

# PREVENTION OF CORROSION

- The huge annual loss due to corrosion is a national waste and should be minimized
- Materials already exist which, if properly used, can eliminate 80 % of corrosion loss
- Proper understanding of the basics of corrosion and incorporation in the initial design of metallic structures is essential

# Factors that affect the rate of corrosion

Temperature

Oxygen

Humidity

Chemical Salts

Chemicals and airborne gases

# How to avoid (or control) ?Corrosion

- **Material Selection! Remember – environment key.  
Look at potential pH diagrams!!!**
- **Eliminate any one of the 4 req'ments for corrosion!**
- **Galvanic - Avoid using dissimilar metals.**
  - Or close together as possible
  - Or electrically isolate one from the other
  - Or **MAKE ANODE BIG!!!**

# How to avoid (or control) ?Corrosion

- **Pitting/Crevise: Watch for stagnate water/ electrolyte.**
  - Use gaskets
  - Use good welding practices
- **Intergranular – watch grain size, environment, temperature, etc.. Careful with Stainless Steels and AL.**

# How to avoid (or control) ?Corrosion

- Consider organic coating (paint, ceramic, chrome, etc.) – DANGER IF IT GETS SCRATCHED!!
- OR BETTER YET, consider cathodic protection:
  - such as zinc (or galvanized) plating on steel
  - Mg sacrificial anode on steel boat hull
  - Impressed current, etc..

# Methodes To Control Corrosion

- Design of structures
- Material selection
- Cathodic Protection
- Reduce the activity of the cathode and or electrolyte. (Polarization)
- Protection of the Anode. (Passivation)
- Alteration of environment
- Inhibitors
- Protective Coatings

# DESIGN OF STRUCTURES

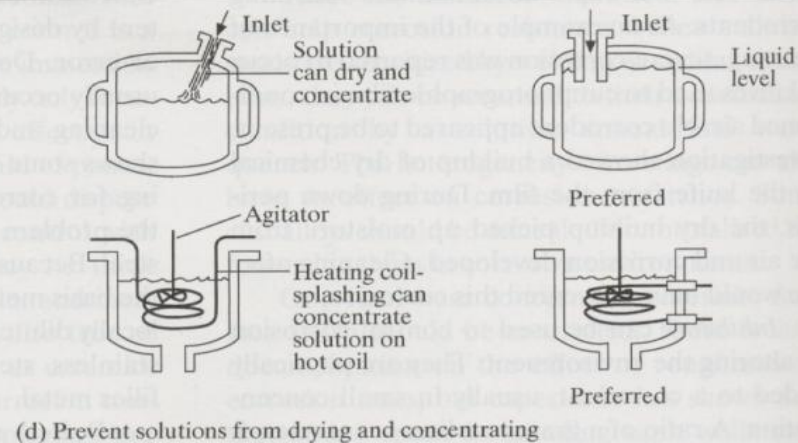
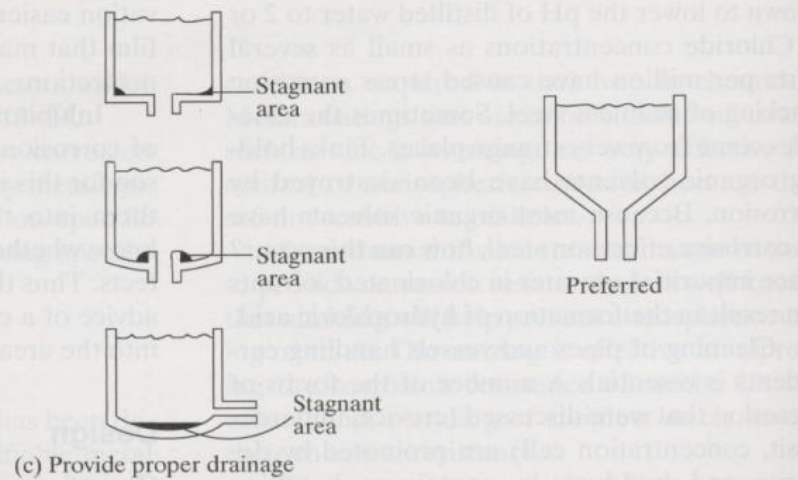
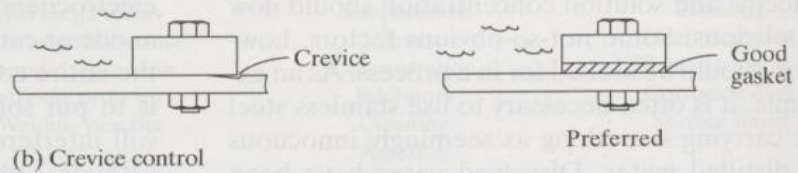
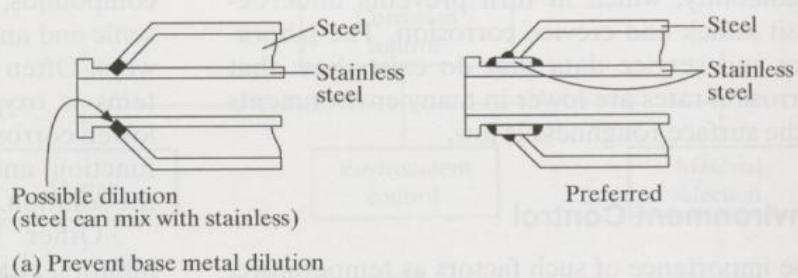
- **Avoid sharp corners**
- **Complete draining of vessels**
- **Avoid sudden changes in section**
- **Avoid contact between dissimilar metals**
- **Weld rather than rivet**
- **Easy replacement of vulnerable parts**
- **Avoid excessive mechanical stress**

# Design Do's & Don'ts

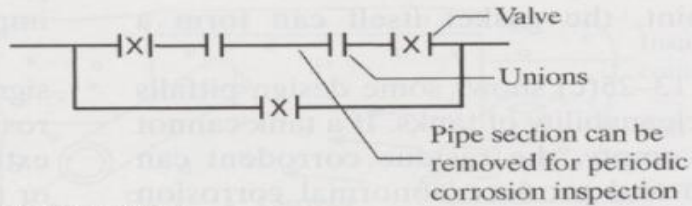
- **Wall thickness – allowance to accommodate for corrosion effect.**
- **Avoid excessive mechanical stresses and stress concentrations in components exposed to corrosive mediums. Esp when using materials susceptible to SCC.**
- **Avoid galvanic contact / electrical contact between dissimilar metals to prevent galvanic corrosion.**
- **Avoid sharp bends in piping systems when high velocities and/or solid in suspension are involved – erosion corrosion.**
- **Avoid crevices – e.g weld rather than rivet tanks and other containers, proper trimming of gasket, etc.**



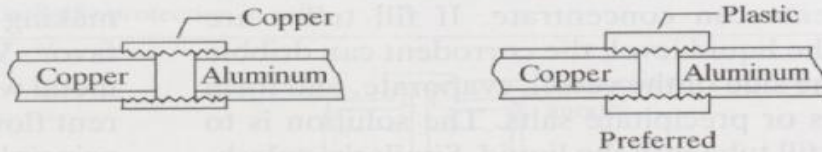
- **Avoid sharp corners – paint tends to be thinner at sharp corners and often starts to fail.**
- **Provide for easy drainage (esp tanks) – avoid remaining liquids collect at bottom. E.g steel is resistant against concentrated sulfuric acid but if remaining liquid is exposed to air, acid tend to absorb moisture, resulting in dilution and rapid attack occurs.**
- **Avoid hot spots during heat transfer operations – localized heating and high corrosion rates. Hot spots also tend to produce stresses – SCC failures.**
- **Design to exclude air – except for active-passive metals and alloys coz they require  $O_2$  for protective films.**
- **Most general rule : AVOID HETEROGENEITY!!!**



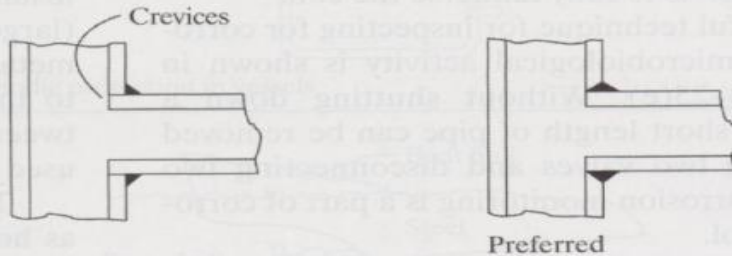
# DESIGN for Corrosion



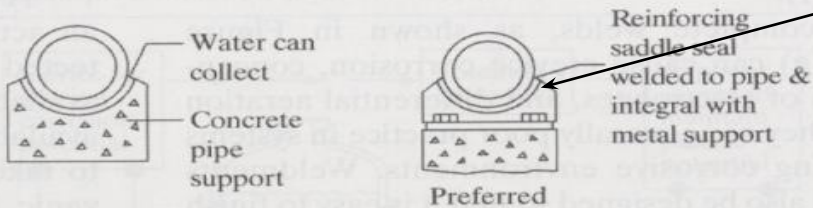
(e) Provide for inspection



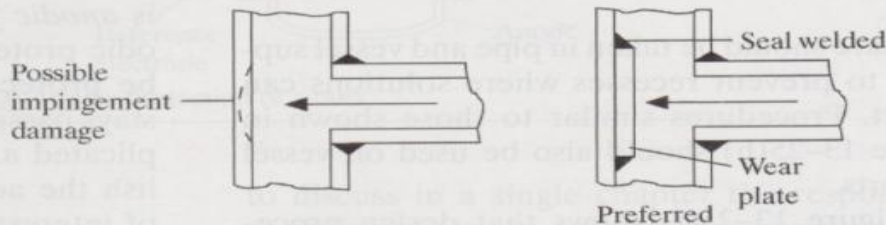
(f) Prevent galvanic couples



(g) Avoid incomplete weld penetration



(h) Avoid water accumulation in outdoor construction



# DESIGN for Corrosion

Bracket easier to replace than pipe!











# Material Selection



# MATERIAL SELECTION

(selection of proper material for a particular corrosive service)

✓ **Metallic** : [metal and alloy]

✓ **Nonmetallic** : [rubbers (natural and synthetic),  
plastics, ceramics, carbon and graphite, and wood]

# IMPROVEMENTS OF MATERIALS

- Purification of metals: Al , Zr
- Making more noble, e.g. Pt in Ti
- Passivating, e.g. Cr in steel
- Inhibiting, e.g. As & Sb in brass
- Scavenging, e.g. Ti & Nb in S.S
- Improving other properties



# Material Selection - Galvanic Series [Seawater at 77° F.]



**Magnesium**

**Zinc**

**Aluminum**

**Mild Steel**

**Cast Iron**

**Copper**

**Stainless Steel**


**Gold**

**Platinum**

**Combining dissimilar metals can result in corrosion. It may be very rapid or it may be relatively slow, depending on the metals combined, the environment, and the ratio of one to the other. We can also use this concept to protect a surface, such as when we hot dip galvanize steel. The zinc we apply to the steel is the more active metal and will sacrifice itself to protect the steel. When we combine zinc and steel the zinc becomes the anode and the steel becomes the cathode.**

# Metals and Alloys

No	Environment	Proper material
1	Nitric acid	Stainless steels
2	Caustic	Nickel and nickel alloys
3	Hydrofluoric acid	Monel (Ni-Cu)
4	Hot hydrochloric acid	Hastelloys (Ni-Cr-Mo)
5	Dilute sulfuric acid	Lead



<b>No</b>	<b>Environment</b>	<b>Proper material</b>
<b>6</b>	<b>Nonstaining atmospheric exposure</b>	<b>Aluminium</b>
<b>7</b>	<b>Distilled water</b>	<b>Tin</b>
<b>8</b>	<b>Hot strong oxidizing solution</b>	<b>Titanium</b>
<b>9</b>	<b>Ultimate resistance</b>	<b>Tantalum</b>
<b>10</b>	<b>Concentrated sulfuric acid</b>	<b>Steel</b>

# Cathodic Protection (CP)

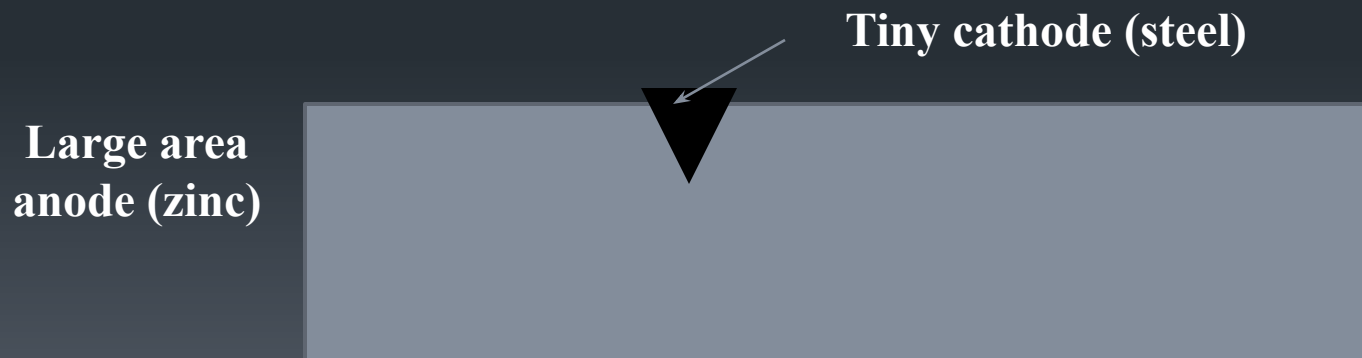
- Cathodic protection (CP) is a technique to control the corrosion of a metal surface by making it work as a cathode of an electrochemical cell. This is achieved by placing in contact with the metal to be protected another more easily corroded metal to act as the anode of the electrochemical cell. Cathodic protection systems are most commonly used to protect steel, water or fuel pipelines and storage tanks, steel pier piles, ships, offshore oil platforms and onshore oil well casings.
- Types of CP:
  - sacrificial anodes (zinc, magnesium or aluminum): The sacrificial anodes are more active (more negative potential) than the metal of the structure they're designed to protect. The anode pushes the potential of the steel structure more negative and therefore the driving force for corrosion halts. The anode continues to corrode until it requires replacement,
  - Impressed current CP: done for large structures (pipes, offshore platforms, etc) where a galvanic (or sacrificial) anode can not economically deliver enough current.
  - Galvanized steel (see previous slide): again, steel is coated with zinc and if the zinc coating is scratched and steel exposed, the surrounding areas of zinc coating form a galvanic cell with the exposed steel and protects it from corroding. The zinc coating acts as a sacrificial anode.

# CATHODIC & ANODIC PROTECTION

- **Cathodic protection:** Make the structure more cathodic by
  - Use of sacrificial anodes
  - Impressed currents
  - Galvanized steel
- **Anodic protection:** Make passivating metal structures more anodic by impressed potential. e.g. 316 s.s. pipe in sulfuric acid plants.

# Sacrificial Anodes

- **Galvanization of Steel**
- **Dip steel sheet in molten zinc. Get a pretty thin coating.**
- **Zinc will be anode. Steel exposed by crack is the cathode. Since we have a huge anode having to be served by a small cathode, corrosion rate will be slow.**



**An example of a favorable area ratio. Bad deal: huge cathode, tiny anode**

# Another Example

- Zinc is attached to the steel hull of the vessel.



Attachment points

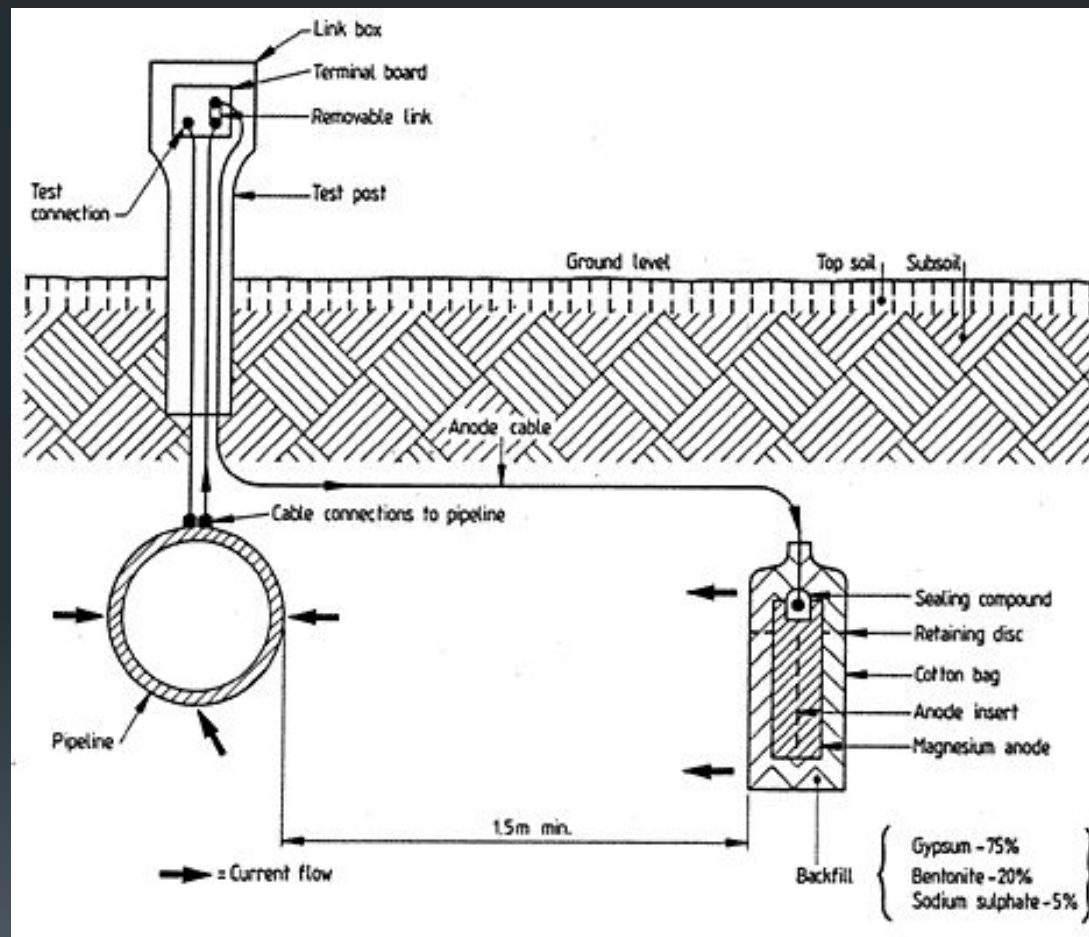


**Table 17.2 The Galvanic Series**

	Platinum
	Gold
	Graphite
	Titanium
	Silver
	[316 Stainless steel (passive)
	[304 Stainless steel (passive)
	[Inconel (80Ni-13Cr-7Fe) (passive)
	[Nickel (passive)
	[Monel (70Ni-30Cu)
	Copper-nickel alloys
	Bronzes (Cu-Sn alloys)
	Copper
	[Brasses (Cu-Zn alloys)
	[Inconel (active)
	[Nickel (active)
	Tin
	Lead
	[316 Stainless steel (active)
	[304 Stainless steel (active)
	[Cast iron
	[Iron and steel
	Aluminum alloys
	Cadmium
	Commercially pure aluminum
	Zinc
	Magnesium and magnesium alloys

**Source:** M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright 1986 by McGraw-Hill Book Company. Reprinted with permission.

# Sacrificial Anode for a Pipeline

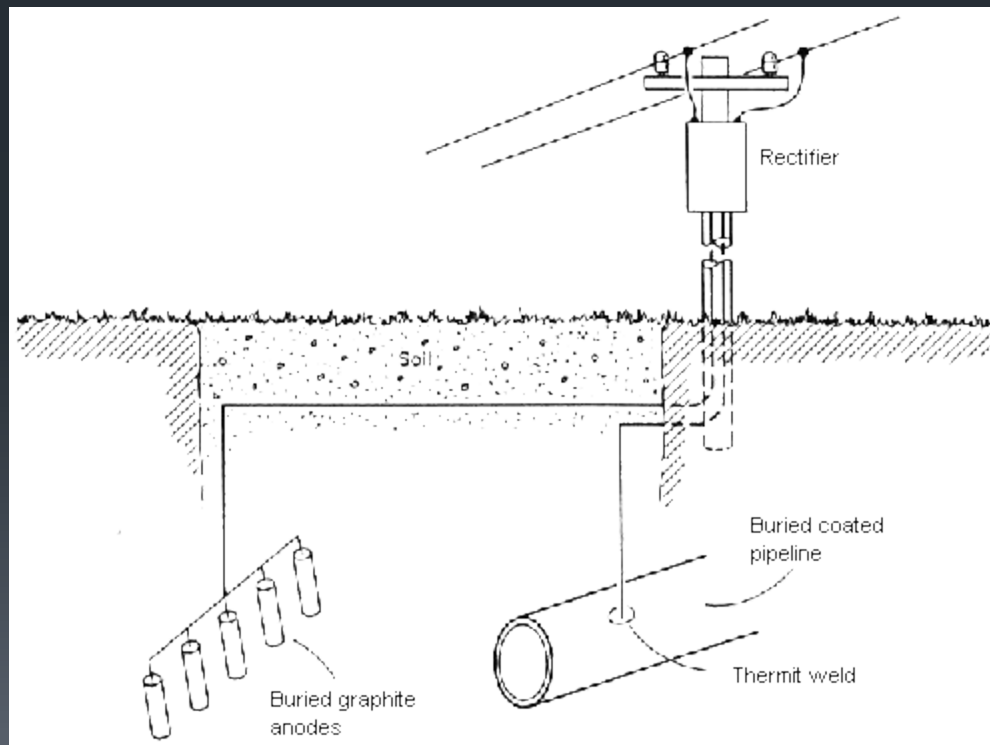


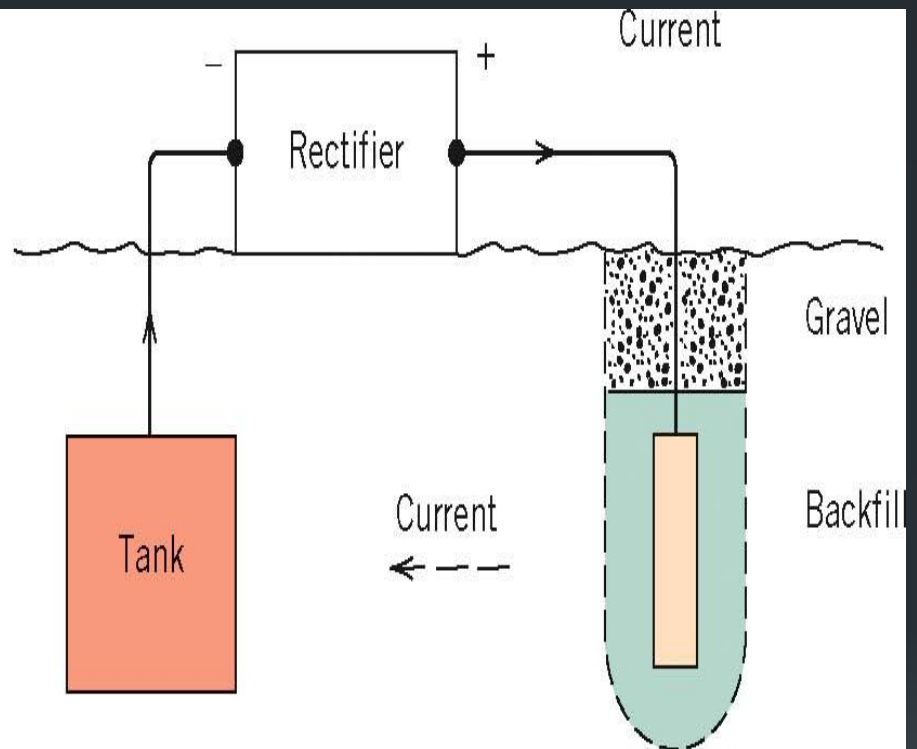
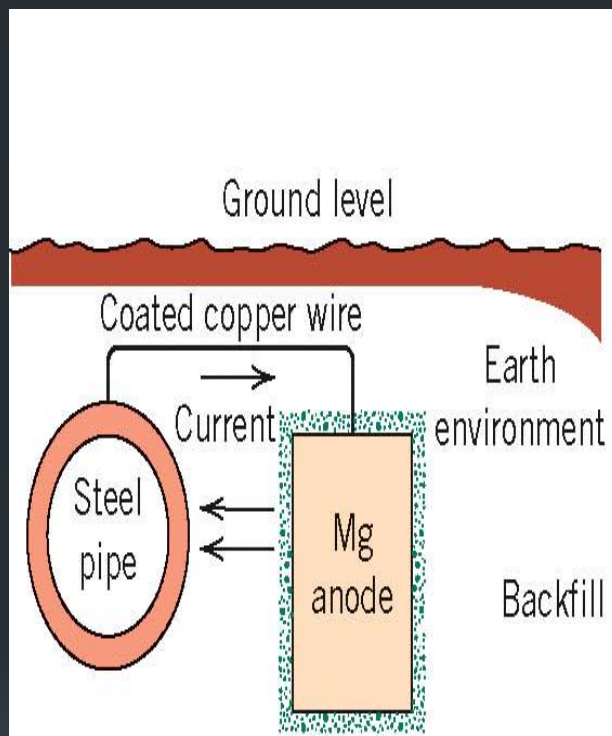


Aluminium anodes mounted on a steel jacket structure – using galvanic corrosion for corrosion control! Called cathodic protection (aka sacrificial anode)

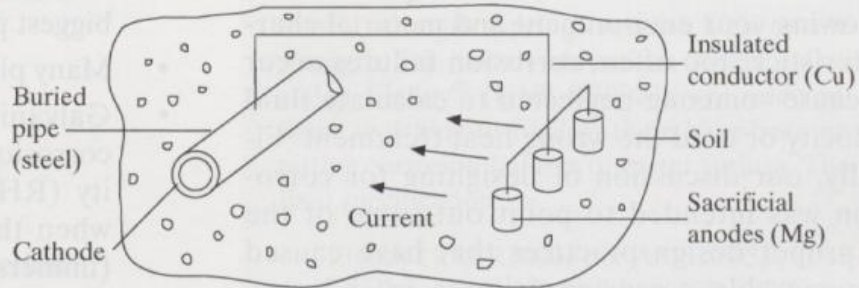
# Impressed Voltage

By imposing a voltage which causes electrons to flow towards the object to be protected, we make it less anodic and protect it from corrosion damage.

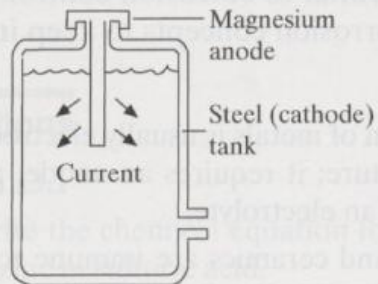




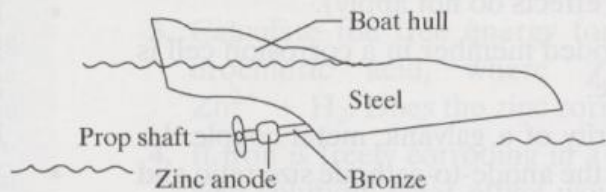




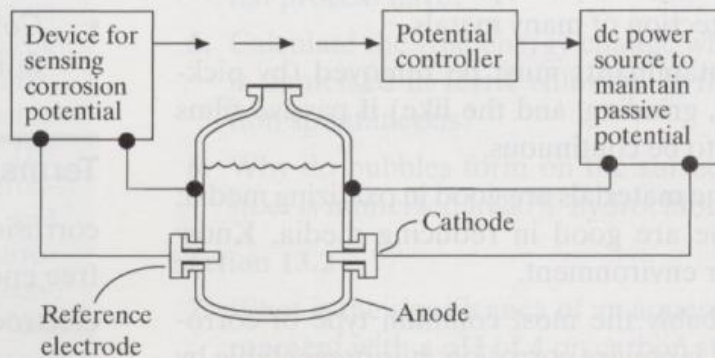
(a) Cathodic protection in soil



(b) Cathodic protection in vessels



(c) Galvanic protection with an active anode metal



(d) Anodic protection of a tank



See Exxon Mobil example

# Polarization

- This is an effect which reduces the actual chemical potential driving of the cell. If the thermodynamic force driving the ion into solution is reduced, this is polarization.
- Easy example. By lowering the electrolyte temperature, we find that it is usually less corrosive. Diffusion of ions is slowed.
- Inhibitors are chemicals which slow corrosion. Some of them do this by promoting the polarization of the cathode.

# Passivation of the anode

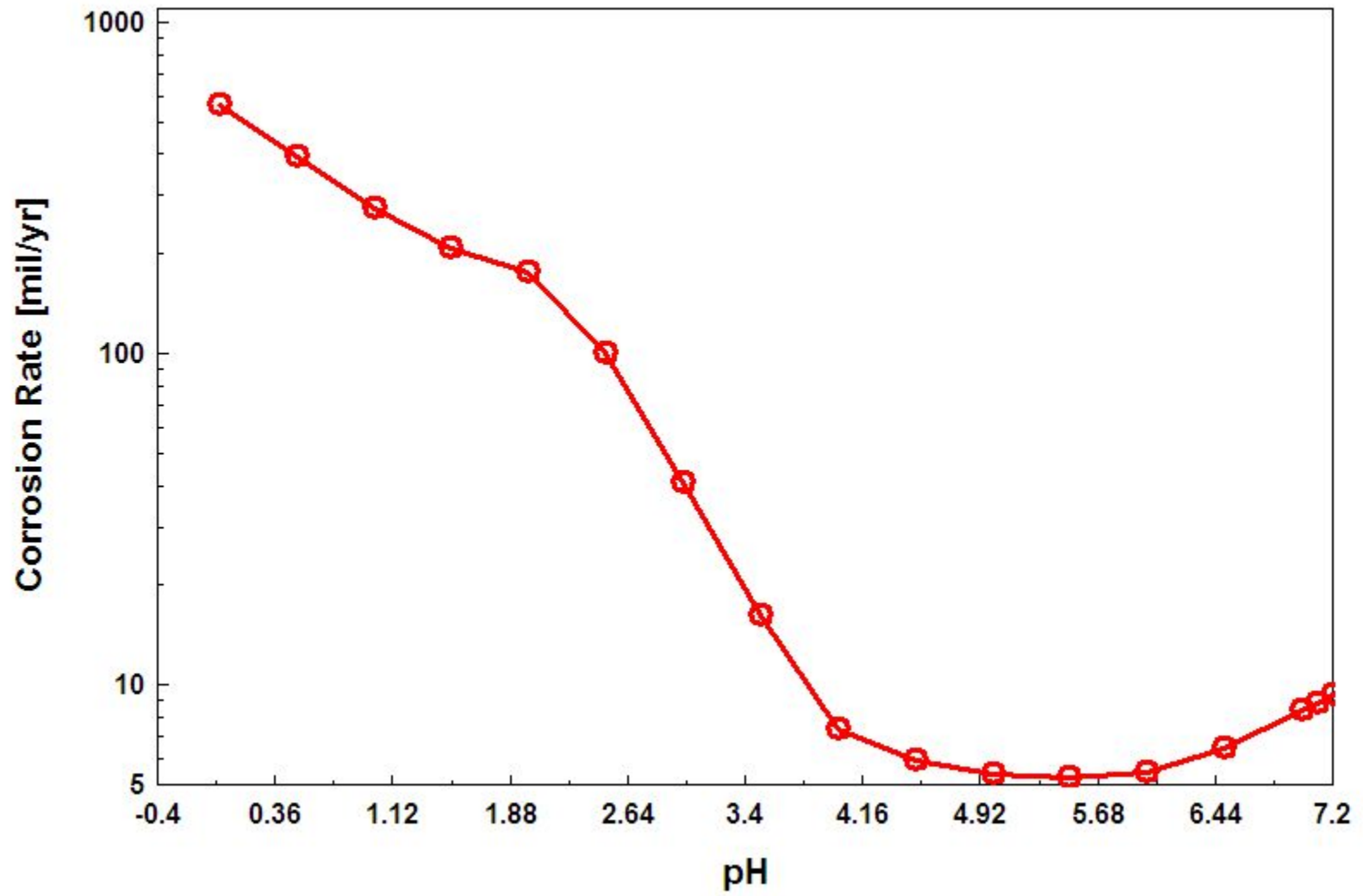
- We have two examples already. Stainless and aluminum.
- A thin oxide layer forms on the surface and isolates the metal from the environment.
- Zn, Mg, Cu and Ti are also capable of passivation under normal conditions of operation.
- Steel will also passivate in the presence of an alkaline environment, such as rebar in concrete.
- Corrosion inhibitors. Some of these, such as the chromates, are capable of coating a steel and passivating it.
- Coatings, paints, etc.





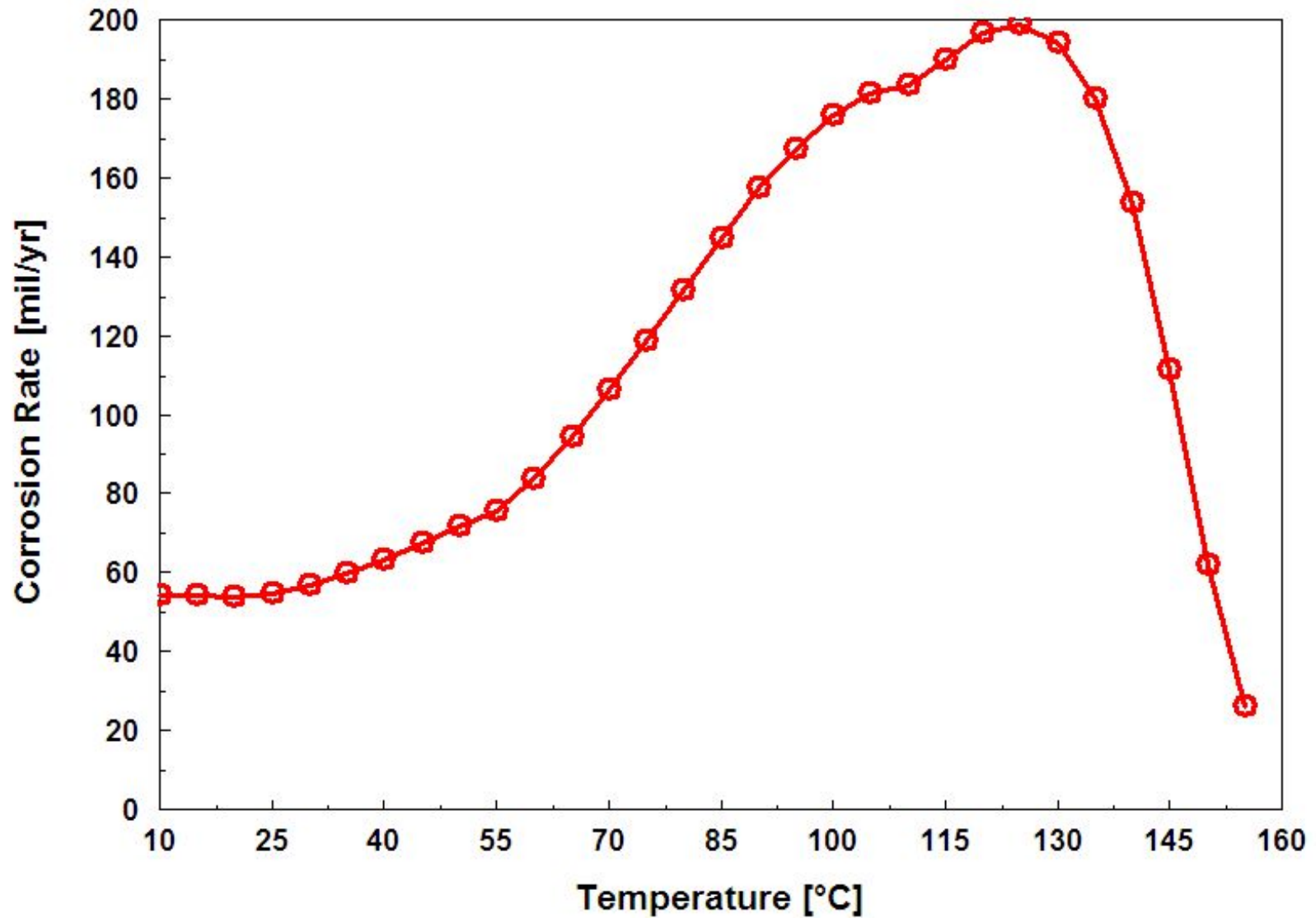
# **Effect of environmental parameters on the rate of corrosion**

## Corrosion Rate vs pH



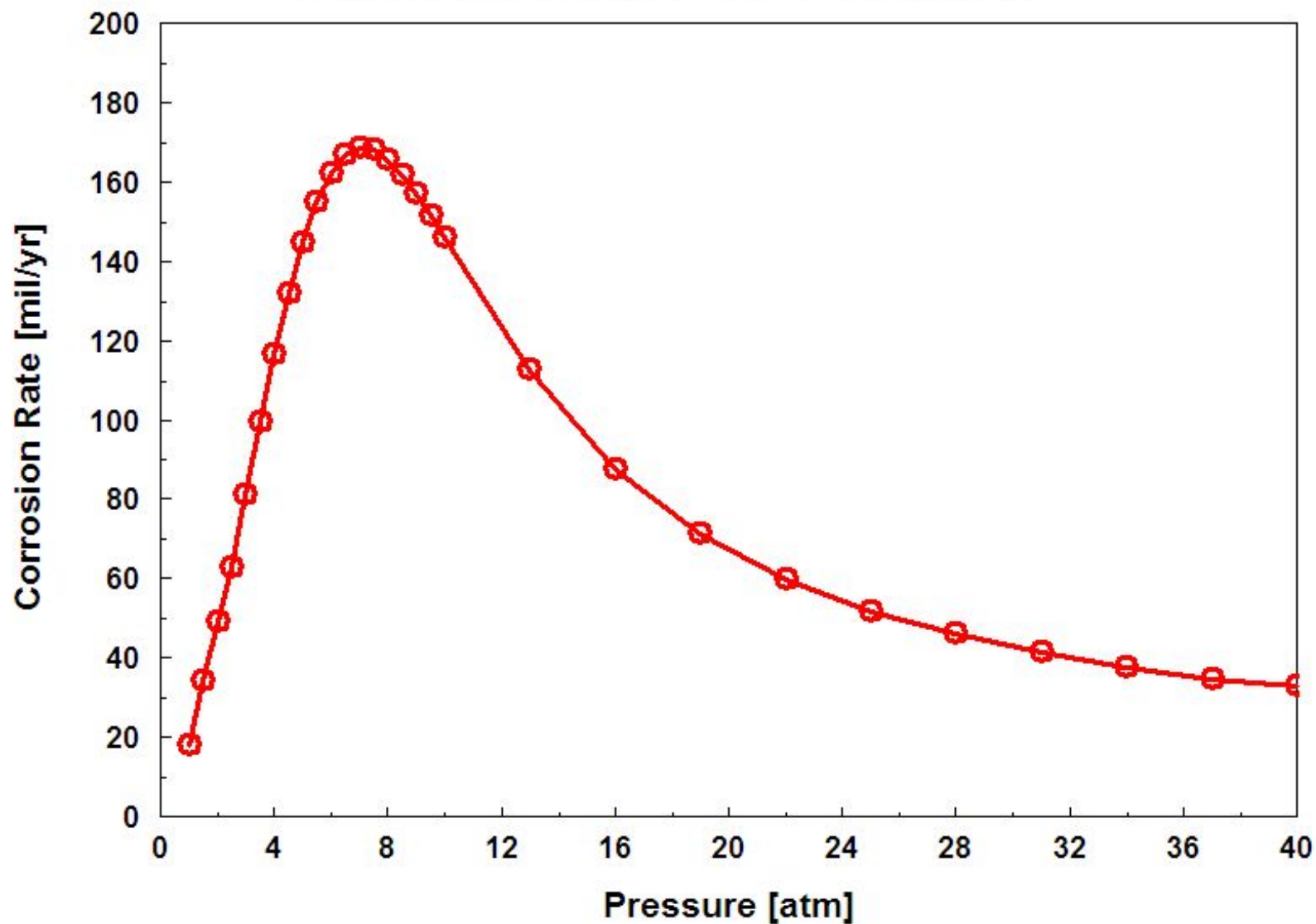
NaCl 5.5%

## Corrosion Rate vs Temperature



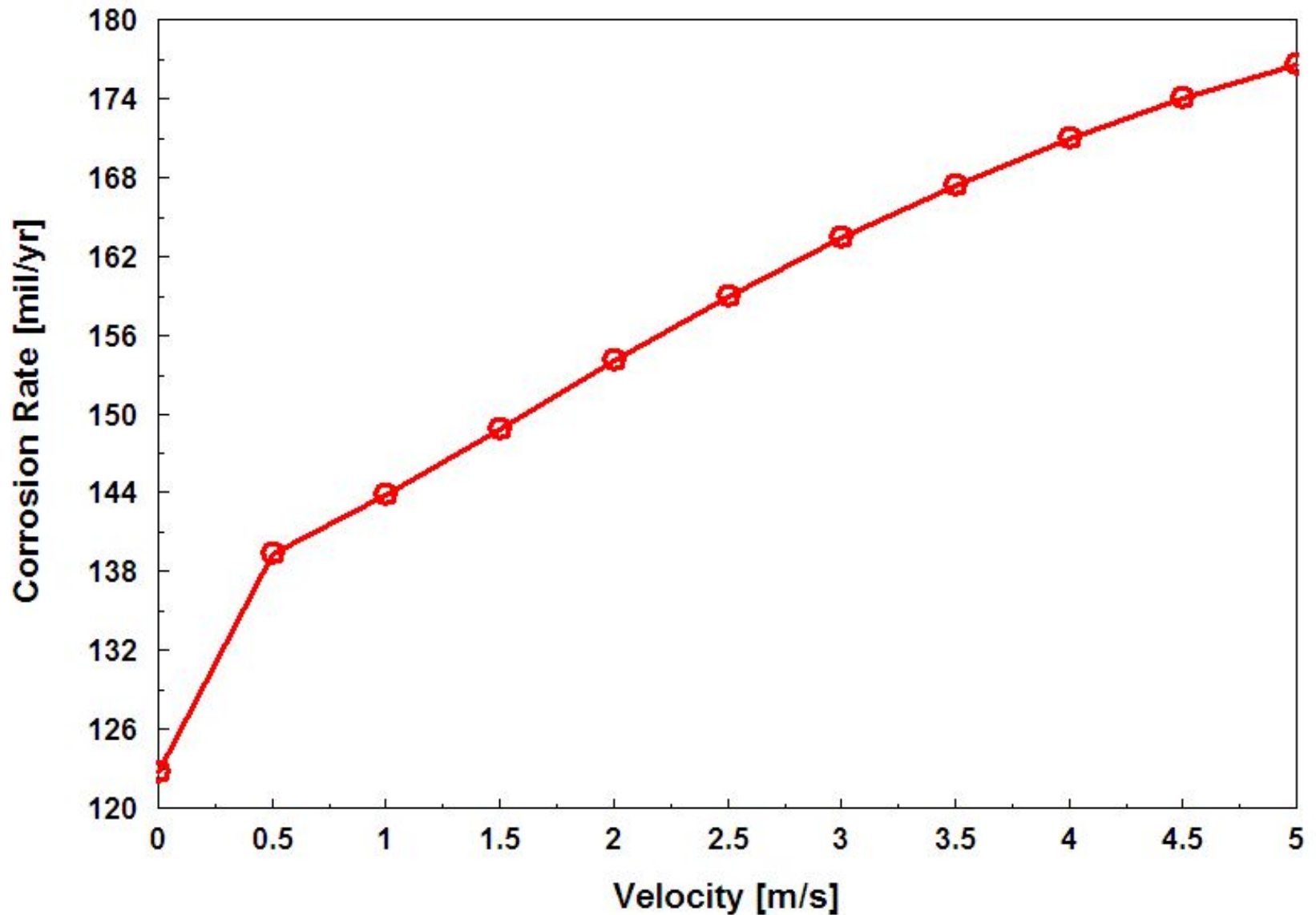
NaCl, 5 atm 5.5%

## Corrosion Rate vs Pressure



NaCl, 85 °C 5.5%

## Corrosion Rate vs Velocity



NaCl, 10 °C, 15 atm 5.5%

# Alternation of Environment

- Lower temperature and velocity
- Remove oxygen/oxidizers
- Change concentration
- Add Inhibitors
  - Adsorption type, e.g. Organic amines, azoles
  - H evolution poisons, e.g. As & Sb
  - Scavengers, e.g. Sodium sulfite & hydrazine
  - Oxidizers, e.g. Chromates, nitrates, ferric salts

# Alteration of Environment

- **Typical changes in medium are :**
  - **Lowering temperature** — but there are cases where increasing T decreases attack. E.g hot, fresh or salt water is raised to boiling T and result in decreasing O<sub>2</sub> solubility with T.
  - **Decreasing velocity** — exception ; metals & alloys that passivate (e.g stainless steel) generally have better resistance to flowing mediums than stagnant. Avoid very high velocity because of erosion-corrosion effects.

- **Removing oxygen or oxidizers** – e.g vacuum treatment, inert gas sparging, or thru the use of oxygen scavengers. However, not recommended for active-passive metals or alloys. These materials require oxidizers to form protective oxide films.
- **Changing concentration** – higher concentration of acid has higher amount of active species (H ions). However, for materials that exhibit passivity, effect is normally negligible.



# Environment factors affecting corrosion

- Dust particles and man-made pollution – CO, NO, methane, etc.
- Temperature – high T & high humidity accelerates corrosion.
- Rainfall – excess washes corrosive materials and debris but scarce may leave water droplets.
- Proximity to sea
- Air pollution – NaCl, SO<sub>2</sub>, sulfurous acid, etc.
- Humidity – cause condensation.

# Inhibitors



**Inhibitors are materials that may be injected into the system . They plate out on the surface and inhibit the formation of corrosion cells. They are commonly used in pipelines and other vessels that will contain materials that are corrosive.**

**Some metals, such as gold and platinum, corrode very slowly or not at all. Choosing a corrosion resistant material can reduce the rate of corrosion.**

They are sometimes injected into the water stream that may be used for the surface preparation of steel, as in the case of water jetting.

In the formulation of some primers inhibitive pigments are used . These inhibitive pigments inhibit, or interfere, with the corrosion process.

Examples of inhibitive pigments are red lead and barium meta borate.

## Why Metals Corrode – Recommended!!



<http://www.westcoastcorrosion.com/Papers/Why%20Metals%20Corrode.pdf>

<http://www.corrosionsource.com/>

<http://www.corrosioncost.com/home.html>

<http://www.intercorr.com/failures.html>

[http://www.3ninc.com/Cast\\_Magnesium\\_Anodes.htm](http://www.3ninc.com/Cast_Magnesium_Anodes.htm)

[http://en.wikipedia.org/wiki/1992\\_explosion\\_in\\_Guadalajara](http://en.wikipedia.org/wiki/1992_explosion_in_Guadalajara)