologist, cartographer, and writer … perhaps the most diversely talented person ever to have lived!

“Water is the driving force in corrosion”

Mohsen Achour: unknown!
“Water is the Driving Force in Corrosion”

- We can never eliminate corrosion, we can only hope to control it.
- Managing water/electrolyte is key to corrosion control when environment is fixed and materials are selected.

- e.g. Carbon Steel
- O₂, CO₂, H₂S, bacteria
- Water/Moisture
- Material
- Oxidants
- Electrolyte

- Corrosion
Ideal Water to Minimize Corrosion

Deoxygenated, degassed, bacteria free, high alkalinity (high pH), low/no solids, cold and flowing just right.

- Casing
- Production tubing
- Flowlines
- Gathering lines
- Risers
- Trunk lines
- Gas lines
- Oil export lines
- Injection lines
- Water lines
- Facilities

Courtesy of Kongsberg®
## Variability in Water Chemistry

<table>
<thead>
<tr>
<th>Component (mg/lit)</th>
<th>Gas production water</th>
<th>Oil production produced water</th>
<th>Oil production produced water</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>665</td>
<td>29910</td>
<td>50200</td>
<td>11050</td>
</tr>
<tr>
<td>Potassium</td>
<td>10</td>
<td>325</td>
<td>500</td>
<td>410</td>
</tr>
<tr>
<td>Magnesium</td>
<td>8</td>
<td>540</td>
<td>500</td>
<td>1323</td>
</tr>
<tr>
<td>Calcium</td>
<td>9</td>
<td>2120</td>
<td>20200</td>
<td>422</td>
</tr>
<tr>
<td>Barium</td>
<td>10</td>
<td>270</td>
<td>920</td>
<td>0.02</td>
</tr>
<tr>
<td>Chloride</td>
<td>900</td>
<td>52110</td>
<td>120120</td>
<td>19875</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>366</td>
<td>235</td>
<td>473</td>
<td>145</td>
</tr>
<tr>
<td>Sulfate</td>
<td>1</td>
<td>10</td>
<td>8</td>
<td>2782</td>
</tr>
<tr>
<td>Weak Acids</td>
<td>e.g. CO₂, H₂S, organic acids ... affecting pH calculations and corrosion/scale potential</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Account for systematic variations in the production environment
Corrosion Control in Gas pipelines

Driven by gas pressure

Pressure depletion

By water content & chemistry

Water production

Science: Thermodynamics, flow modeling, pressure depletion, water chemistry, dehydration

Engineering: Dry vs. wet gas, slug dynamics, inhibition program, corrosion monitoring, In Line Inspection (ILI), top of line corrosion.

Best Practice: Assume dry is wet, design for pigging, inspect at start up for ILI baseline survey, reinforce and monitor dew point spec.
Corrosion Control in Oil Export Line

Science: Hydrocarbon chemistry, Flow modeling, Pressure and temperature profiles, Water chemistry

Engineering: Velocity range, Oil/water wetting, Inhibition program, MIC, Monitoring/ILI, Pipeline layout and profile, Understand/monitor 3\textsuperscript{rd} party input

Best Practice: Assume BS&W upsets will occur, Design for pigging, ILI baseline profile, No short cuts in maintenance pigging and chemical treatment programs
Water is Unavoidable and Corrosive

Inhibition can be Answer

but … need to understand:

- Water wettability of the steel wall
- Inhibitor performance testing and QA/QC
- Partitioning of inhibitor between oil & water
- Effect of solids (BaSO$_4$, CaCO$_3$, FeCO$_3$, FeS … )
- Effect of inhibitor under dosing or over dosing
- Effect of emulsion
- Compatibility of inhibitor with other production chemicals (biocide, scale inhibitor, KHI … )
- Residual analysis & discharge into environment
Case History 1
Low Water Cut Oil Pipeline Corroding

- Reviewed water cut history, changed chemical treatment
- Initiated aggressive cleaning and inspection program
- Saved replacement of the pipe section

- 500,000 BPD of crude, 356 km, 34” Subsea
- 2% water cut spec, Multiple input streams
- In operation for 20 years
- First 50 km heavily corroding, proposed for replacement (over $150MM capital only)

Distance along the pipeline (km)

WT: wall thickness
red & blue: new defects, other colors: old defects
Case History 2
Dry Gas Pipeline Corroding

Scenario

- 350 MMSCFD of dry gas
- 654 km, 22-28” Subsea lines
- Dew point spec 55F @ 700 psi
- Multiple subsea tie-in streams
- In operation for 7 years
- Filters plugged at arrival
- Metering system jeopardized
- Risking 27 yr sales contract
- Call for pigging facility inst. (over $100MM investment)

Assessment/Solution

- Dew point spec violated
- Incidents of seawater ingress
- Pipeline not completely cleaned after hydrotest
- Salt and corrosion products
- Lowered dew point spec
- Installed monitoring points
- Showed proof of self cleaning
- Saved pigging installation
“Water is the driving force in corrosion”

A successful corrosion management program requires:

- Multidiscipline skills
- Corrosion conscious basis of design
- Sound engineering practices
- Operations Excellence
- Budgeting
- People
Thank you All
Thank you for your attention
Gracias por su atención
Grazio per l'attenzione
Благодарю вас за ваше внимание
Merci pour votre attention
Muito obrigado pela vossa atenção
Thak u voor uw aandacht
感谢您的关注
Tusen Takk for at du kom
Dhanyavaad

Questions ?
Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation:

Click on: Section Evaluation

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Backup Slides
Carbon Steel & Inhibition vs. Corrosion Resistant Alloys (CRA)

Type: gas pipeline, oil export, gathering/transfer line
Location: onshore/offshore, remote, populated area
Length: CAPEX/OPEX, life cycle cost analysis
Content: water, gas/oil, sweet/sour
Operating conditions: T, P
Economics: $/barrel, market
CRA: 13 Cr, Super 13 Cr, Duplex, Inconel, Hastelloy
Under Deposit Corrosion (UDC)
Salt Induced Corrosion
Erosion – Erosion/Corrosion
Jet Pig – Cleaning and inhibitor Application
Smart Pigging – MFL Tool