Research in Progress

CORROSIVE SEDIMENTS IN PIPELINES

Trevor Place, Enbridge Pipelines

PHMSA Forum, Atlanta

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Preface:

Limitations on work

- Based on high capacity, large diameter transmission crude oil system (Enbridge)
  - Tariff quality crude oils only (<0.5% S&W)
  - Line velocity: 0.9 – 1.9 m/s
  - Heavy crude oils: 910 – 935 kg/m^3 (API 21-25)

- The results or conclusions drawn from these investigations may not apply to other pipelines or other pipeline operating conditions.

Origin of Interest:

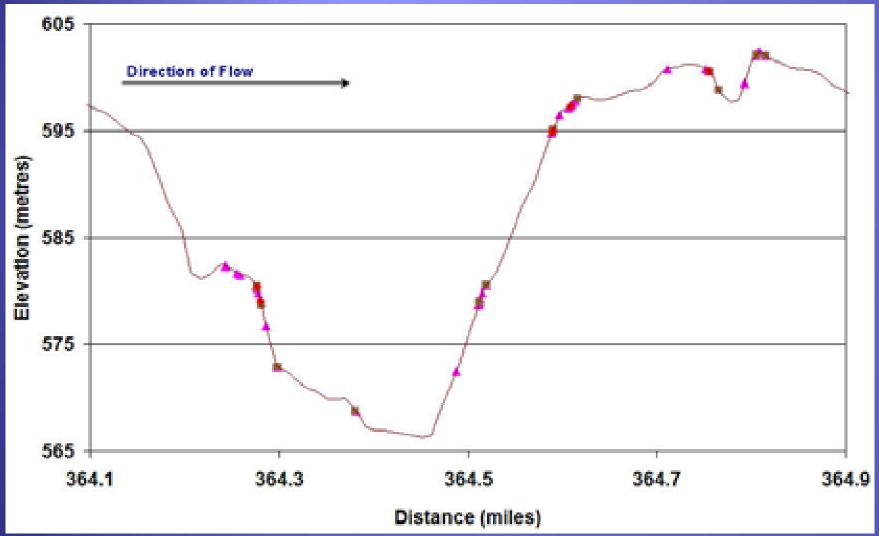
Internal Corrosion History

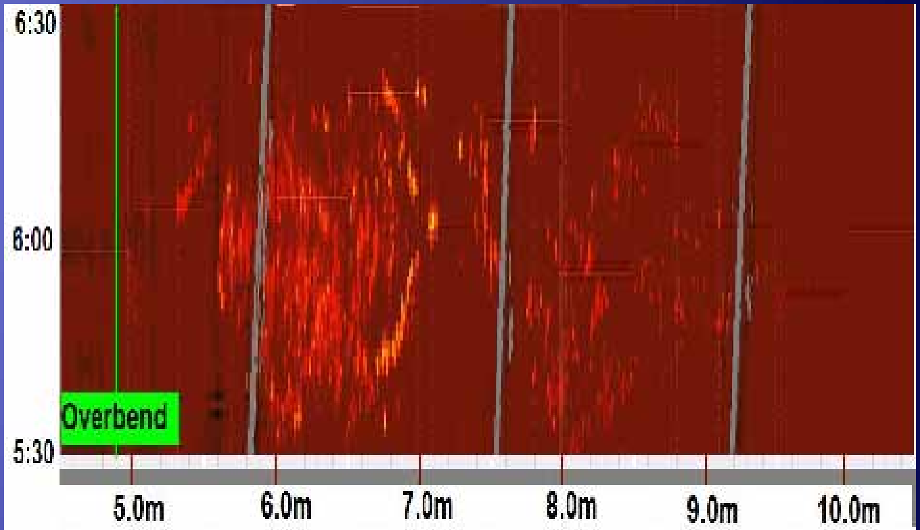
- 30+ year old lines with no internal corrosion
  - Transmission quality oil considered non-corrosive
- Higher incidence of corrosion identified in late 1980's on a newer asset
  - Unique configuration (looped, large diameter)
  - Cleaning and chemical treatment was initiated
  - Mitigation program is effective

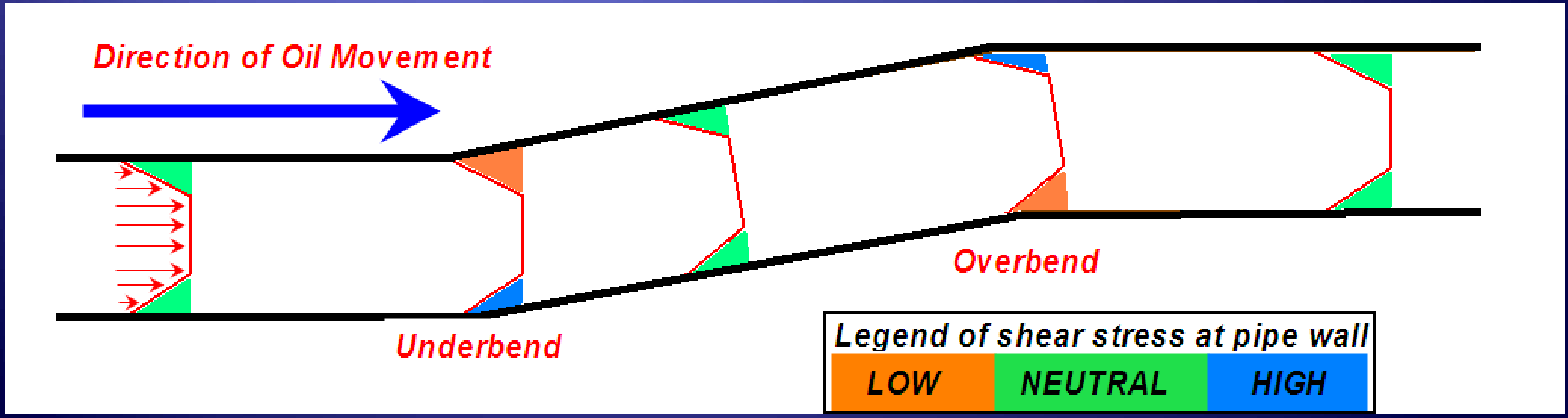
- While the mitigation program is proven to be very effective, we have a desire to improve/optimize mitigation through better understanding of the rare occurrence of corrosion

Location Factors:

Incidence of Corrosion

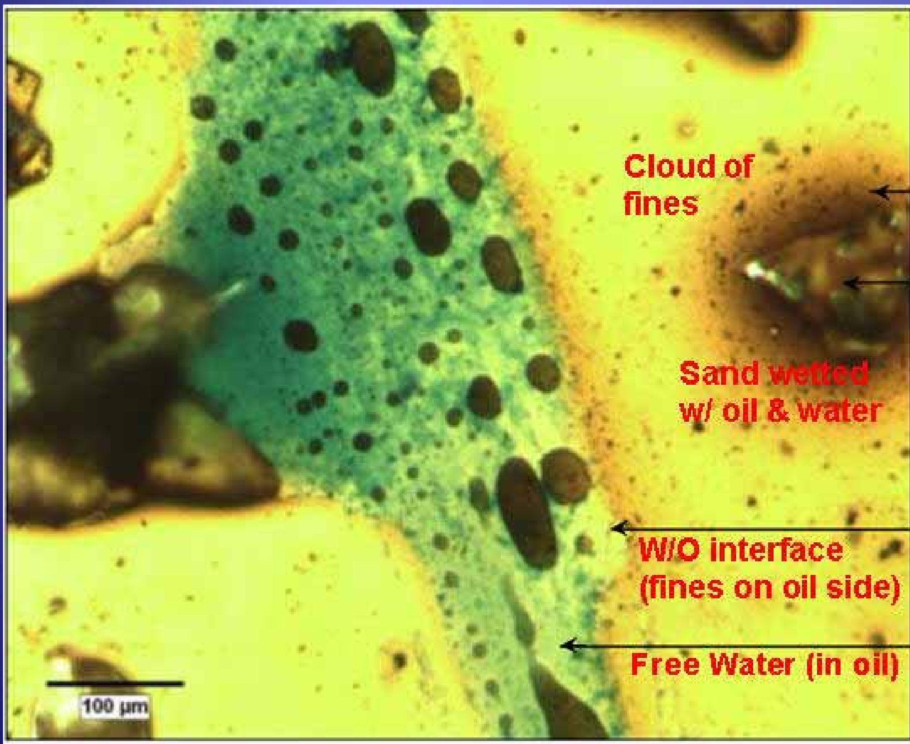


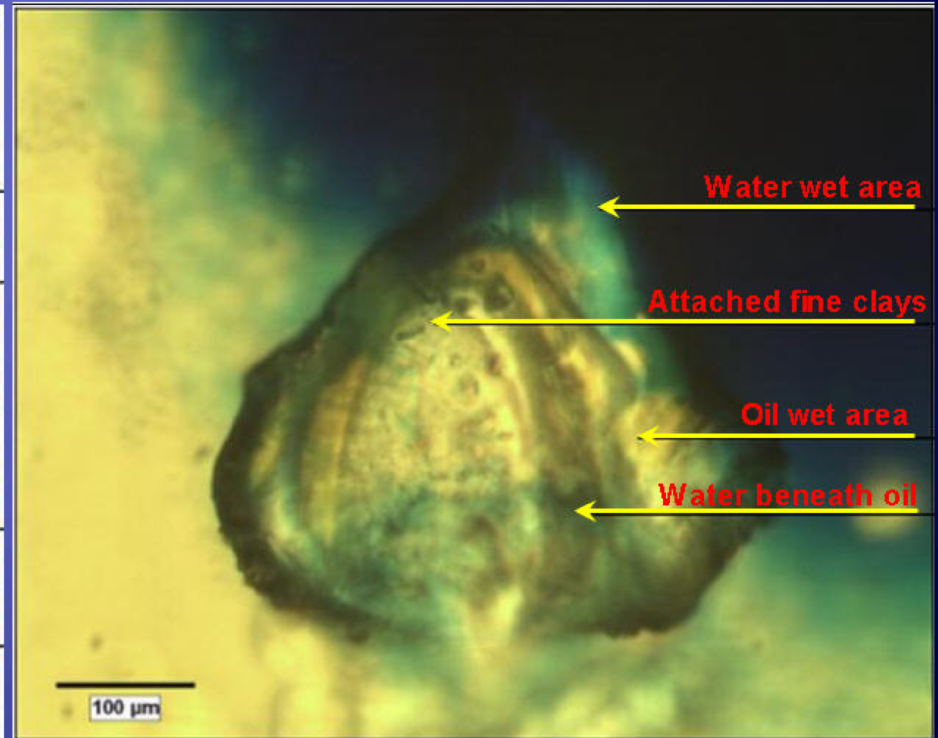




Sediment characteristics:

Water/Sediment Relationship

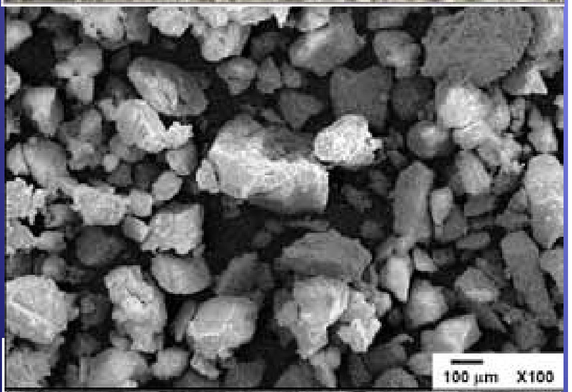




- Sand particles have sufficient density to concentrate near the pipe floor under normal pipe flow conditions
- Resulting 'slurry' is transported in an equilibrium condition, easily upset by slight changes in wall shear

Sediment characteristics:

Sediment Composition



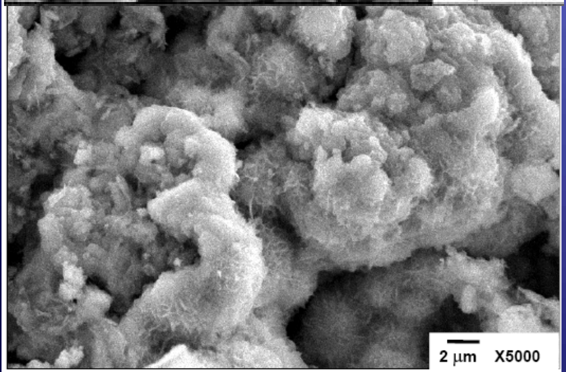


TABLE 1
Summary of Compounds in Pipeline Solids

Name	Chemical Composition
Silica sand	Quartz [SiO_2]
	Microcline [$KalSi_3O_8$]
	Illite [KalSiO(OH)]
Iron Compounds	magnetite [Fe3O4]
	goethite [FeO(OH)]
	greigite [Fe3S4],
	pyrite [FeS2]
	mackinawite [Fe9S8])
Wax	
Secondary Compounds	sulphur compounds
	Sodium oxide Na_2O
	aluminum oxide [Al_2O_3]
	magnesium oxide [MgO]
	Clays kaolinite [AlSiO(OH)]
	calcium carbonate scale [CaCO3]
	iron carbonate scale (siderite [FeCO3]
	salt (halite [NaCl])
	titanium oxide [anatase (TiO2)]
	non crystalline iron bearing compounds
	Asphaltines
	organics (non organic solvent soluble carbon containing compounds such as large polymeric carbon compounds or biologic material)

- Analysis dependent on collection and handling
- Particle size: <1 micron to 400 micron
- Contains water and is often microbiologically active

Investigation:

Corrosivity of Sediment

"OPEN" coupon test results

Test Condition	CGR (mpy)	St. Dev.
Bare coupon in uninhibited brine	2.62	0.78
Coupon with uninhibited sediment in uninhibited brine	2.33	0.68
Coupon with inhibited sediment in uninhibited brine	1.93	0.73

- Sediment less corrosive than the brine
- Inhibitor reduced sediment corrosivity (NB: only one inhibitor chemical was used ('B'); results are expected to vary with different chemistries)
- Results hard to distinguish (brine corrosivity)
- Expect better results by completely encapsulating the coupon with sediment

Investigation:

Corrosivity of Sediment

"Static Autoclave" test results

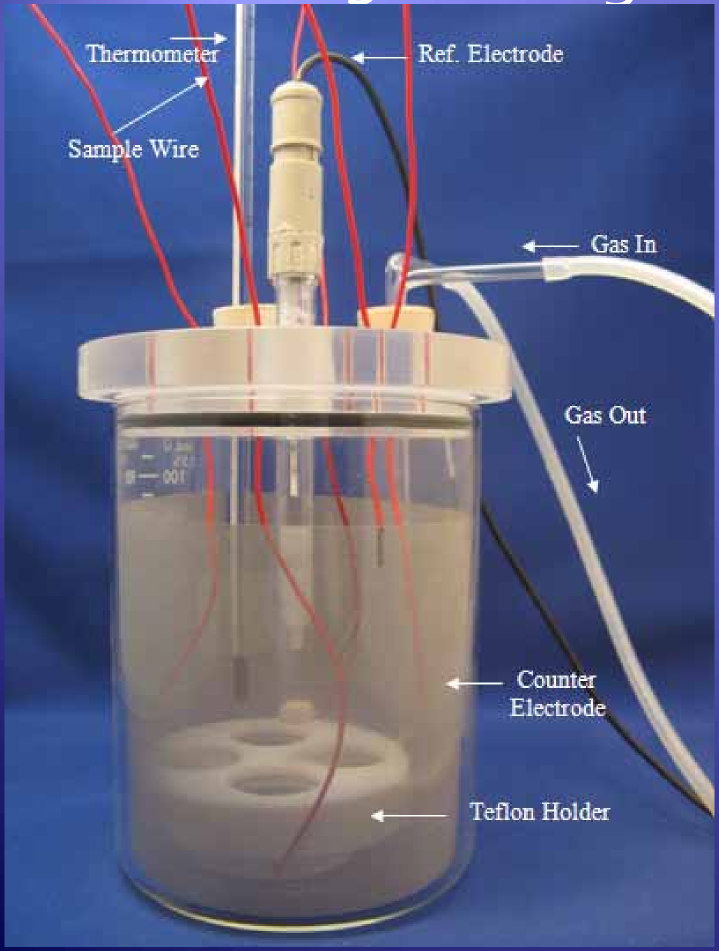
Test Condition	CGR (mpy)	St. Dev.
Coupon with uninhibited sediment in uninhibited brine	2.23	0.53
Coupon with uninhibited sediment in inhibited brine	2.36	0.25
Coupon with inhibited sediment in uninhibited brine	0.73	0.17
Batch treated coupon with uninhibited sediment/brine	0.88	0.09

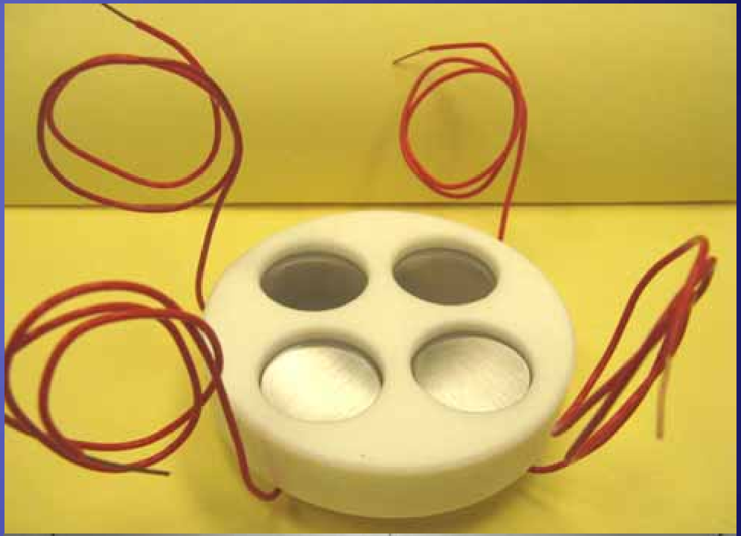
- Less scatter than 'open' coupon test
- Inhibiting brine had no effect (NB: only one inhibitor chemical was used ('C'); results are expected to vary with different chemistries)
- Treating sediment was as effective as batch treating the coupon before exposure

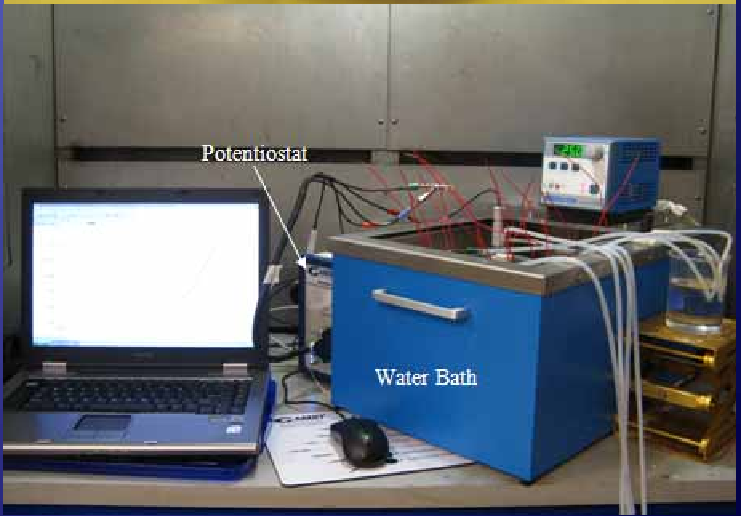
Investigation:

Corrosivity of Sediment

"Method 3" testing



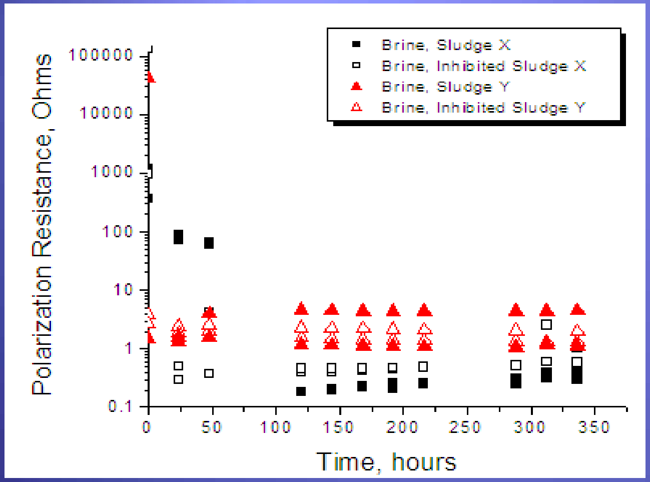


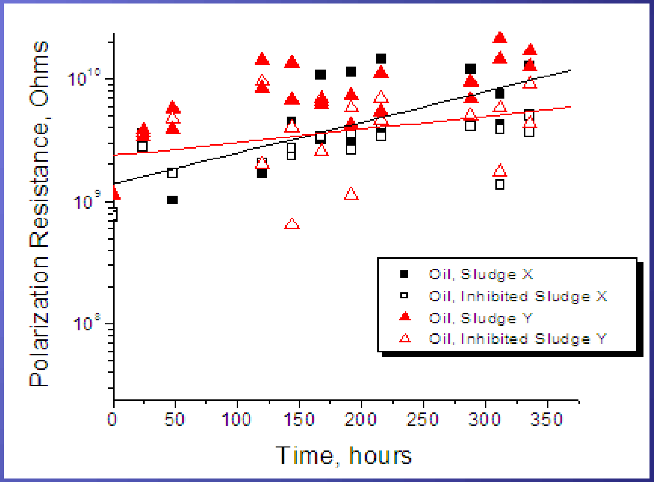


Investigation:

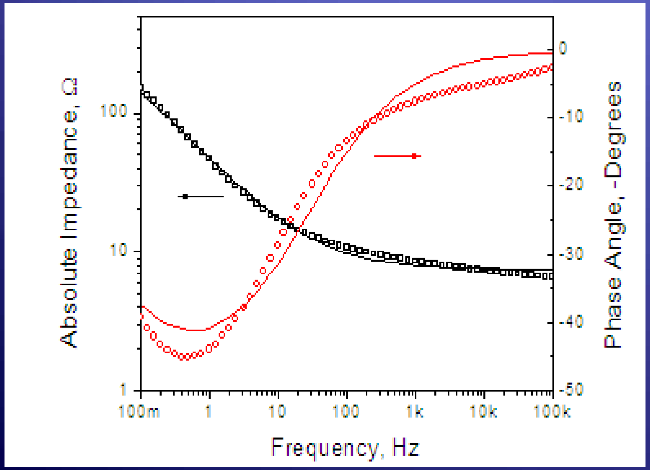
Corrosivity of Sediment

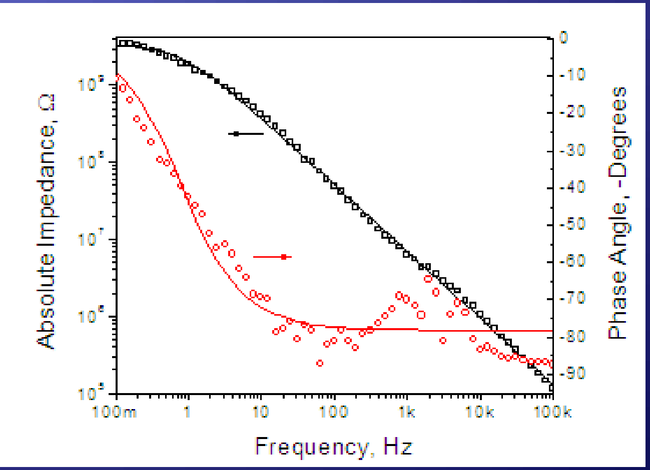
EIS could be performed in brine (but not oil)





Significantly increased scatter in oil





LRP was done in brine, but could not be performed in oil (results not shown)

Investigation:

Corrosivity of Sediment

"Method 3" corrosion rate test results in mpy (st.dev)

	1 week exposure	2 week exposure	weighted average
Coupon in brine	3.55 (-)	--	3.55 (-)
Coupon in brine with sediment 'A'	59.52 (2.36)	17.44 (1.72)	32.6 (23.5)
Coupon in brine with sediment 'B'	10.66 (-)	16.08 (5.75)	
Coupon in oil	0.59 (-)	--	0.59 (-)
Coupon in oil with sediment 'A'	10.36 (4.73)	4.00 (1.73)	7.40 (4.33)
Coupon in oil with sediment 'B'	8.29 (4.73)	4.00 (1.15)	
Coupon in oil with inhibited sediment 'A'	--	4.92 (0.57)	6.50 (1.72)
Coupon in oil with inhibited sediment 'B'	--	8.08 (-)	

Conclusions:

Corrosivity of Pipeline Sediment

- Sediment accelerates corrosion in brine and oil
- Heavy oil sediments can be corrosive without the presence of free water
- Direct application of inhibitor to sediment reduces corrosion (see note 1)
- Application of inhibitor to fluid may not reduce corrosion rates (see note 1)

Note 1: only one inhibitor chemical was used ('G'); results are expected to vary with different chemistries

Ongoing Investigations:

Solids mixing device

Simulates energy of mixing and particle collisions between solids flowing in slurry

Similar to erosion tester by Patterson-Cooke

Partly filled with liquid and solids, then rotated

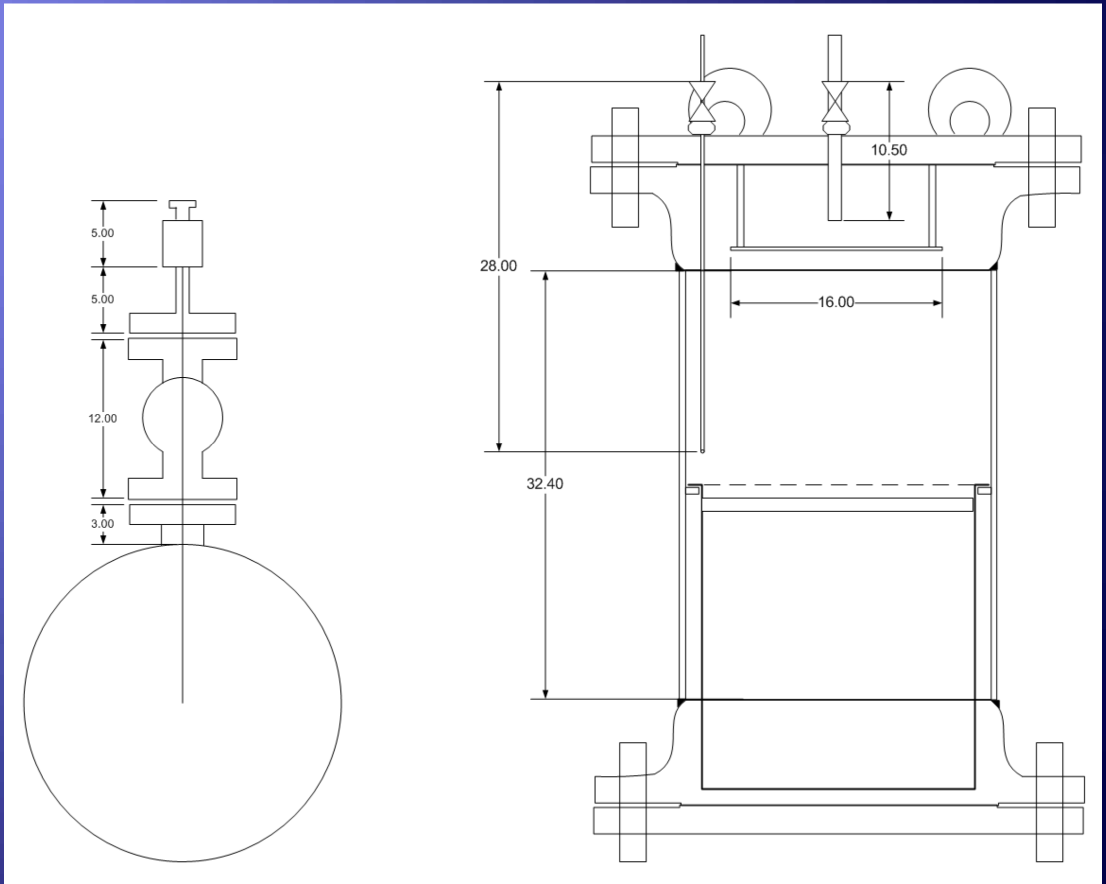
Sand in water

Sand in mineral oil

Ongoing Investigations:

On-Line Sediment Sampler

- Hot insertable sampling probe to evaluate sediment stratification
- Obtain subsamples based on particle settling velocity
- To be used to evaluate inhibitor programs



Future steps:

Further R&D Required

- Standardized sludge corrosivity test method
  - PRCI is working on gas pipeline solids
- Better understanding of operating parameters conducive to, or mitigating sedimentation
- Pigging for line cleaning:
  - How clean is clean? (metric required)
  - Required cleaning frequency needs definition
  - Acceptance criterion must be established

Future steps:

Further R&D Required

- Chemical mitigation of solids needs to be developed and as technically robust as inhibition of aqueous systems
  - Mechanistic understanding needs refinement
  - Monitoring systems to be improved and supported
- Best methods need to be identified:
  - Reduce corrosivity of sludge
  - Film metal for protection
  - Use of solvents/dispersants to mobilize solids
  - Combination effects

The End:

QUESTIONS