Flow Induced Corrosion in Pulping Liquor Environments

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  – Examples of Erosion Corrosion in Pulp Mills

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  – Rotating Cylinder Tests

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• Conclusions and Mitigation Steps
Influence of Flow on Corrosion Reactions?

- By Transporting Reactants or Products
  - Higher Flow Rate – Better Transportation – Higher Reaction Rate

- By Disruption of Passive Film at the Surface
  - Film Breakdown Above Critical Velocity, $V_c$ (Breakaway Velocity)
    - Flow-Assisted Corrosion Regime
  - $V_c$ depends on alloy/environment systems

V.A.C rate

- $V_c$ depends on alloy/environment systems

Suspended Solids and Erosion Corrosion

- Flow-accelerated corrosion depends on the repassivation kinetics and erosion rate.
  - Alloy
  - Environmental Parameters (pH, Temperature, Chemical Composition etc.)
  - Flow Parameters
Flow Induced Corrosion of Cast Iron Valve

Valve in Weak Black Liquor Line

Erosion Corrosion in Sand Separator 2205 DSS

Courtesy – Dr. Angela Wensley
Flow-Induced Corrosion 2205 DSS Sand-Separator Cone Exposed to Weak Black Liquor

Courtesy – Dr. Angela Wensley

Flash Tank - SS Overlaid Inlet Nozzle

Courtesy – Dr. Angela Wensley
Accelerated Corrosion of 2205 Duplex SS Pipe Carrying Heavy Black Liquor

Failed DSS 2205 Pipe to Liquor Gun
Preferential Corrosion Attack of Austenite Grains

<table>
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<th>Element</th>
<th>Weight%</th>
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<td>Cr K</td>
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<td>Mn K</td>
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<td>Fe K</td>
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<td>Ni K</td>
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<td>Mo L</td>
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Black Liquor Evaporator

<table>
<thead>
<tr>
<th>Element</th>
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<tbody>
<tr>
<td>Si K</td>
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1D Evaporator

Erosion Corrosion in Evaporators – Liquor Inlet
Erosion Corrosion of 304L Evaporator Tubes

Erosion Corrosion Regimes for Active-Passive Alloys

Current Density (A/cm²) vs. Potential (V)

- Cathodic Region
- Active Corrosion
- Passive Region

Velocity vs. Potential (E)

- Pure erosion
- No corrosion or erosion
- Erosion-dominated
- Erosion-dissolution-dominated
- Dissolution-dominated
- Passivation-dominated
Effect of Particle Size – Chromium Steel in 1M NaOH (Deaerated)

Corrosion of 304 Stainless Steel in Softwood Black Liquors Taken From Mill-B @ 170°C
Flow Induced Corrosion or “Erosion Corrosion” Testing in Laboratory

Cylindrical Electrode and Flow in Pipe - Erosion Corrosion Testing

\[
U_{\text{Cyl, electrode}} = \frac{\pi \cdot d_{\text{cyl}} \cdot F}{60}
\]

\[
U_{\text{Cyl, electrode}} = 0.1185 \left( \frac{\rho}{\mu} \right)^{0.25} \left( \frac{d_{\text{cyl}}}{d_{\text{pipe}}^{5/28}} \right)^{3/7} Sc^{-0.085} F^{1/4}
\]

Where
- \(U_{\text{cyl}}\) (cm s\(^{-1}\)), Target surface velocity at rotating cylinder
- \(U_{\text{pipe}}\) (cm s\(^{-1}\)) is flow rate in pipe
- \(d_{\text{cyl}}\) (cm) is the diameter of the pipe,
- \(Sc\) is the Schmidt number,
- \(\mu\) is absolute viscosity of solution in g/cm/s and
- \(\rho\) is solution density in g/cm\(^3\).
- \(F\) is RPM of electrode

Using this equation:

- If water is flowing through a smooth 10-inch Schedule 40 pipe at 1.0 ft/sec,
- A Rotating Electrode with 1.2 cm diameter (and 3.0 cm\(^2\) area) rotating at 149 RPM will match the flow conditions in that pipe
Corrosion Rate as a Function of Velocity - 65% solids BL

Cast Iron

Carbon steel (516-Gr70)

Corrosion Rate as a Function of Velocity in 65% solids BL

316L

304L

304L in 65% ISC Black Liquor

316L in 65% ISC Black Liquor
Corrosion Rate as a Function of Velocity in 65% solids BL

**LDX 2101**

**DSS 2205**

Critical Velocity in Different Pulping Liquors at 60ºC

- Tested at 60ºC
- 516-Gr70
- CF8M Cast Steel
- 316
- 2101
- 2205
Critical Velocity in Different Pulping Liquors at 90ºC

Conclusions - Lab Results

- Below the flow velocity of ~5 meters/sec, effect of flow on the corrosion rate for tested materials in tested pulping liquors was negligible.

- Alloys that form a stable passive film on the surface in pulping liquors showed a critical flow rate
  - Above a critical velocity range the corrosion rates for tested stainless steels approached same order of magnitude as carbon steel.
  - Below critical velocity stainless steels had significantly lower corrosion rates in tested pulping liquors, as is expected.

- Cast iron had very high corrosion rate in tested pulping liquors so no significant acceleration was seen due to flow velocity.

- For carbon steel, the effect of flow on corrosion rate was gradual compared to that for the stainless steels tested in pulping liquors.
  - Critical flow rate value was not clear for the C-Steel in white and green liquors.
Strategies to Mitigation Erosion Corrosion

- Modify the fluid flow (*locally or globally*) to minimize turbulent flow
  - by either modifying the fluid flow rates or by minimizing the flow disruptions, especially at the joints and pipe entry points
- Keep flow rates below critical flow rate
  - However, data of flow conditions is not always available to make a good decision.
  - In such case, generation of data under given environment and under realistic flow conditions should be considered, whenever possible
- Use a more corrosion resistant alloy with stable passive film in a given environment
- If possible, other changes to environment to stabilize passive film
  - Temperature, pH, Concentration, Presence of Solids

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Questions?