Materials Selection - Basics

Subsea Pipelines
Basics of Materials Selection

- What is Materials Selection (SURF)?

- How it is Carried out?

- Examples
  - Carbon Steel & Corrosion Resistant Material
  - Corrosion Resistant Alloys
  - Cost / Availability Trend
Basics of Materials Selection

- Materials Selection
  - Mechanisms for Choosing Suitable Materials
    - Corrosion Resistance – Internal External Corrosion
    - Mechanical Properties – Yield Strength and Toughness
    - Easy of Fabrication/Installation – Weldability Formability Inspection

- Establishing Cost of Selected Materials
  - Carbon Steel + Corrosion Inhibition
  - Corrosion Resistant Materials
  - Bimetallic Materials
  - Fabrication & Installation Costs

- Operation
- Maintenance Costs
Basics of Materials Selection

Risers

Umbilicals

Pipeline

Subsea Production System

Courtesy of Xodusgroup
Basics of Materials Selection

- Materials Selection – Subsea Pipelines
  - Selection Mechanism
    - Internal Corrosion
    - External Corrosion
    - Strength
    - Toughness
  - Flow Assurance
  - Operating & Design Data

- Optimised Cost Based On
  - Procurement, Installation
  - Operation & Maintenance
  - Design & Regulatory Compliance

- Existing Track Record & Contractor Capability
  - Welding
  - NDT
  - Installability
Basics of Materials Selection

- Material Selection
- Corrosion
  - Subsea Pipelines - Saline Muds, Seawater & Process Fluids
    - Wet Acid gases (CO$_2$, H$_2$S) or O$_2$
    - Halide ions
    - Bacterial Activity
  - Corrosion - Process

To corrode or not to corrode?!!

\[
\text{Fe} \quad \text{Fe}^{2+} + 2\text{e}^- \\
M \quad \text{M}^{n+} + \text{n} \text{e}^-
\]
Basics of Materials Selection

- Several Relationships exist that predict corrosion rates based on
  - CO$_2$
  - H$_2$S
  - H$_2$O
  - O$_2$
  - Cl$^-$
  - pH level
  - Presence of Corrosion inhibitors
  - Flow velocity
  - Total System and Active Gas Partial Pressure
- Many different corrosion rate models available
Basics of Materials Selection

- Internal Corrosion – Carbon Steels & Low Alloy Steels
  - De Waard Milliams or Flow Chemistry
    - Shell - HydroCor
    - BP - Cassandra
    - TOTAL - Corplus
    - Intetech – ECE (Electronic Corrosion Engineer)
    - Norsok - M 506
    - Honeywell - PREDICT
    - IFE - KSC
    - OLI - SCORE
    - Scandpower - OLGA
Basics of Materials Selection

• Internal Corrosion – Corrosion Resistant Alloys
  • Flow Chemistry
    • Honeywell – SOCRATES
      • Selection of Corrosion Resistant Alloys Through Environment Specification
    • Intetech - ECE
    • Established Domains
    • Qualification Testing
  • Experience
    • Operator
    • Engineer
Basics of Materials Selection

- Selection Mechanism – How It Is Done
  - Internal Corrosion
    - Collection of Information
      - Design & Operating Data
      - Flow Assurance & Production Profiles
  - Default Selection – Carbon Steel
    - Determine corrosion rates using known Algorithms
    - Establish if Inhibition is possible
    - Calculate Corrosion Allowance

\[
CA = (CR_{inhibited} \times \frac{A\%}{100}) + CR_{uninhibited} \times (1 - \frac{A\%}{100})
\]
Basics of Materials Selection

Carbon Steels

Sweet Corrosion

Sour Corrosion

Fe + CO₂ + H₂O ⇌ Fe^{2+} (Z) + H₂

CO₂ + H₂O ⇌ H₂CO₃

H₂CO₃ ⇌ H⁺ + HCO₃⁻

HCO₃⁻ + H⁺ ↔ H₂CO₃

H₂S ↔ H⁺ + HS⁻

FeCO₃ → Fe + CO₂ + H₂O

Courtesy of Jacek Banas
Basics of Materials Selection

De Waard Milliams

\[
\frac{1}{V_{corr}} = \frac{1}{V_r} + \frac{1}{V_m}
\]

\[
V_m = 2.45 \frac{U^{0.8}}{d^{0.2}} pCO2
\]

\[
Log V_r = 4.93 - \frac{1191}{(t + 273)} + 0.58Log pCO2 - 0.34(pH \text{ actual} - pH CO2)
\]

\[
Log V_r = 5.8 - \frac{1710}{(t + 273)} + 0.67Log pCO2
\]
Basics of Materials Selection

Oldfield Swales & Todd

\[ CR = \frac{0.0565 \times V \times C_{o}}{Re^{0.125} \times Pr^{0.750}} \]

\[ CR = \frac{0.0565 \times D^{0.75} \times V^{0.875}}{V_{k}^{0.125} \times d^{0.125}} \times C_{o} \]
Basics of Materials Selection

- Cumulated Thickness Loss (CTL)
  - Establish Corrosion Rate at various location
  - Plot Corrosion rate against Time
  - Calculate Area under worst Trace
    - CTL
    - ATL (Acceptable Thickness Loss typically 3mm or 6mm)
    - L Design life
  - Consider
    \[ CR_{max} \times \frac{L}{CA} \quad \text{or} \quad \frac{CTL}{ATL} \]
Basics of Materials Selection

Courtesy of FEESA

Inhibited Corrosion Rate (mm/year)

Year

0 km
3.49 km
3.5 km
8.49 km
8.5 km
16.99 km
17 km
19.99 km
20 km
21.2 km
Basics of Materials Selection

Courtesy of FEESA

Wall Loss Due To Corrosion (mm)

Distance (km)

Year 1
Year 5
Year 10
Year 15
Year 20
# Basics of Materials Selection

Courtesy of IFE

<table>
<thead>
<tr>
<th>CTL/ATL</th>
<th>Likelihood of corrosion categories</th>
<th>Approximate Impact on system life for a new system</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.5</td>
<td>Negligible</td>
<td>System will last longer than required with no failures</td>
</tr>
<tr>
<td>&gt;0.5 and ≤1</td>
<td>Low</td>
<td>System will reach its design life without a failure</td>
</tr>
<tr>
<td>&gt;1 and ≤4</td>
<td>Medium</td>
<td>System will only reach 25% of its design life before a failure occurs, if no action is taken</td>
</tr>
<tr>
<td>&gt;4</td>
<td>High</td>
<td>A failure will occur before the system reaches 25% of its design life, if no action is taken</td>
</tr>
</tbody>
</table>
Basics of Materials Selection

- **Decision**

  - If \( \frac{CR_{max} \times L}{CA} \) or \( \frac{CTL}{ATL} \) > 1

  - Carbon Steel is Risky; Select CRA

- **CS + CRA**
  - Solid CRA
  - CRA – Clad or Lined
  - CRA - Plastic Liner
# Basics of Materials Selection

<table>
<thead>
<tr>
<th>Material</th>
<th>Selection Guide</th>
<th>Trigger Point</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMn</td>
<td>Predicted CO₂ corrosion rate is less than 0.3mm/yr.</td>
<td>Only used if corrosion rate is less than 0.30mm/yr and/or process stream is dry otherwise CRA is required.</td>
<td>Use inhibitors and model must be conservative otherwise prediction could be very optimistic.</td>
</tr>
<tr>
<td>13%Cr</td>
<td>If corrosion rates predicted are &gt; 0.30mm/yr and pppH₂S is less than 0.1 bar.</td>
<td>If corrosion in CMn is unacceptable and pppH₂S is generally less than 100mbar depending on the level of chlorides present.</td>
<td>Sensitive to HISC and SSC if pppH₂S chloride levels are not properly assessed.</td>
</tr>
<tr>
<td>316L Clad</td>
<td>More resistant than 13%Cr</td>
<td>If 13%Cr is unacceptable due to level of chlorides and or pppH₂S</td>
<td>Limited by its resistance to pitting in certain levels of pppH₂S/Cl. pppH₂S &gt; 100mbar is acceptable for certain combinations of pH and chloride levels.</td>
</tr>
<tr>
<td>22%Cr &amp; 25%Cr</td>
<td>More resistant than 316L. Exhibits very good SCC and SSC resistance than 316L</td>
<td>If 316L is not acceptable due to pitting in the presence of chlorides and H₂S.</td>
<td>Relaxed pppH₂S &amp; Temp levels in NACE MR 0175/ISO 15156-3. Yield strength de-rating may require more wall thickness at elevated temperatures than the other materials such as CRA clad CMn or 13%Cr.</td>
</tr>
<tr>
<td>Alloy 825 and 904L clad CMn</td>
<td>More resistant to SSC than 22%Cr or 25%Cr.</td>
<td>If SSC is considered i.e. 22%Cr and 25%Cr are not options due to pppH₂S.</td>
<td>If qualification programmes are undertaken it is possible that 316L, 22%Cr or 25%Cr can be viable options if service environments are assessed and welds qualified based on the intended installation method.</td>
</tr>
<tr>
<td>625 clad CMn</td>
<td>Resistant to both SCC and SCC</td>
<td>If pppH₂S is considerable and alloy 825 or 904L are not options</td>
<td>Very costly.</td>
</tr>
</tbody>
</table>
Basics of Materials Selection
Basics of Materials Selection

![Graph showing corrosion resistance index (PREN^a) vs. temperature (°C) for different materials: 13% Cr, Other CRA and Austenitic Material, Inhibited CMn, Uninhibited CMn, 316L / 825, 22% Cr, 25% Cr, No PLHT, and PLHT.](image)
Basics of Materials Selection

Courtesy of Arcelor Mittal

Typical Yield Strength (MPa)

Duplex

- 2202
- 2304
- 2205
- 2507 Cu
- 2507 W

Austenitic

- 304L
- 316L
- 904L

Corrosion Resistance

Suitable for Solid CRA

Suitable for Clad/Lined CS

SURF_Subsea Pipelines
# Basics of Materials Selection

## Relative cost ratings of alloys

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost factor (weight basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>1</td>
</tr>
<tr>
<td>13Cr for downhole tubing</td>
<td>1.1 - 1.8</td>
</tr>
<tr>
<td>Weldable martensitic stainless steels /Super 13Cr</td>
<td>2.2 - 3.5</td>
</tr>
<tr>
<td>AISI 316 (solid or clad)</td>
<td>3.5 - 4.5</td>
</tr>
<tr>
<td>22Cr Duplex</td>
<td>4.0 - 4.6</td>
</tr>
<tr>
<td>AISI 904L</td>
<td>4.2 - 4.8</td>
</tr>
<tr>
<td>25Cr Duplex</td>
<td>5.0 - 5.6</td>
</tr>
<tr>
<td>6Mo</td>
<td>5.0 - 5.6</td>
</tr>
<tr>
<td>Alloy 825 clad</td>
<td>5.2 - 5.5</td>
</tr>
<tr>
<td>Alloy 625 clad</td>
<td>5.4 - 6.0</td>
</tr>
<tr>
<td>Alloy 825 solid</td>
<td>7.5 - 8.5</td>
</tr>
<tr>
<td>Alloy 625</td>
<td>8.5 - 10.0</td>
</tr>
<tr>
<td>Higher nickel alloys</td>
<td>10.0 - 15.0</td>
</tr>
</tbody>
</table>
Basics of Materials Selection

- Q&A