Alberta Innovates Technology Futures

Internal Corrosion of Crude Oil Pipelines Research at AITF

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Corrosion Engineering

Alberta Innovates Technology Futures

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Outline

- Introduction to Internal Pipeline Corrosion of Crude Oil Pipelines
- Underdeposit Corrosion
  - Inhibitor Evaluation Test Protocol
    - Bacterial Kill Experiments
    - Underdeposit Corrosion Experiments
  - Mechanism
- **Pi**peline **Co**rrosion **M**anagement (**PiCoM**) working group
  - Corrosion Monitoring and Underdeposit Corrosion in Pilot Scale Flow Loop
- Summary of Research Direction

Introduction

Internal Pipeline Corrosion when Water-Wet (gathering pipelines)

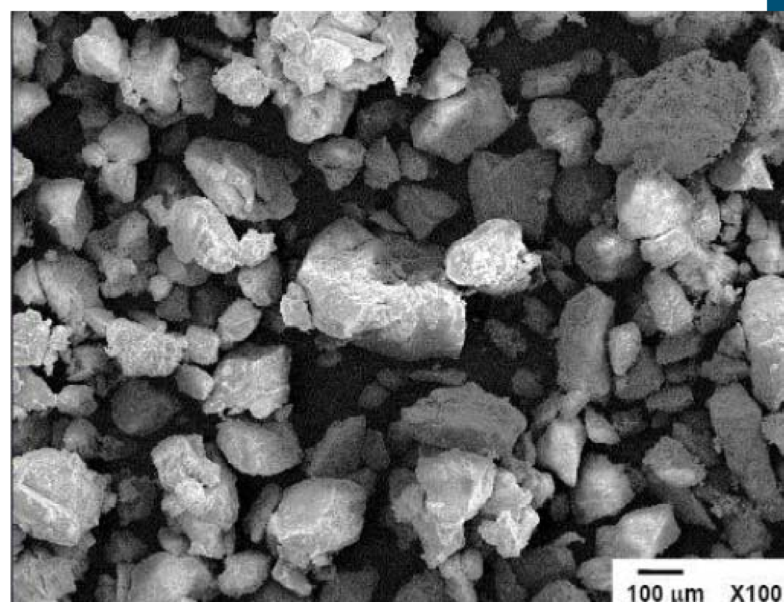
- Steel wet by oil does not corrode
- Critical water content that will lead to water-wet conditions is generally much greater than 10%
- For corrosion to occur, separation of a water phase from the oil is required
- Internal pitting corrosion models for water-wet conditions

Introduction

- Crude oil transmission pipelines (<0.5% BS&W) have a long history without significant corrosion
- 0.5% is usually not a corrosion concern unless conditions exist that enable the precipitation of water on the pipe wall
- Solubility of water in oil only 50-100 ppm
- Water is present as an emulsion, droplets <10 microns, carry chlorides and solids
- Water emulsion droplets are stabilized by asphaltenes and ultrafine submicron clay particles
- Speculation that polar asphaltene flocs can precipitate with water droplets and clay particles, forming larger 100 – 1000 micron clusters

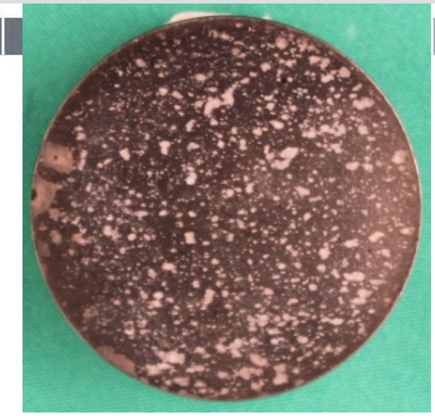
Introduction

- Precipitation at low flow conditions to form sludge in low pressure areas
- Most solids are fine at <44 microns, some are >400 microns and consist primarily of silica sand and iron compounds
- Sludge deposits are mixtures of hydrocarbons, sand, clays, corrosion by-products, bacteria, salts, and water
- Deposits may be layered resulting in variability within the sludge



Underdeposit Corrosion

- Corrosive water film can form on the pipe wall containing salts, chlorides, and organic acids
- Sludges can contain large bacterial populations (SRB, APB, HAB)
- Sludges with waxy oil can exhibit low or no corrosion
- No corrosion observed in the absence of sludge



Sludge covered sample exposed to crude oil for 4 weeks

Bare sample exposed to crude oil for 4 weeks

Sludge Composition

		X	Y	Phase I	Phase II
Soluble in: (wt %)	Heptane	17.8	17	15	-
	Xylene	1.3	1.1	6.4	-
	Water	0.8	0.4	0.7	-
	Acetic acid	1	0.3	8.3	-
	HCl	0.8	1.8	23.3	-
	Residue	78.3	79.4	46.5	-
EDX (wt %)	C	6.1	5	11.6	6.6
	O	54.9	49.2	37.1	46.2
	Si	31.3	30	14.4	26.9
	S	0.6	1.6	6	1
	Fe	3.4	10.8	27.34	14.6

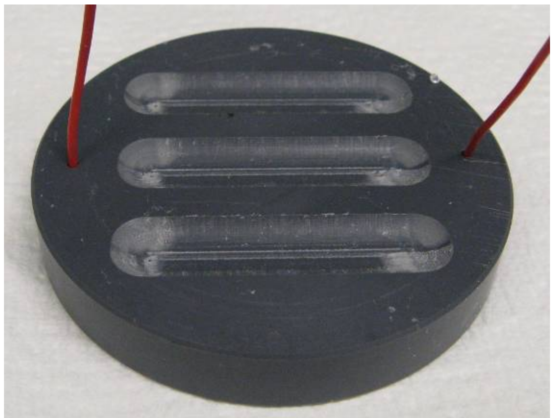
Dean Stark Analysis

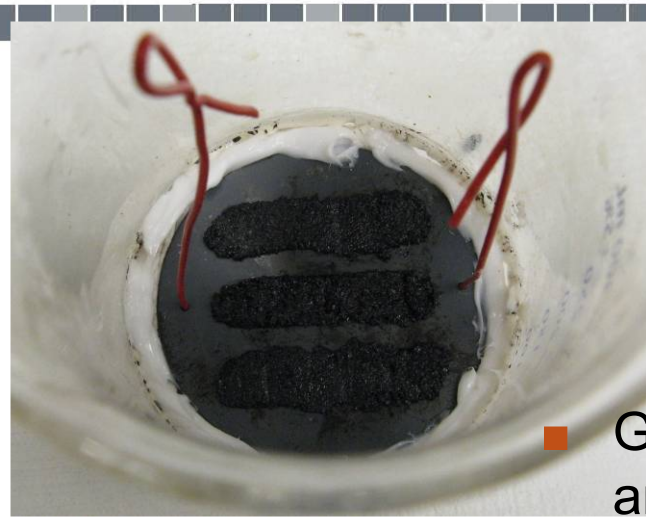
	Phase I	Phase II
Solid (wt %)	72.3	85
Oil (wt %)	24.8	4.5
Water (wt %)	2.9	10.4

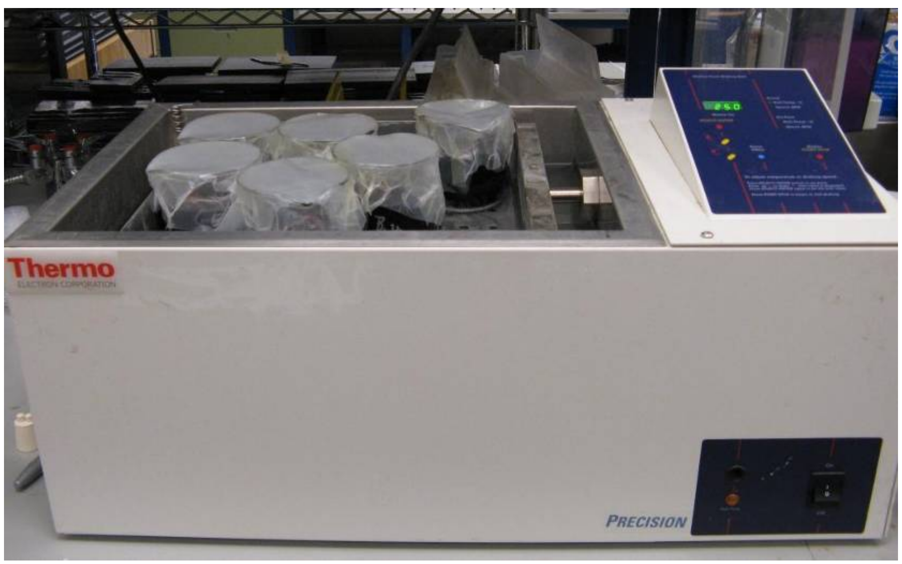
Inhibitor Test Protocol

- Mitigation includes pigging and chemical treatment
- Need to understand the corrosive influence of sediment and the effectiveness of mitigation
- Five chemical inhibitor vendors were encouraged to develop chemical treatments aimed at reducing underdeposit corrosion
- Inhibitor test protocol was developed in collaboration, considering a multifunctional batch inhibitor:
  - Ability to penetrate sludge
  - Filming effectiveness
  - Bacteriocidal properties
- Testing methodology components of bacterial kill experiments and underdeposit corrosion experiments

Bacterial Kill Experiments

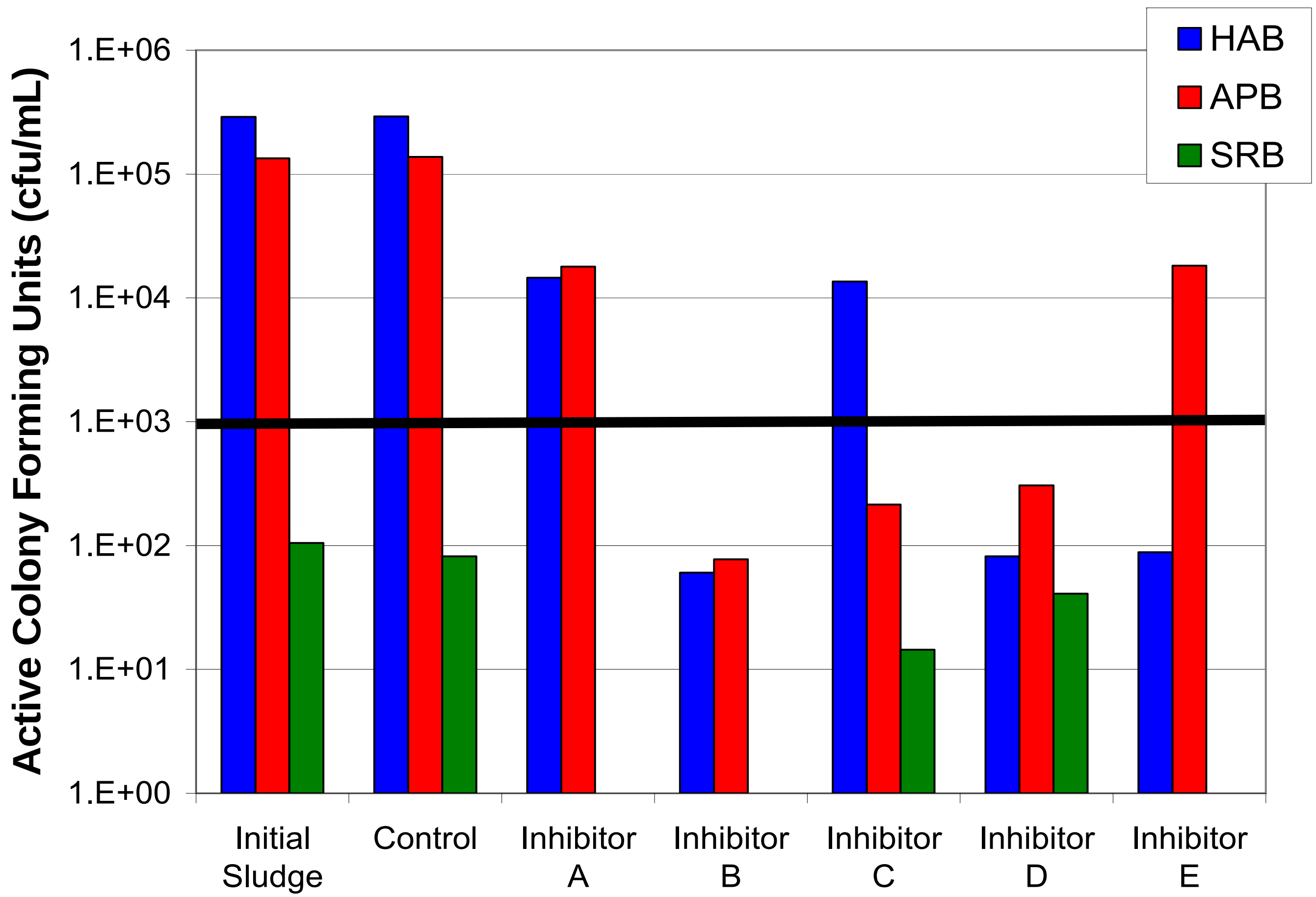






- Greater surface area for inhibitor penetration
- 2 mm deep sludge
- Oil + 5000 ppm of inhibitor under N_2
- Placed on rocking table for 24 h

Bacterial Kill Experiments



- Sludge with low SRB population
- Inhibitor effectiveness can be measured
- Differences in inhibitor effectiveness are observed

Bacterial Kill Experiments

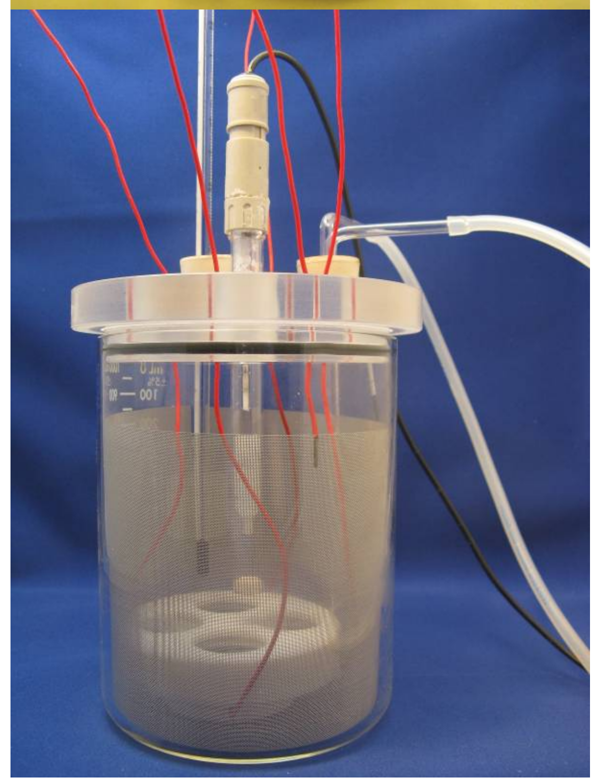
- Methodology may be appropriate, but how well does the inhibitor assessment predict its performance in the field?
  - Complex system
  - Variable oil chemistry
  - Variable sludge chemistry; heterogeneous
  - Bacteria populations are a function of time

Underdeposit Corrosion Testing

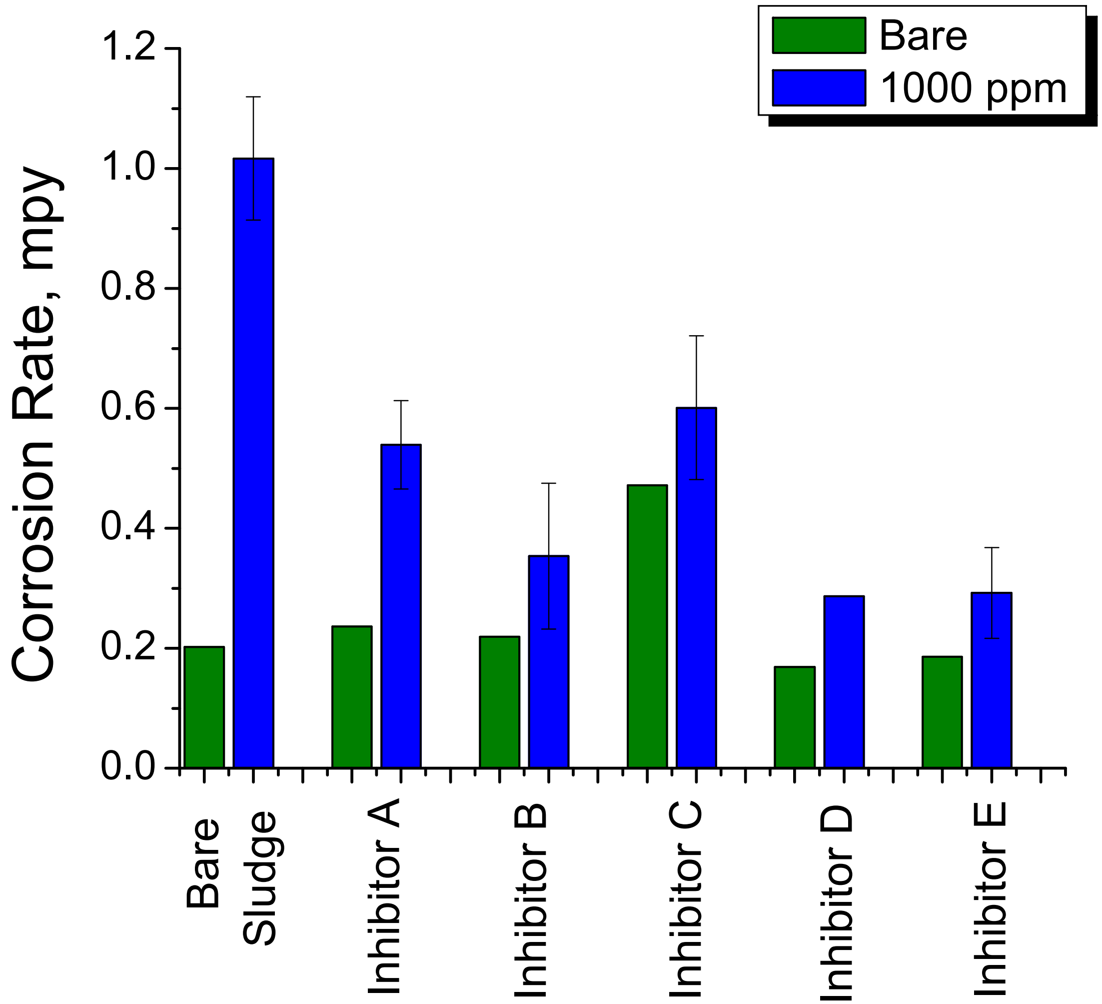
- No standardized underdeposit test procedure
- Oil free sand or oil wetted sand has been used in brine solutions
- Nature of sludge is critical in evaluating the success of an inhibitor
- The test method should be able to assess the inhibitor effectiveness at conditions that can be extended to the pipeline

Underdeposit Corrosion Experiments

- CS coupon, recessed in Teflon holder by 1 mm
- 1 mm thick layer of sludge
- Inhibitor added to the oil
- Controls with no inhibitor
- Pipeline heavy crude oil
- 4-week long exposure experiment on rocking table in anaerobic chamber
- 10% CO_2 / N_2; 25 C
- Visually examined for pits and corrosion and using an optical profiler
- BART before and after



Underdeposit Corrosion Experiments



- 1 mm sludge deposit
- 1000 ppm inhibitor added to oil
- Inhibitors provide protection
- Ability to assess inhibitor performance possible

Underdeposit Corrosion Testing

- The developed methodology enables assessment of inhibitor performance
- Remaining challenges:
  - Variable and dynamic sludge properties
  - Uncertain what the controlling corrosion mechanism is (bacterial corrosion, aqueous corrosion, or combination):
    - Long term corrosion exposure experiments
    - Correlating the corrosion results to the sludge chemistry and bacterial populations

Internal Corrosion of Crude Oil Transmission Lines

Underdeposit corrosion

- Questions remain on:
  - the controlling corrosion parameters
  - the sludge deposition mechanism
  - **the role of crude oil chemistry**
  - **the role of delivery process steps**
- There are crude oil lines that have operated trouble-free for over 25 years
- Not unique to dilbit lines
  - BP experienced leaks in Trans-Alaska pipeline attributed to underdeposit corrosion in the presence of CO_2 and bacterial populations

Trans-Alaska pipeline systems, The Guardian, Jan 2011

PiCoM

PiCoM
PIPELINE CORROSION MANAGEMENT

- The Pipeline Corrosion Management (PiCoM) program at AITF is directed by an Industry Working Group addressing issues of pipeline corrosion and integrity management
- Supported by Alberta government (AET & AITF) and GE Water and Process Technologies
- As of April 2013, the PiCoM program will be an R&D consortium managed by AITF and directed by the operating industry members

Current PiCoM Research

- Directed towards internal Corrosion Monitoring & Mitigation of crude oil pipelines
  - Corrosion underneath sludge deposits (water, MIC)
  - for base-lining and optimization of mitigation tools
- Laboratory experiments evaluating monitoring technologies and mitigation effectiveness
- Design, construction, and commissioning of pilot scale flow loop

Crude Oil Flow Loop

- Crude oil pipeline simulation
- Flow rate and Temperature controlled
- Pig design evaluation
- Chemical inhibitor evaluation
- Real time corrosion rate monitoring
- Simulation of localized corrosion (pitting and MIC)

Crude Oil Flow Loop

Project Proposals

- Effectiveness of Corrosion Inhibitor in Simulated Crude Oil Transmission Pipelines (0.5% BS&W)
- Assessment of the Corrosivity of Sludge from Dilbit Lines versus Sludge from Conventional Crude Oil Lines
- Effectiveness of Corrosion Inhibitor in Simulated Upstream Pipelines (higher water cut)
- Effect of Flow rate on Corrosion in Crude/Water Systems
- Evaluation of Pig Design for Sludge Removal from Corrosion Pits in Heavy Oil Pipelines
- The Effect of Cleaning Pigs on Corrosion Rates when Applied after Inhibitor Filming
- Scoping Study/Survey of Pipe Manufactures and Pipeline Operators with respect to Mill Defects and Solutions to Off-Spec Pipe
- Scoping Study/Literature Review of Life Cycle Analysis for New Non-Metallic Pipeline Materials

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