Protective Coatings

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References:

1. Corrosion and Corrosion protection handbook by A. Schweitzer
2. Corrosion Prevention by Protective Coatings by C.G. Munger (NACE)
3. Corrosion Control by S.A. Bradford
Coatings and Lining

- The most widely used method for corrosion control
- 6.7 Billion dollar in 1997 for corrosion protection by coatings
- A coat is a thin protective layer, typically 50-100 μm.
- A lining is thick, typically 0.5-3 mm in thickness.
  - Linings are usually applied in the interiors of tanks, pipes, vessels, where immersion is continuous and corrosion is severe.
  - Coatings are usually applied on surfaces where immersion is not continuous such as the external surfaces of tanks and pipes.
Coatings and Lining

- Corrosion protection by coatings can be achieved by one of the following mechanisms:
  1. A barrier coating that prevents the corrosive environment from reaching the base metal (thick lining).
  2. A sacrificial metal coating that corrodes while giving cathodic protection to the base metal (galvanizing).
  3. A noble metal coating that ensures that the base metal is in the passive state.
  4. An inhibitor coating that slows electrode reactions.
  5. An electrically resistive coating that slows down electrochemical corrosion reactions (organic coating).
Organic Paints

- An organic paint consists of a liquid part known as a vehicle and a solid part.
- The vehicle part consists of:
  - A binder or a resin (non-volatiles, it does not evaporate after drying)
  - A Solvent (volatiles)
  - Liquid additives
- The solid part consists of:
  - Powdery particles or pigments
  - Solid additives
Binders

- A binder is an organic liquid (oil or resins) that forms a dense and tight protective skin or film in different ways:
  - Oxygen reactive binders: resins forming solid film by reacting with $O_2$.
    - Thermosetting resins such as epoxy-esters, urethane-alkyds.
  - Evaporation of the solvent which leaves behind a film of the polymer that was dissolved or suspended in water or oil based solvents.
    - Thermoplastic resins such as PVC and acrylcs
  - Polymerization reaction
    - Mixing a resin and a hardener (thermosets)
  - The binder provides the basic coating properties in terms of chemical resistance, permeability, abrasion resistance, and hardness.
**Binders: thermoplastics**

- **Thermoplastic binders:**
  - The solid film consists of entangled linear chains as shown in the figure.
  - The most common thermoplastic binders are:
    - Vinyls (polyvinyl chloride and polyvinyl acetate copolymer)
      - High impermeability
      - Widely used for steel immersed in water
      - Highly resistant to oil and grease
      - Applied by spraying
    - Acrylics (dissolved in water or solvents)
      - Highly resistant to UV
      - High stability of color
      - Excellent for protection against atmospheric exposure
      - Used in cars external body
Binders: Thermosets

- Thermosetting binders:
  - The solid film consists of rigid 3-dimensional network of molecules.

- The most common thermoplastic binders are:
  - Epoxy
    - Excellent resistance to acid and alkaline environments
    - Excellent adhesion and used as primers
  - Phenolic
  - Poly-urethanes
    - UV resistant
    - Excellent abrasion resistant
    - Used in aircraft, cars,
  - Polyester
    - Thick films (1 mm)
    - Excellent abrasion resistant
Binders: Thermosets

- An example showing polymerization of a thermosetting Polymer (phenolic)
Binders: organic oils

- **Organic oil binders:**
  - The solid film form after drying vegetable oils by oxidation to form 3-dimensional network of the oil molecules.
  - Takes long time to dry up (few days).
  - The most common oil based binders are:
    - **Alkyd (Good resistant to atmospheric condition)**
      - linseed oil + ALCOHOL+ ORGANIC ACID
$\textbf{Binders}$

- **Zinc rich organic binders:**
  - combination of fine powder of zinc and an organic binder where Zn corrodes and provides galvanic protection to steel
  - The binder can be any thermoplastic or thermosetting resins such as vinyls, acrylics, or epoxies.
  - Commonly used as primers
Binders

- The binder provides the following functions:
  - Binding the pigments together
  - Adherence to substrate (metal surface)
  - Cohesion (strength of the coat)
  - Flexibility to the coating film
  - Abrasion resistance
  - Anti-corrosive properties
  - Chemical resistance
Solvents

- Solvents are added to keep the binder in solution during storage and to provide fluidity during application.
- Examples: aromatic hydrocarbons (toluene, xylene), alcohol, ethers, esters, water in latex paints.
- Solvents determine:
  - Application properties
  - Evaporation rate or drying time
  - Flash point
Pigments

- Pigments are solid particles in powder form that are added to the coat to:
  - Produce desired color
  - Determine opacity
  - Protect the binder from UV radiation
  - Inhibit corrosion
  - Increase abrasion resistance
  - Increase strength and toughness
  - Improve coating adhesion
  - Examples: (Na₂CrO₄, ZnPO₃, phosphates)
Additives

- Additives are small amounts of solids or liquids that control a number of important features such as:
  - speed of drying and curing
  - Wetting agents
  - Anti-skinning
  - Settling and sagging agents
  - Storage agents
Definitions

• A coat: a liquid applied as a thin layer which is converted to a solid-protective adherent film after DRYING.
• Enamel: a coat that can form very smooth film.
• Varnish: a liquid that converts to a transparent solid film after application as a thin layer.
• Lacquer: a coating composition based on thermoplastic binders dissolved in organic solvent that dries by solvent evaporation.
Requirements for Good Coats

- Chemical resistance
- Low moisture permeability
- Good adhesion
- Flexibility (expand and contract with the metal substrate)
- Good impact and abrasion resistance
- Ease of applications
- Durability
- Low cost
- Hence, no single coat can provide all needed properties
- For example:
  - Coats for underground structures: resistance to abrasion
  - Coats for atmospheric corrosion: resistance to UV
  - Coats for marine environments: resistance to high humidity and Cl-
  - Coats to industrial environments: resistance to high temp, high acidity
- We must use multiple coats to satisfy these requirements.
A coating system consists of multiple layers coats.

Top Coat
- Resistant to ion penetration
- Alkali Resistant
- Insulator

Intermediate Coat
Low moisture and vapor transfer rate

Primer
- Adheres to substrate
- Resists corrosion

Metal Surface

Dimensions:
- Top Coat: 50 µm
- Intermediate Coat: 100 µm
- Primer: 20-50 µm
Coating System

– Primer Coat: the coat next to the substrate.
  • Strong adhesion to substrate
  • Good adhesion to intermediate coat
  • Resist chemical attack
  • Resist water permeability
  • Carries corrosion inhibitor
Coating System

– **Intermediate Coat**: the main function is to increase the thickness of the coat.
  - To reduce rate of moisture permeability
  - To increase chemical resistance
  - To Increase resistance to electricity and impact, and abrasion

– **Top Coat**: in contact with the electrolyte.
  - To provide durability
  - To provide color, gloss, and texture
  - Usually more dense but less thick than the intermediate.
Coating Procedure

1. Surface Preparation
2. Selection of a coat system
3. Application method
4. Coating Inspection and Testing
5. Coating maintenance
6. Coating Failure
1. Surface Preparation

Good surface preparation is essential for good coating performance.

Objectives:

– To remove any foreign substance from the surface such as dirt, dust, oils, chemicals, and corrosion products by one of the following methods:
  – solvent or chemical washing
  – steam cleaning
  – hand tool cleaning

– To create a profile to provide anchor to the binder for good mechanical adhesion. The surface roughness can be increased by:
  • High pressure water-blasting
  • Wet abrasive-blasting
  • Air abrasive-blasting

– At least 25-50 µm (1-2 mils) anchor pattern must be made to provide adhesion to the primer.

Anchor pattern
1. Surface Preparation

- SP1 (solvent cleaning) using solvents to remove grease and oil
- SP2 (hand tool cleaning) using hand scrapers to remove dirt, dust, coat
- SP3 (power tool cleaning) using power wire brushes, grinders, sanders to remove loose corrosion products
- SP4 (Flame cleaning) removing contaminants by a flame or high velocity oxyfuel burner
1. Surface Preparation

- SP5 (white metal blast) using abrasive blasting to remove oil, mill scale and paint. Uses high pressure air (690 kPa) with abrasives (Al$_2$O$_3$)
- Abrasive blasting can provide 50-115 µm anchor pattern.
Table 1  Steel Structure Painting Council (SSPC) designations of surface preparation methods for painted coatings

<table>
<thead>
<tr>
<th>SSPC designation</th>
<th>Method of surface preparation</th>
<th>NACE designation</th>
<th>Equipment and materials</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP1</td>
<td>Solvent cleaning</td>
<td></td>
<td>Mineral spirits, chlorinated solvents, coal tar solvents, using tack rags or dip tanks</td>
<td>For the removal of grease, oil, or other soluble materials before removing mill scale, rust, and coatings by other methods. Alkaline cleaners saponify oils and greases, but these cleaners must be neutralized with 0.1 wt% chronic acid, sodium dichromate, or potassium dichromate</td>
</tr>
<tr>
<td>SP2</td>
<td>Hand tool cleaning</td>
<td></td>
<td>Hand scrapers</td>
<td>Hand tool cleaning should be limited to removing loose materials for maintenance and normal atmospheric exposure; coatings with good wetting properties are brush applied</td>
</tr>
<tr>
<td>SP3</td>
<td>Power tool cleaning</td>
<td></td>
<td>Power wire brushes, grinders, sanders, impact tools, needle guns</td>
<td>For the removal of loose rust, loose mill scale, and loose paint by power tool chipping, descaling, sanding, wire brushing, and grinding without excessive roughing that causes ridges, burns, or burring. Used when primer is to be brush applied.</td>
</tr>
<tr>
<td>SP4</td>
<td>Flame cleaning</td>
<td>(a)</td>
<td></td>
<td>Removal of contaminants by high-velocity oxyacetylene flame burners. Usually followed by wire brushing</td>
</tr>
<tr>
<td>SP5</td>
<td>White metal blast</td>
<td>1</td>
<td>Abrasive blasting</td>
<td>Removal of 100% of oil, grease, dirt, rust, mill scale, and paint. Cleaning rate 9.3 m³/h (100 ft³/h), using 7.84 mm (5/32 in.) nozzle with 600 kPa (100 psig) at nozzle. Because of atmospheric contamination, maintaining this degree of cleanliness before primer application is difficult</td>
</tr>
<tr>
<td>SP6</td>
<td>Commercial blast</td>
<td>3</td>
<td>Abrasive blasting</td>
<td>Removal of 67% of oil, dirt, rust, mill scale, and paint. Cleaning rate 35 m³/h (370 ft³/h), using 7.84 mm (5/32 in.) nozzle with 600 kPa (100 psig) at nozzle. Used for general-purpose blast cleaning to remove all detrimental matter from the surface, but leaves staining from rust or mill scale</td>
</tr>
<tr>
<td>SP7</td>
<td>Brush-off blast cleaning</td>
<td>4</td>
<td>Abrasive blasting</td>
<td>All loose mill scale and rust are removed, with tight mill scale, paint and minor amounts of rust and other foreign matter remaining. The remaining rust is an integral part of the surface. This level of surface preparation is used for mild exposure and is suitable where a temperature change of less than 11 °C/h (20 °F/h) can be anticipated. Cleaning rate 81 m³/h (870 ft³/h) using 3.8 mm (5/32 in.) nozzle</td>
</tr>
<tr>
<td>SP8</td>
<td>Pickling</td>
<td></td>
<td>Hydrochloric acid, sulfuric acid with inhibitors, or phosphoric acid with a final phosphate treatment</td>
<td>A shop method of surface preparation for removal of rust and mill scale from structural shapes, beams, and plates where there are few pockets or crevices to trap acid. Excess acid must be rinsed off with water. Washing is required as soon as possible to prevent recontamination of the surface</td>
</tr>
<tr>
<td>SP9</td>
<td>Weathering</td>
<td>(b)</td>
<td></td>
<td>Although mill scale is weathered away, this process is detrimental because surface contamination is more difficult to remove when weathered</td>
</tr>
<tr>
<td>SP10</td>
<td>Near-white blast</td>
<td>2</td>
<td>Abrasive blasting</td>
<td>Removal of 95% of oil, grease, dirt, rust, mill scale, and paint. A cost savings of 25% can be realized on average where this level of cleanliness can be tolerated. Shavings, streaks, or discolorations are distributed over the surface but are not concentrated in any area</td>
</tr>
</tbody>
</table>
2. Selection of a Coat System

- **Factors considered in coating selection:**
  - **Service environment**
    - Operating condition (i.e., a coat selected for acid environment should be resistant to acids)
    - Temperature, humidity, contaminants (the coat selected should withstand the range of operating conditions)
    - Ultra violet (UV) exposure
  - **Metal to be protected (the substrate)**
    - Chemical compatibility
    - Thermal compatibility
    - Adhesion
2. Selection of a Coat system

- Factors considered in coating selection (cont.)
  - Environmental regulations
  - Standards
  - Appearance and Color
  - Cost
  - Temperature and humidity at time of application
  - Application during shutdowns or during operation?
  - Availability of maintenance

- A paint system includes specification for type, method of application, and number of layers of various paints required for a particular job.
2. Selection of a Coat system

- The coat selection process depends on the performance properties of the binder. The table below compares the major binders in terms of humidity, corrosion, UV resistance, and chemical resistance.

![Table 8.1](image)

**TABLE 8.1 Performance Properties* of Common Coating Resins**

<table>
<thead>
<tr>
<th>Resin type</th>
<th>Humidity resistance</th>
<th>Corrosion resistance</th>
<th>Exterior durability</th>
<th>Chemical resistance</th>
<th>Mar resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Alkyd</td>
<td>F</td>
<td>F</td>
<td>P</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Epoxy</td>
<td>E</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Polyester</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>E</td>
<td>G</td>
<td>E</td>
<td>G</td>
<td>E</td>
</tr>
<tr>
<td>Vinyl</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
</tbody>
</table>

*E—excellent; G—good; F—fair; P—poor.

- See [www.sherwin-williams.com](http://www.sherwin-williams.com) for information of over 1000 paint systems for industrial and marine coatings.
2. Selection of a Coat system

- Example: an ARAMCO approved paint system by HEMPEL.

- Note:
  - For atmospheric service
  - Surface preparation specification
  - Primer coat
  - Intermediate coat
  - Topcoat
2. Selection of a Coat system

- To decide upon a suitable system for the work you want to do, follow this sequence:
  - identify the material to be painted
  - note which primer is most suitable
  - note which undercoats and topcoats are suitable for each primer
  - decide on your topcoat preference.
  - select the primer and undercoat which allow that topcoat.
3. Applications

• Manual (brushing and rolling)
  – Easy but difficult to control coating thickness

• Spraying
  – Air spray (air is used to atomized and propel the coating)
  – Airless spray (the coating container is pressurized to atomize the coating in the gun)
Air-Spray Gun

1. Spray Gun
2. Fluid Hose
3. Air Hose
4. Pressure Pot
5. Air Regulators
6. Air Compressor
3. Applications

- Wet film thickness (WFT): assuming that the substrate is flat and no paint is lost.
- 1 liter (1000 cm³ or 1x10⁻³ m³) = area x WFT
  - Example: Suppose you want to cover 1 m² by 1L:
    \[ WFT = \frac{1 \times 10^{-3} \text{ m}^3}{1 \text{ m}^2} = 1 \times 10^{-3} \text{ m} = 1 \text{ mm}. \]
- Dry film thickness (DFT): volatiles evaporate and only pigments and binder will be left in the coat and the dry film becomes thinner
  - Example: Suppose that the above paint consists of 50% volatile and 50% of solids by volume.
    \[ DFT = WFT \times \%\text{solids} = 1\text{mm} \times 0.5 = 0.5 \text{ mm}. \]
3. Applications

• Theoretical Coverage on flat surfaces.
  Coverage (m²) = liters of coating × %solids × 1000/DFT (µm)

• Example: What is the coverage area of one liter of paint (50% solids) with a DFT of 250 µm?
  Coverage = 1 × 0.5 × 1000/250 = 2 m²
4. Coating Inspection and Testing

- **Holiday**: bare area in the coated surface where there is a direct contact between the environment and the coated metal.
- It is important to locate small holidays and recoat.
Holiday Detection System

- Low voltage wet-sponge holiday detector can detect holidays in non-conductive coatings less than 20 mil thick (500 µm)
- The holiday detector is connected to the metal substrate of the test piece using a wetted sponge that conducts electricity. A low voltage is applied b/w the detector and the metal.
- At holidays, a current will flow between the holiday and the detector. A beep is sounds.
5. Coating Failure

- Coating failure can be the result of many factors:
  - Poor surface preparation
  - Poor selection
  - Poor application technique
  - Unexpected changes in service environment
  - Aging (weathering effects)

- Types of discontinuities in coating failure
  - Holidays
  - Pinholes: a hole in the coating penetrating all the way to the substrate
  - Coating discontinuities usually appear at:
    - Fabrication defects
    - Joints (welds, nuts, bolts, rivets)
    - Hard to reach area during applications (corners)
    - Sharp edges of the structure to be protected
5. Coating Failure

• Common types of coating failure
  – Blistering:
    • appear as surface bubbles which are filled by water vapor, air, or solvent vapor.
    • blisters may be
      – at coating-substrate interface
      – between adjacent coating layers
    • Caused by the penetration of moisture through the coating into areas of poor adhesion.
    • Incorrect selection of primer
5. Coating Failure

- **Cracking:**
  - appear as cracks
  - caused by different degree in thermal expansion and contraction between the coat and the metal.
  - reduce corrosion protection

- **Wrinkling:**
  - appear as ridges at the surface of the coat
  - usually appear in thick coatings
  - result from swelling of the surface
  - Caused by difference in drying between the surface and the body of the coat
  - little effect on corrosion protection
5. Coating Failure

- **Flaking and Peeling**
  - Loss of paint due to loss of adhesion
  - Caused by incorrect surface preparation or incorrect primer/ primer/topcoat
Cement Linings

- Cement lining (3-10 mm) provides excellent internal layer of protection against corrosion in pipes and tanks.
- The cement layer is permeable but form alkaline solution in contact with steel which protects steels.
- Cement lining is widely used in cast iron piping systems for potable water and sewage.
- Cement is applied in a pipe internally as shown in the figure.
- There are different cement materials for different applications.
Inhibitors

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References:

1. Handbook of Corrosion Engineering by P. R. Roberge
2. Corrosion Control by S.A. Bradford
Inhibitors

- Inhibitors are chemicals added in small amounts to the electrolyte to reduce corrosion in closed systems such as in recirculation-cooling systems, cooling towers, condenser tubes, and boilers.
- The decision of using inhibitor involves an economical balance between the cost of the inhibitor against the cost of corrosion.
- Inhibitors are used widely in the oil extraction and production industries and in cooling systems.
- The composition of industrial inhibitors are secrets of their manufacturers.
- Inhibitors react and adsorb to the metal surface and form one of the following films:
  - A stable metal passive film
  - A barrier film of adsorbed inhibitor
  - A thick barrier layer of corrosion products or the inhibitor
Inhibitors

- Depending on the effect of the adsorbed films on corrosion reactions, inhibitors are classified as either:
  - anodic inhibitor (slow anodic reactions)
  - cathodic inhibitor (the presence of the adsorbed film slow down cathodic reactions)
  - general inhibitor (slow both anodic and cathodic)
  - Organic inhibitors

Figure 11.5 Effect of adding (a) an anodic inhibitor, (b) a cathodic inhibitor, or (c) a mixed (general) inhibitor. Dash lines show inhibitor addition.
Cathodic Inhibitors

- Cathodic inhibitors can provide inhibition by two different mechanisms:
  - cathodic poisoning
    - slow the kinetics of cathodic reactions
    - Example: arsenic compounds make the recombination of hydrogen more difficult
      - $\text{H}^+ + \text{H}^+ + 2e^- \rightarrow \text{H} + \text{H} \rightarrow \text{H}_2$
  - cathodic precipitates
    - Active elements of the inhibitor react with the electrolyte and form oxides which precipitate on the cathodic areas to increase the surface impedance and limit the diffusion of reducible cations
    - Example: Ca, Zn, and Mg salts.
Passivating Inhibitors

- Passivating inhibitor: shift the corrosion potentials into the passive region.
- The added inhibitor must exceed a critical concentration to reach the passive region as shown in figure 1.
- It is essential to monitor the inhibitor concentration to avoid acceleration of corrosion.
- The example shown in figure 2 is for a stainless steel in:
  - 15%H₂SO₄
  - 15%H₂SO₄ + CuSO₄
  - Note the change in $E_{\text{corr}}$

Figure 11.6 Passivation of stainless steel washers in 15% H₂SO₄ + Cu²⁺. Without Cu²⁺ the corrosion rate would be excessive.
Passivating Inhibitors

• **Examples of passivating inhibitors:**
  – Inhibitor based on oxidizing anions such as chromate (CrO$_4^{-}$), nitrite (NO$_2^{-}$), and nitrate (NO$_3^{-}$) which can passivate steel even in the absence of oxygen.
  – Inhibitors based on non-oxidizing anions such as phosphate (PO$_4^{3-}$) and molybdates (MoO$_4^{2-}$) which require oxygen to passivate steel.

• **Passivating inhibitors are very effective and consequently the most widely used especially in cooling water systems.**

• **The use of passivating inhibitors are usually limited by environmental regulations applied to reduce pollution and carcinogenic effect.**
Organic Inhibitors

- Organic inhibitors form thin protective organic films on the entire metal surface. The film consists of molecules that adsorb to the metal surface and reduce the available surface for corrosive ions (such as Cl\textsuperscript{-}) to react with the surface.
- Example: amines (-NH\textsubscript{2}) and their salts.
- The effectiveness of these inhibitors depends on the chemical composition, their molecular structure, their affinities for the metal surface, and the temperature and pressure in the system.

\[
\begin{align*}
\text{H} & \quad \text{N} & \quad \text{C} & \quad \text{H} \\
\text{H} & & \text{H} & \\
\text{H} & & \text{H} & \\
\text{methylamine}
\end{align*}
\]
Scavengers

- Scavengers: a chemical added to eliminate dissolved oxygen from closed system at neutral or alkaline pH.
- Sulfite is used widely in water at ambient temperature:
  - $\text{Na}_2\text{SO}_3 + \frac{1}{2}\text{O}_2 \rightarrow \text{Na}_2\text{SO}_4$
- Hydrazine ($\text{N}_2\text{H}_4$) is a scavenger used in boilers:
  - $\text{N}_2\text{H}_4 + \text{O}_2 \rightarrow \text{N}_2 + 2\text{H}_2\text{O}$
Examples of Inhibitors

<table>
<thead>
<tr>
<th>Environment/Inhibitors</th>
<th>Conditions</th>
<th>Metals Protected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water, Potable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca(HCO₃)₂</td>
<td>10 mg/L</td>
<td>Steel, cast iron, etc.</td>
</tr>
<tr>
<td>Polyphosphate</td>
<td>5-10 mg/L</td>
<td>Fe, Zn, Cu, Al</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>To pH 8.0</td>
<td>Fe, Zn, Cu</td>
</tr>
<tr>
<td>Na₂SiO₃</td>
<td>10-20 mg/L</td>
<td>Fe, Zn, Cu</td>
</tr>
<tr>
<td><strong>Water, Cooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca(HCO₃)₂</td>
<td>10 mg/L</td>
<td>Steel, cast iron, etc.</td>
</tr>
<tr>
<td>Na₂CrO₄</td>
<td>0.1%</td>
<td>Fe, Zn, Cu, Al</td>
</tr>
<tr>
<td>Na polyphosphates</td>
<td>pH 6.5-7.5</td>
<td>Fe, Cu alloys</td>
</tr>
<tr>
<td>Mercaptobenzotriazole</td>
<td>If no Cl₂</td>
<td>Cu, brass</td>
</tr>
<tr>
<td>Tolyltriazole</td>
<td></td>
<td>Cu</td>
</tr>
<tr>
<td>Zn phosphonates</td>
<td>pH 6.5-9</td>
<td>Fe</td>
</tr>
<tr>
<td>NaNO₂</td>
<td>0.05%</td>
<td>Fe</td>
</tr>
<tr>
<td>NaH₂PO₄</td>
<td>1%</td>
<td>Fe</td>
</tr>
<tr>
<td>Morpholine</td>
<td>0.2%</td>
<td>Fe</td>
</tr>
<tr>
<td><strong>Water, Boiler</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaH₂PO₄</td>
<td>10 mg/L</td>
<td>Fe, Zn, Cu</td>
</tr>
<tr>
<td>Polyphosphate</td>
<td>10 mg/L</td>
<td>Fe, Zn, Cu</td>
</tr>
<tr>
<td>Morpholine</td>
<td>Variable conc.</td>
<td>Fe</td>
</tr>
<tr>
<td>Hydrazine</td>
<td>O₂ scavenger</td>
<td>Fe</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Neutralizer</td>
<td>Fe</td>
</tr>
<tr>
<td>Octadecylamine</td>
<td>Variable conc.</td>
<td>Fe</td>
</tr>
</tbody>
</table>
# Examples of Inhibitors

<table>
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<tr>
<th>Environment/Inhibitors</th>
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<tbody>
<tr>
<td><strong>Seawater</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na$_2$SiO$_3$</td>
<td>10 mg/L</td>
<td>Zn</td>
</tr>
<tr>
<td>NaNO$_2$</td>
<td>0.5%</td>
<td>Fe</td>
</tr>
<tr>
<td>Ca(HCO$_3$)$_2$</td>
<td>pH dependent</td>
<td>All</td>
</tr>
<tr>
<td>NaH$_2$PO$_4$ + NaNO$_2$</td>
<td>10 mg/L + 0.5%</td>
<td>Fe</td>
</tr>
<tr>
<td><strong>Engine Coolants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na$_2$CrO$_4$</td>
<td>0.1-1%</td>
<td>Fe, Pb, Cu, Zn</td>
</tr>
<tr>
<td>NaNO$_2$</td>
<td>0.1-1%</td>
<td>Fe</td>
</tr>
<tr>
<td>Borax</td>
<td>1%</td>
<td>Fe</td>
</tr>
<tr>
<td><strong>Glycol-Water Coolant</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borax + Mercaptobenzotriazole</td>
<td>1% + 0.1%</td>
<td>All</td>
</tr>
<tr>
<td>Na benzoate + NaNO$_2$</td>
<td>5% + 0.3%</td>
<td>All</td>
</tr>
<tr>
<td>Monoethanolamine</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Diethanolamine</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td><strong>HCl Acid</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylaniline</td>
<td>0.5%</td>
<td>Fe</td>
</tr>
<tr>
<td>Mercaptobenzotriazole</td>
<td>1%</td>
<td>Fe</td>
</tr>
<tr>
<td>Pyridine + phenylhydrazine</td>
<td>0.5% + 0.5%</td>
<td>Fe</td>
</tr>
<tr>
<td>Rosin amine + ethylene oxide</td>
<td>0.2%</td>
<td>Fe</td>
</tr>
<tr>
<td>HCO$_3$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>