Cost Effective Corrosion Protection for Steel Water Storage Tanks

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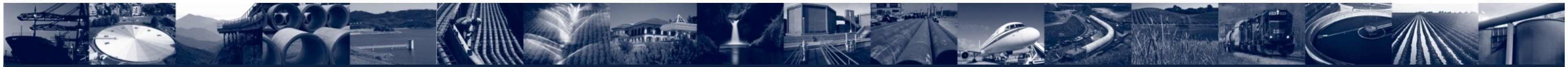
Engineers & Scientists



Water Storage Tanks

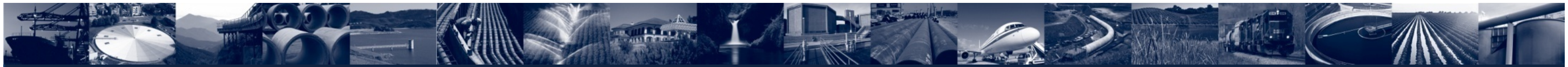
- **Life Expectancy – 60 years* or more**

***Source: California State Controller's Office Division of Local Government Affairs, 1979, "Suggested Useful Lives of Depreciated Assets"**

- **Steel Corrodes – and Mild Corrosion at 10 mils (0.01 inch)/year will perforate a ¼-inch-thick shell plate in 25 years.**

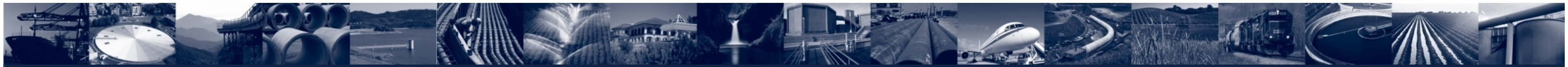
- **Coating Systems – Useful Life:**
  - **Epoxy Interior Coatings – 15 years±**
  - **Polyurethane Exterior Coatings – 20 years±**

Expect 4 or 5 interior recoatings in life of steel tanks – cost and out-of-service periods.



Recoating Dilemma

The most favorable time to recoat a water storage tank is in summer (warm, dry seasons) when usually a storage tank is most needed to be in-service for fire protection and peak water demands. Cool, damp coating periods are problematic for good sand-blasting of surfaces, adhesion and curing – Result blistering, holidays and lousy results at extra costs and frustration.



Coating Systems are not as Durable as in the Past

Can't use typical past coating systems because of drinking water toxicity issues and volatile organics air quality issues

i.e. past coating systems no longer acceptable: red lead primers, coal tar or coal tar epoxy coatings, rubberized coatings, vinylester coatings (excessive VOC)

What is left for interior coatings?

High build epoxy amide coatings (low VOCs, but application more difficult and shorter life) – NSF 61 Approved

Zinc rich primers for sacrificial galvanic protection of steel corrodes more rapidly than steel but costly NSF61 approval for a few but are they really in contact with water?

Our Wetter Climate Works Against Durable Paint Coatings

Typical:

Summer – Warm, dry, low humidity days – cool nights that moisture condenses, so repetitive wetting-drying cycles, and salts build-up, chlorine vapors, etc.

Winter – Humid, wet, cool, but corrosive

Water Tanks – Most Corrosion Vulnerable Locations

- **Interior roof plates – wet-dry cycles, condensation salt buildup**
- **Roof plate support purlins (edges and particularly at roof plate junction) that can't be seal welded because of expansion over diameter of 80-feet**
- **Support angles and juncture of interior roof and shell plate**

Water Tanks – Most Corrosion Vulnerable Locations (cont'd)

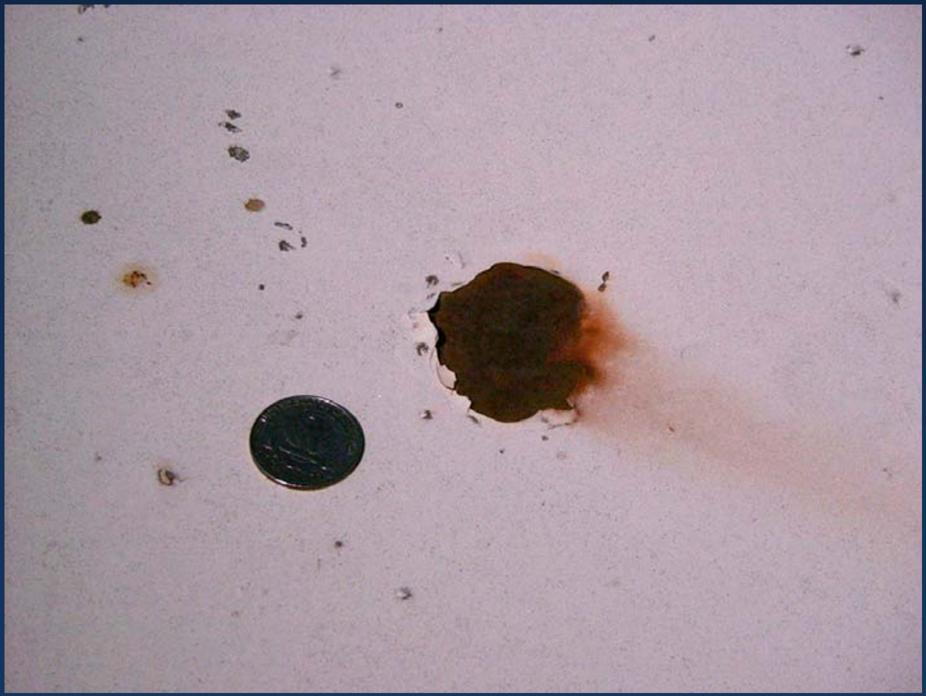
- **Interior shell plate to water line**
- **Horizontal and vertical welds of shell and bottom plates**
- **Exterior – underneath bottom plate near exterior shell plate connection**
- **Any edge – organic coatings become brittle, shrink and crack as they age**
- **Vents and vent connections**

Andover Tank Photo 9 (08-16-06)
Interior

Andover Tank Photo 10 (08-16-06)
Interior

Andover Tank Photo 12 (08-16-06)
Exterior

Andover Tank 2 Photo 3 (08-16-06)
Exterior



Andover Tank Photo 5 (08-16-06) Exterior

Andover Tank Photo 6 (08-16-06) Exterior

Brace Tank 2 Photo 3 (08-16-06)
Exterior

Andover Tank 2 Photo 8 (08-16-06)
Interior

Health Safety vs. Coatings Durability

- **Shell plate side ventilation to center vent for better air circulation and drying interior roof plate – no longer permitted (roof vents required to prevent potential cross connections)**
- **Oil filled gravel support for bottom plates and refill ports**
- **NSF 61 and low VOC coating requirements**
- **Confined space entry OSHA requirements – make coating application and inspection more difficult and costly**

Water Storage Tanks – Coating and Cathodic Protection Evaluations

Current:

- **The Dalles, OR – 2.8 MG reservoir**
- **Camp Rilea, Warrenton, OR – 400,000 gal. reservoir**
- **Yuma ASPC, AZ – 1 MG (2); 120,000 gal. (1) reservoirs**
- **North Coast CWD, Pacifica, CA – 2 MG (2); 1 MG (1) reservoirs**
- **Jamieson Canyon, Napa, CA – 2-MG reservoir**
- **McCortney Road Leachate, Grass Valley, CA – 1 MG reservoir**

Water Storage Tanks – Coating and Cathodic Protection Evaluations (cont'd)

Recent:

- Burbank Water Dept., CA – 19 existing tanks from 42,000 gal. to 2 MG
- Soquel Creek WD, Santa Cruz, CA – 18 existing tanks from 60,000 gal. to 1.2 MG
- Sonoma State Univ., Rohnert Park, CA – 350,000 gal. tank
- Calaveras CWD, Copperopolis, CA – 430,000 gal. tank
- Castaic Lake Water Agency, Santa Clarita, CA – 1.5 MG tank
- Washoe County, Reno, NV – 1-MG (2) tanks
- Humboldt Bay MWD, Eureka, CA – (2) 1 MG tanks

Facility Corrosion Investigations

Needs: Avoid premature failures and costly repairs

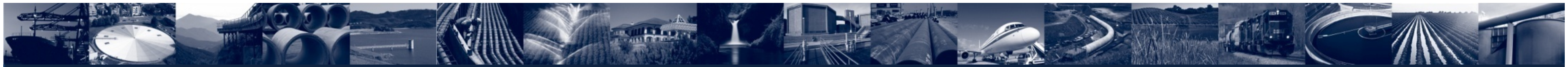
New Facilities: As important as geotechnical and topographic survey and should be a standard procedure before design.

- **Interior corrosivity of water quality**
- **External - atmospheric corrosivity**
- **Soil corrosivity for bottom plate and connecting piping**

Facility Corrosion Investigations (cont'd)

Existing Facilities

- Develop a methodology for assessing condition of tank and coating systems
- Evaluate more frequent recoating compared to cathodic protection
- Develop a priority of rehabilitation and extended budgets for 10 to 20 years

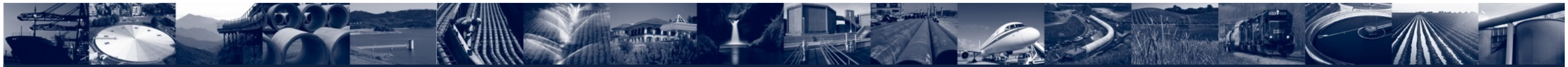


Water Quality Factors for Corrosion Assessment

Tank Interiors	Average	Maximum	Minimum
Temperature			
pH			
Conductivity			
Chlorine Residual			
Dissolved Oxygen			
Color			
Turbidity			
Calcium			
Magnesium			
Sodium			
Alkalinity			

Water Quality Factors for Corrosion Assessment (cont'd)

Tank Interiors	Average	Maximum	Minimum
Carbon dioxide			
Chloride			
Sulfate			
Ammonia			
Nitrate			
Total Phosphate			
Orthophosphate			
Silica			
Iron			
Manganese			

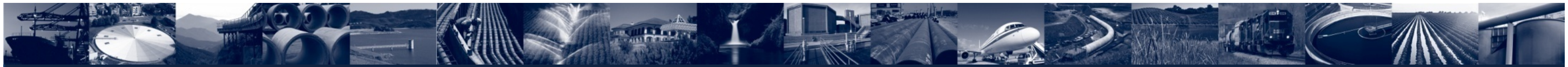


Water Corrosivity Indicators

- **Langelier Index – $CaCO_3$ – pH of saturation**
  -pH-pHs
- **Ryznar Index – degree of corrosivity or scaling – 2pHs-pH-steel corrosion >8 increasingly corrosive**
- **Aggressive Index – pH + log Ca + log Alk – Concrete – AC pipe < 12**

Water Corrosivity Indicators

- **Larson Ratio – Cl+SO_4/Alk – as MEQ > 0.40 increased pitting**
- **SO_4/Cl Ratio – Copper pitting potential > 3:1**
- **Chlorine Residual – Rapidly increase > 0.8 mg/l**
- **Carbon Dioxide – Rapidly increase > 5 mg/l**
- **Conductivity – > 500 – Rapidly increase**
- **Dissolved Oxygen – > 0.5 – Increase**
- **Silica – < 20 mg/l**



Soil Corrosion Assessment

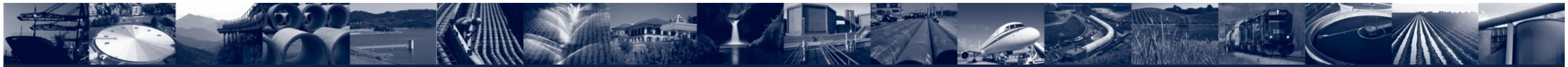
Tank – Bottom Plate and Buried Piping

- **Type – Texture – i.e. clay, silt, sand, gravel, rock**
- **Moisture and water table – seasonal and maximum**
- **Resistivity – seasonal and maximum**
- **Chlorides**
- **Sulfate**
- **pH**
- **ORP**
- **Volatile organics**
- **Stray D.C. electric currents on nearby pipeline cathodic protection**

Atmospheric Corrosion Assessment

Outside Roof and Shell Plates

- Temperatures
- Rainfall
- Relative humidity
- Proximity to seashore – salt spray condensation
- Urban-Industrial Locations – SO_2, NOX, etc.
- Sun/shade exposure

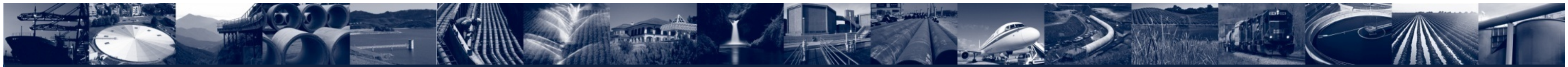


Probable Corrosion Rates of Carbon Steel

Characteristic	Units	Very Low or None	Low	Moderate	Heavy	Severe
pHs $CaCO_3$	-	>10	8.5-10	6.5-8.5	5-6.5	<5
Langelier Index	LI	>+3	+1 to +3	+1 to -1	-1 to -3	<-3
Ryznar Index	RI	<6	6-7.5	7.5-8.5	8.5-10	>10
Larson Ratio	LR	<0.2	0.2-0.5	0.5-1	1-2	>2
Carbon Dioxide	mg/l	<2	2-5	5-15	15-30	>30
Chlorine Residual	mg/l	<0.5	0.5-1	1-2	2-3	>3
Silica	mg/l	>75	50-75	20-50	-	-
Conductivity	us	<20	20-100	100-250	250-1,000	>1,000
Rate	mil/yr	<5	5-10	10-20	20-50	>50

Life Expectancies

	Years
Carbon Steel	60
Epoxy Coatings	15
Epoxy Coatings with Cathodic Protection	30
Sacrificial C.P. Anodes Magnesium or Zinc	20
Impressed Current C.P. Anodes Silica iron Mixed metal - Niobium	 60 60+



Comparison of Cathodic Protection Anodes

	Water or Soil Resistivity	Loss/Rate
Sacrificial Anodes		
High purity magnesium	< 2,000 OHM-CM	500 AH/pound
Standard high magnesium	2,000-5,000 OHM-CM	500 AH/pound
Zinc	>5,000 OHM-CM	370 AH/pound
Impressed Current Anodes		
High silicon cast iron	>50	10,000+ AH/pound
Mixed metal anodes (platinum, nobium, titanium, copper)	>10	100,000+AH/pound

Interior Recoating Cost Variables

Tank Size	3-coat Epoxy	Zinc Primer and 2-coat Epoxy
Large (>2MG)	$10/SF	$12/SF
Mid (500,000 gal)	$12/SF	$14/SF
Small (50,000 gal)	$20/SF	$22/SF

Advantages/Disadvantages of Differing Cathodic Protection Systems

Costs are generally less than 10% of coating costs and 5% total tank costs

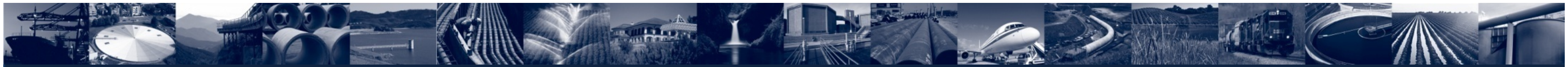
Sacrificial Anodes

- No electrical service or consumption
- Less likely to produce excessive potential and current to cause paint blistering
- More simple – less frequent inspection and testing necessary
- Shorter service life
- Frequently less expensive (particularly smaller <1MG tanks)
- Can meet NSF61 requirements

Advantages/Disadvantages of Differing Cathodic Protection Systems

Impressed Current Anodes

- Can be used in any water quality – particularly advantageous – low resistivity, high-purity water
- Highly flexible in current and potential output
- Very long service life
- Relatively expensive – smaller tank sizes
- Yearly inspection, testing, and calibration required
- Automatic potential control – highly desirable
- Can meet NSF61 requirements



The Dalles Reservoir Corrosion Protection Options

2.8 MG – 120 ft x 35 ft high

Exterior – 2 coat polyamide epoxy and finish coat polyurethane

Interior Air Space – Bottom of roof plate purlins and shell plate above waterline

Ventilation – Four “J” vents circumference of rooftop and center vent seal weld purlins to roof

Coating – Zinc rich primer and 2-coat epoxy amide

The Dalles Reservoir Corrosion Protection Options (cont'd)

Interior Submerged

1. **Protective System 1 – 3-coat epoxy, 15-year service at $12/sf**
2. **Protective System 2 – Zinc primer, 2-coat epoxy, 20-year service at $14/sf**
3. **Sacrificial Current CP System and Coating System 1 – 30-year anode and coating system life**
4. **Impressed Current CP System and Coating System 1 – 30-year coating life, 60-year CP system life**

The Dalles – 2.8 MG Water Storage Tank Corrosion Control Comparison

Water Quality-Corrosion / Scaling Characteristics	Average
pH	7.1
Conductivity	88 uS
Total Hardness	26 mg/l $CaCO_3$
Orthophosphate	0.6 mg/l
Langelier Index	-2.1
Ryznar Index	11.3
Aggressive Index	9.8
Carbon Dioxide	12 mg/l
Chlorine Residual	1
Larson Ratio	1.5
Resistivity	11,400 OHM-CM
Probable Steel Corrosion	5-10 MPY by shallow crater pitting underlying rust tubercules
Perforate a ¼-inch Shell Plate	25 years or less

The Dalles Water Storage Tank Comparison of Interior Corrosion Protection Alternatives

2.8 mg – 120' D x 30' H = 24,000 SF surface

Alternative	Capital Cost	Life Span Cost	Cost/Year	Rank
Coating System 1	$348,500	x4 = $1,394,000	$1,394,000 / 60Y = $23,200/y	4
Coating System 2	$418,200	x3 = $254,600	$1,254,600 / 60Y = $209,910/y	3

The Dalles Water Storage Tank Comparison of Interior Corrosion Protection Alternatives

Sacrificial Anode System – 16 50-pound Hi-purity Mg Anodes and Coating System 1				
	Capital Cost	**Life Span Cost**	**Cost/Year**	**Rank**
Sac Anode System	$70,200	x2 = $140,400	$140,400 / 60Y = $2,340	
Amoritization/30Y			$2,340	
Maintenance @2%			$2,110	
Anode Replacement			$770	
Ref Electrode Replacement			$30	
			$6,750/	
Coating System	$348,500	X2 = $697,00	$6,970/60 = $11,620	
Total			$18,000	2

The Dalles Water Storage Tank Comparison of Interior Corrosion Protection Alternatives

Impressed Anode System – Mixed Metal Anodes				
	Capital Cost	**Life Span Cost**	**Cost/Year**	**Rank**
Coating System	$348,000	x2 =	$697,000 / 60 = $11,620	
Impressed Current CP	$30,000		$30,000 / 60 = $500	
Annual Cost				
Amortization		$30,000/60	$500	
Maintenance @2%			$900	
PEF Electrode Replacement			$40	
Energy 1 KW x 8,760 H/Y x $.05/KWH		$40	$40	
Testing and reports			$1,500	
Coating System		$348,300 x 2	$697,000 / 60 = $11,620	
Total			$16,100	1

Conclusions

1. A corrosion/deterioration investigation is desirable for any existing water storage tank to determine the cost-effective method of preserving its service life.
2. Corrosion investigations are usually a small fraction of design costs and should be of equal importance to geotechnical and topographic surveys.
3. A comprehensive look at interior, soil, and exterior corrosion and alternative control methods is desirable.
4. Usually most vulnerable location for corrosion is underside of roof and purlins in air space above vents.

Conclusions (cont’d)

5. Cathodic protection is justifiable by cost analysis of the interior of most projects.
6. Always compare alternatives of sacraficial or impressed current corrosion as they will vary with tank size and water quality.
7. Cathodic protection systems should be tested and calibrated at least annually.