Internal SCC in Ethanol Pipelines

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Introduction

- Significant interest within pipeline industry in transporting fuel grade ethanol
  - Oxygenating agent for gasoline
  - Alternative fuel for motor vehicles

- Ethanol now transported to blending/distribution facilities
  - Tanker trucks
  - Rail cars
  - Barges

- Increased usage of ethanol has prompted the need for alternative, economical means of transporting ethanol

- Pipeline transportation is likely candidate but there are concerns with respect to corrosion / stress corrosion cracking
Background

- Prior to shipment, ethanol is denatured & inhibited
  - Natural gasoline is most common denaturant
  - Octel DCI-11 is most common inhibitor for general corrosion

- At blending/distribution facilities, large tanks and piping facilities are used for blending operation and for storage

- SCC has been observed in carbon steels in contact with fuel grade ethanol

- Failures documented back to early 1990s
  - User terminals
  - Storage tanks
  - Loading/unloading racks

- No failures at ethanol producer sites nor after ethanol was blended with gasoline
Cracked Bottom Plate - Tank

Crack parallel to striker plate weld

Close up of crack
Piping Failures in Terminals

Leak

Weld

Close up of leak area
Piping Failures (Cont’d)

- Leak near pipe support weld
- Cracks start from pipe ID
Background

- API Technical Report [939-D (2003)] provides a review and summary of ethanol SCC of carbon steel
  - Published literature
  - Service experience

- All occurrences of SCC were in first major hold point or downstream
  - Fuel ethanol distribution terminal
  - Subsequent gas blending or distribution terminals

- Majority of cracking found at welds
  - In base metal and HAZ of welds
  - Primary stress leading to SCC is residual welding stresses

- No cases reported in:
  - Manufacturer facilities or other transport facilities directly following blending
    - Tanker trucks
    - Railroad cars
    - Barges
Prior Research Results

- PRCI and API funded research on the roles of chemistry and steel properties on ethanol SCC
  - Fuel grade ethanol that meets ASTM standards is a potent cracking agent
  - Dissolved oxygen concentration is a primary contributing factor in cracking
     - Reflected in potential dependence of cracking
  - Chloride was found to exacerbate cracking and affect cracking mode
     - Intergranular SCC with low Cl (<1 ppm)
     - Transgranular SCC with high Cl (>35 ppm)
  - Testing was inconclusive with respect to relative susceptibility of different line pipe steels
Prior Research Results

- Factors having some effect
  - Coupling to corroded steel
  - Presence of methanol

- Factors that had a minimal effect on SCC
  - Type of Denaturant
  - Acidity within specifications
  - Water content from 170 ppm to 2%
  - One standard inhibitor for general corrosion (Octel DCI-11)
Slow Strain Rate Test Results

Severe SCC
(Aerated Simulated FGE)
Slow Strain Rate Test Results

Aerated SFGE
SCC Crack Depth Measurements
Mixed mode SCC in aerated SFGE
Recent PRCI Research Findings

- Limited success with constant load tests in laboratory
- SSR test technique very effective for evaluating environmental effects
- Corrosion potential generally good cracking indicator

**SCC mitigation**
- One inhibitor and one oxygen scavenger identified in recent PRCI research
  - Di-ethanol amine (DEA)
  - Hydrazine
- Three non-chemical means of oxygen scavenging identified
  - Mechanical deaeration
  - Corrosion reactions (steel wool)
  - Nitrogen deaeration

- E-85 fuel potent cracking agent
- Batching with diesel fuel not shown to inhibit SCC in SSR tests
Recent PRCI Research Findings

![Graph showing the relationship between average corrosion potential and crack growth rate for different additives. The graph includes data points for No Additive, DEA, and Hydrazine.]

- **No Additive**: Shows a general trend of decreasing crack growth rate as the corrosion potential increases.
- **DEA**: Displays a relatively high crack growth rate at lower corrosion potentials and decreases as the potential increases.
- **Hydrazine**: Exhibits a trend with a low crack growth rate at higher corrosion potentials.
Recent PRCI Research Findings

- Crack Growth Rate, mm/s
- Average Corrosion Potential in Test, Ag/AgCl EtOH
- No Deaeration
- Steel Wool
- Nitrogen Deaeration
- Mechanical Deaeration

- Graph showing the relationship between crack growth rate and average corrosion potential for different deaeration conditions.
Other Recent Research Findings

- SCC potency of ethanol-gasoline blends decreases with increasing gasoline concentration
- SCC potency of FGE decreases with decreasing oxygen concentration
- Considerable variability in potency of actual FGE
- Evidence that FGE contains natural inhibitors that degrade with time
Objectives of New Research Programs

- PRCI SCC 4-4
  - Identify FGE blends that can be transported in pipelines
    - Case 1 – Blends that do not require significant modifications of systems and operations
    - Case 2 – Blends that require significant modifications but can be transported in existing systems
    - Case 3 – Blends that require specially designed systems
  - Characterize the time to initiation of SCC in a range of potent FGE environments
    - Identify operating and batching practices that prevent SCC initiation and growth
Objectives of New Research Programs

- PRCI SCC 4-3
  - Design laboratory experimental procedures to better implement various mitigation strategies
    - Inhibitors
    - Oxygen scavengers
    - Other methods of oxygen scavenging
  - Estimate the types and concentrations of chemical treatment required for effective performance.
  - Establish protocols for non-chemical treatment methods
    - Volumes and flow rates for gaseous deaeration
    - Vacuum-time behavior for vacuum deaeration
  - Assess cost effectiveness of scale-up of mitigation methods
  - Assess end-user acceptance of mitigation methods and implications of post transportation issues
  - Develop field procedures to establish effectiveness of mitigation methods