

CWMC



# “Corrosion Management of Water Transport pipes of Power Plants”



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**“Thermal Power Operations and Maintenance Conference”,  
Organized by Mission Energy, New Delhi  
7<sup>th</sup> – 8<sup>th</sup> June 2018,**

**Corrosion and Water Management Consultants**

***“Improving Plant Performance, Availability & Reliability by Chemical Interventions”***

## About Myself

**Name:** Ashwini K. Sinha (Retired as Addl. GM (NETRA), NTPC in July 2012)

**Qualifications:** M.Sc (Electrochemistry)

P.G. Dip. In Corrosion Science & Technology, Univ. of Ferrara  
(Italy)

**Affiliations:** Member NACE International, Life Fellow Member SAEST, IAAPC  
Core Member of CII-Avantha Corrosion Management Committee

**Experience:** Over 40 years experience in Corrosion Analysis, Monitoring and Control in Power Plants (5 Years with BHEL (R&D), 30 years Balance with NTPC (R&D) (now “NTPC Energy Technology Research Alliance (NETRA) and balance as Free Lance Consultant in the areas of Corrosion & Water Management).

**Specialization:** Corrosion Assessment, Failure Investigations, Corrosion Monitoring, Corrosion Audit, Design of Cathodic Protection Systems for Underground Pipelines; Condenser Water Boxes; RCC Structures such as Cooling Towers; etc, Selection of Anticorrosive Coatings, Development & Implementation of Cooling Water Treatments, Waste Water Recycling & Treatment, Chemical Cleaning of Condensers; Boilers; Pipelines; PVC Film Type Fill Packs of Cooling Towers; etc, Material Selection, Water Management, etc. Research Studies on Extraction of Moisture from Flue Gases, Ash Mineralization by Flue Gas, etc.

**Major Association with: - Consultancy, In-house Training,**

1. Adani Power (Mundra, Tiroda, Kawai, Udupi, New Projects)
2. **NOMAC – USC Plant, Dubai; CCPP, Salalah, Oman; Tanger Wind Farms, Morocco**
3. **Sembcorp IWPP, Salalah, Oman** and Nellore, India
4. CLP Paguthan and Jhajjar
5. GSECL Sikka TPS, Jamnagar
6. Mahagenco Chandrapur and Koradi
7. Rajasthan Raja Vidyut Utpadan Nigam Kalisindh , Dholpur, Kota Thermal
8. Essar Sallaya Project, Jamnagar
9. Vedanta Limited, Jharsuguda and Bhatinda
10. Haldia Energy Limited, Haldia
11. IOCL Dibrugarh, Guwahati, Panipat
12. HPCL – Mittal Energy Limited, Bathinda
13. Lanco Kondapally, Gurugram, Udupi (now with Adani Power)
14. Imperial Power, Jharkhand, Prakash Industries, Champa (Chhatisgarh)
15. Sri Mega Power Beawar, Rajasthan
16. Jindal Power, Raigarh; JSPL, Odisha
17. Reliance - Rosa Power, Shajahanpur, Sasan UMPP, MP
18. NTPC (almost all stations)
19. NLC and NTPL, Neyveli
20. Nabha Power Limited, Rajpura, Punjab

- **Ground water**
  - Wells, bore wells and springs
  
- **Surface water**
  - Lake, pond/reservoir, river, canal
  
- **Sea water**
  - Including Back sea water, Estuarine, Brackish water
  
- **Mine Water**
  
- **Treated STP Water/Plant ETP Water/CW Blow Down**
  
- **Harvested Rain Water**

# IMPURITIES IN WATER

- **BACTERIA & VIRUSES**
- **MICRO – ORGANISMS**
- **TURBIDITY**
- **COLOUR**
- **MINERALIZATION**
- **METALLIC**
- **DISSOLVED GASES**
- **AMMONIA**
- **ORGANIC MATTER**
- **POLLUTANTS**

## **Water Transport Systems in Power Plants:**

Raw Water (Fresh, Brackish, Seawater, Mine Water, Harvested Rain Water)

Filtered or Clarified Water

Water for DM Plant (Clarified, RO Treated Water)

Potable Water

Boiler Feed Water

Fire Water

Service Water (Fresh, 1<sup>st</sup> Stage Permeate of Desalinated RO Water)

Cooling Water

Auxiliary Cooling Water

Sewage Treated Water

Effluent Water

Desalinated Water

## Issues Involved in Water Distribution Systems:

### External Side:

- Soil side corrosion (if buried in Soil) including Galvanic Corrosion of Dissimilar Metals joined together.
- Atmospheric Corrosion + Local Concentrating Factors such as Cooling Tower Drift, Chemical Fumes, etc.
- Corrosion under the Pipe Supports, Flanges, etc

### Internal (Water) Side:

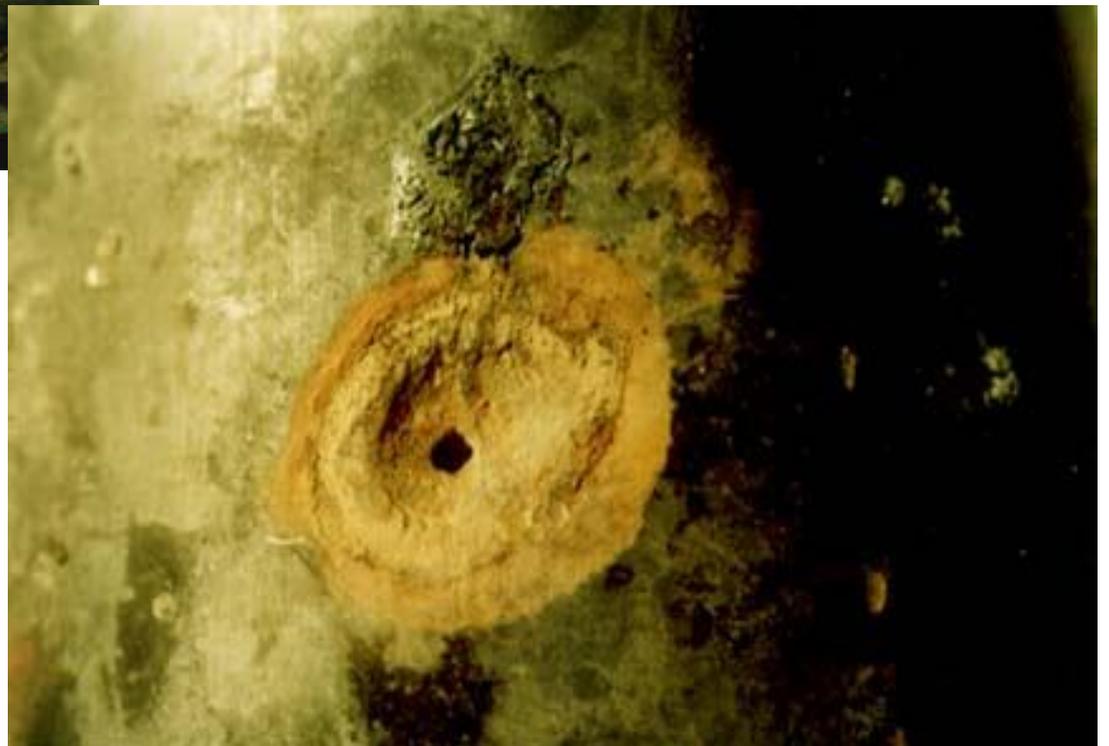
- Corrosion
- Fouling
- Deposition
- Biofouling
- Microbiologically Induced Corrosion

# Examples of Corrosion in Water Distribution Pipelines

# Soil Side Corrosion



# Soil Side Corrosion



## Soil Corrosion

For design and corrosion risk assessment purposes, it is desirable to estimate the corrosivity of soils. One of the simplest classifications is based on a single parameter, soil resistivity. The generally adopted corrosion severity ratings are:

Resistance Classification	Soil Resistivity (ohm-cm)	Corrosion Potential
Very Low	< 1000	Extreme
Low	0 - 2000	Severe
Medium	2000 - 10000	Moderate
High	10000 - 30000	Mild
Very High	> 30000	Unlikely

Sandy soils are high up on the resistivity scale and therefore considered the least corrosive. Clay soils, especially those contaminated with saline water are on the opposite end of the spectrum. The soil resistivity parameter is very widely used in practice and generally considered to be the dominant variable in the absence of microbial activity

# Atmospheric Corrosion



# Corrosion Under Pipe Supports



# Corrosion in Fire Water & Distribution Pipelines



# Corrosion in Fire Water & Distribution Pipelines

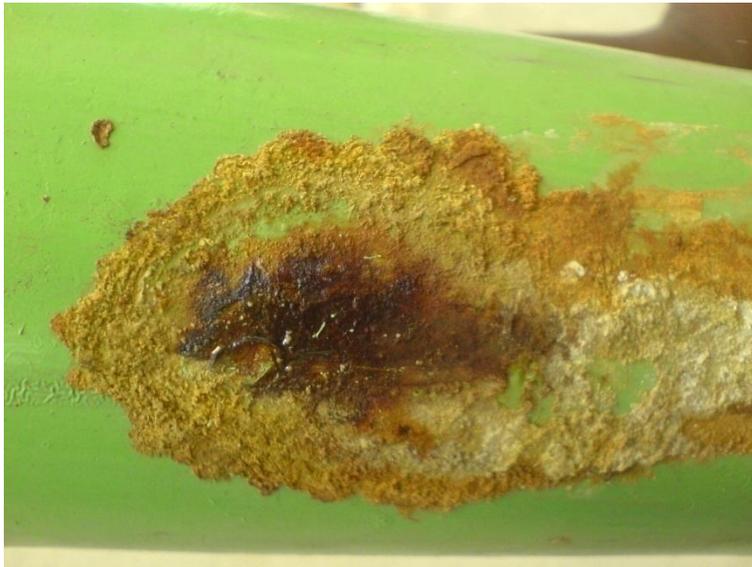


# Corrosion in Fire Water & Distribution Pipelines

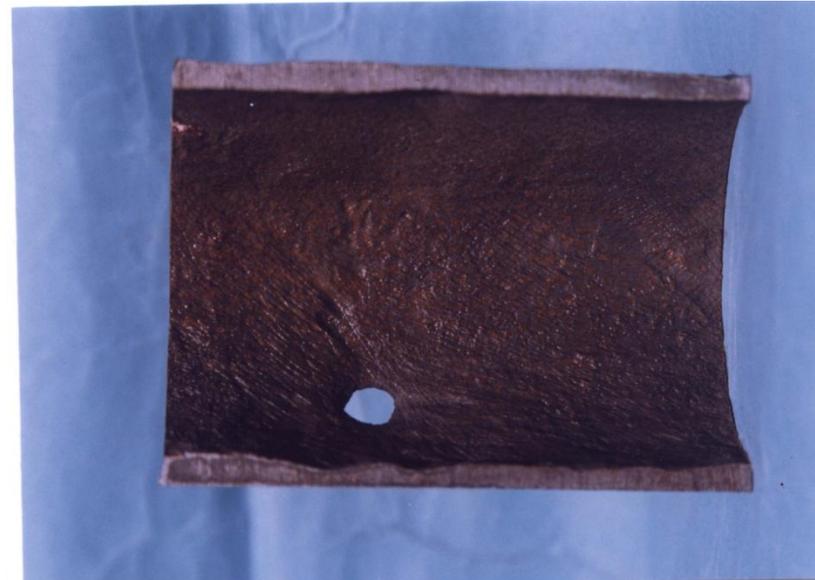


**Repeated Failures of Patch Welded pipeline**

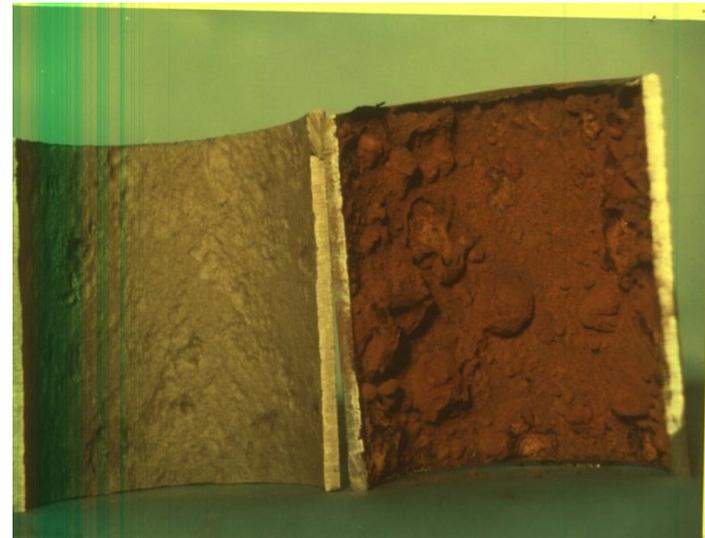
# Corrosion in Fire Water & Distribution Pipelines



# Corrosion in Fire Water & Distribution Pipelines



# Corrosion in Fire Water & Distribution Pipelines



# Corrosion in Fire Water & Distribution Pipelines



# Corrosion in Fire Water & Distribution Pipelines



# Corrosion of Service Water Pipelines



**Tubercles inside the service water pipelines**

# Corrosion of Fire Water Pipelines



**Biofouling/slimy layer inside fire water pipeline**

# Corrosion of Fire Water Pipelines



**Corrosion products and biofouling in fire water pipes**

# Corrosion of OCCW Pipelines



# Corrosion of OCCW Pipelines



**UNIT-1 MARCH 2016**



**UNIT-2 Jan. 2015**

# Corrosion of OCCW Pipelines



# Failure of PHE



Pin hole leakages in PHE

# Failure of PHE



**Corrosion of inlet of pipe in PHE**

# Corrosion in ACW System



Microbiologically Induced Corrosion of ACW system

CWMC

CW Return Line



## Corrosion of ACW Pipelines



**Corroded ACW Valves**

# Corrosion of ACW Pipelines





**Corroding ACW Pipe Seawater**



**Corroding ACW Pipe Brackish Water**



**Corroding Service Water Pipe**



**Corroding Service Water Pipe**

# Corrosion in Fire Water & Distribution Pipelines

# Failure of Service Water Pipelines

Metal	Impact of Corrosion
Steel	Stagnant water tends to induce local attack.
	Fouling induces concentration-cell type corrosion.
	High Cl <sup>-</sup> and SO <sub>4</sub> <sup>2-</sup> tends to increase risks of pitting.
	O <sub>2</sub> saturated water may induce general corrosion.
	Fouling by slime-producing bacteria and the presence of SO <sub>4</sub> <sup>2-</sup> induces corrosion due to sulfate reducing bacteria.
	Coupling with noble metal causes galvanic corrosion.
	A low pH induces rapid, acid-induced wastage and pitting corrosion.
Iron	Presence of some O <sub>2</sub> , plus deposits and low flow, stimulates tuberculation.
	Soft water, low pH, H <sub>2</sub> S can stimulate graphitization.
SS	Vulnerable to depassivation from high Cl <sup>-</sup> .
	Residual or applied stress with Cl <sup>-</sup> induces SCC.
Brass	Ammonia produces cracking & wastage.
	High velocity can induce erosion-corrosion (>6 fps)
	Uninhibited brass suffers dezincification.
Zinc	High alkalinity causes white rust.
Al	pH over 9 with OH <sup>-</sup> causes rapid corrosion

# Station Water Quality

## Water Quality Parameters of Raw, Clarified and Cooling Water,

Sampling Date: 10.05.2016

S.No	Parameter	Unit	Raw Water	Make-up to CW	Cooling Water	COC
1	pH			7.91	7.94	
2	cond	µmhos/cm		362	1266	3.50
3	Total hardness	ppm as CaCO <sub>3</sub>		128	438	3.42
4	CaH	ppm as CaCO <sub>3</sub>		90	312	3.47
5	MgH	ppm as CaCO <sub>3</sub>		38	126	3.32
6	P alk.	ppm as CaCO <sub>3</sub>		0	0	
7	M alk.	ppm as CaCO <sub>3</sub>		82	92	1.12
8	T. alk.	ppm as CaCO <sub>3</sub>		82	92	1.12
9	Chloride	ppm as Cl		21.3	132.06	6.2
10	Turbidity	NTU		3.11	9.3	2.99
11	SiO <sub>2</sub>	ppm as SiO <sub>2</sub>	1.65	2.04	12.11	5.94
12	Sulphate	ppm as SO <sub>4</sub>	32.92	64.19	400.9	6.25
13	Iron	ppm as Fe	0.52	0.17	0.21	1.24
14	PO <sub>4</sub>	ppm	ND	0.41	1.55	3.78
15	Mn	ppm	0.154	0.08	ND	
16	COD	ppm	177.28	64.12	18.86	
17	NO <sub>3</sub>	ppm	0.23	ND	1.92	
18	NO <sub>2</sub>	ppm	0.026	0.033	ND	
19	TKN	ppm	69	32.74	78.72	2.40
20	Sulphide	ppm	ND	ND	ND	
21	NH <sub>3</sub>	ppm		0.21	0.44	2.1
22	Chlorine Demand	ppm	0.34	0.51	0.67	
23	PSI			8.05	6.9	
24	RSI			7.45	6.35	
25	LSI			0.23	0.8	
26	Larsen Skold Index			1.18	6.54	

# Station Water Quality

## Microbiological Analysis of Service Water, Cooling Water and Deposits

S.No	Parameter	Unit	Service Water	Cooling Water	Service Water Deposit	Cooling Water Deposit
1	Total Viable Count	CFU/ml	6.9 X 10 <sup>4</sup>	2.9 X 10 <sup>5</sup>	9.5 X 10 <sup>4</sup>	1.3 X 10 <sup>4</sup>
2	Total Fungal Count	CFU/ml	< 10	< 10	< 10	< 10
3	Organic acid producing Bacteria	MPN/100 ml	130	110	80	60
4	Sulphate Reducing Bacteria	MPN/100 ml	< 2	< 2	500	1600
5	Slime Formers	MPN/100 ml				
	a. Pseudomonas Spp		500	240	140	< 2
	b. Enterococcus Spp		< 2	< 2	< 2	< 2
6	Gas Producing Bacteria	MPN/100 ml				
	a. CO2 Producers		500	50	50	34
	b. Ammonia Producers		< 2	< 2	< 2	< 2
7	Sulphur Oxidizing Bacteria	MPN/100 ml				
	a. Thiobacillus Thiooxidizers		< 1	< 1	< 1	< 1
	b. Thiobacillus Thioparus		< 1	< 1	< 1	< 1
8	Nitrifying Bacteria	MPN/100 ml	< 1	< 1	3	2
9	Iron Oxidizing Bacteria	MPN/100 ml	Absent	Absent	Absent	Absent
10	Algae	MPN/100 ml	NT	NT		
	a. Blue-green Algae				Absent	Absent
	b. Green Algae				Absent	Absent
	c. Diatom				Absent	Absent
11	Sulphide (as S <sup>2-</sup> )	ppm	NT	NT	ND (< 0.2 ppm)	ND (< 0.2 ppm)
12	Ammoniacal N (as NH <sub>3</sub> )	ppm	NT	NT	1.74	1.19
13	Nitrate (as NO <sub>3</sub> )	ppm	NT	NT	ND (< 0.2 ppm)	ND (< 0.2 ppm)
14	Nitrite (as NO <sub>2</sub> )	ppm	NT	NT	0.041	0.043
15	Chlorine Dioxide Demand as ClO <sub>2</sub>	ppm	NT	NT	4.3	5.5

# Water Quality

Parameter	Service water	Blow down water
pH	7.84	7.92
FRC, ppm	0	0.1
Conductivity, ms	271	1428
Turbidity, NTU	3.02	15.7
Alkalinity, ppm	86	82
Total Hardness, ppm	130	620
Ca-Hardness, ppm	90	440
Mg-Hardness, ppm	40	180
Chloride, ppm	25	113.6
Iron, ppm	0	0.16
Silica, ppm	21.45	80

# Deposit Analysis of Fire Water System

S. No.	PARAMETER	As	Deposit A	Deposit B	Deposit C
1.	Calcium	CaO (%)	0.1	0.1	0.1
2.	Magnesium	MgO (%)	0.1	0.1	0.1
3.	Silica	SiO <sub>2</sub> (%)	4.3	5.7	3.8
4.	Copper	CuO (%)	0.1	0.1	0.1
5.	Iron	Fe <sub>2</sub> O <sub>3</sub> (%)	78.3	79.6	84.5
6.	Sodium	Na <sub>2</sub> O (%)	0.4	0.9	1.1
7.	<b>Sulphate</b>	<b>SO<sub>4</sub> (ppm)</b>	<b>67</b>	<b>62</b>	<b>52</b>

# Deposit Analysis of Fire Water System

S.No	Parameter	Test Results (Sample details)			Unit	Acceptable Value
		Deposit A	Deposit B	Deposit C		
1	Total Viable Count	$3.1 \times 10^5$	$5.7 \times 10^5$	$4.4 \times 10^7$	CFU/ml	$<1 \times 10^5$ * $<2 \times 10^3$ **
2	Total Fungal Count	<10	<10	$5 \times 10^2$	CFU/ml	<10
3	Sulphate Reducing Bacteria	<2	<2	26	MPN/100ml	<100/100 ml
4	Sulfur Oxidising Bacteria:					
	a. Thiobacillus thiooxidans	0	0	0	"	<2
	b. Thiobacillus thioparus	0	0	0	"	
5	Acid Producing Bacteria	17	21	220	"	<100/100 ml
6	Gas Producing Bacteria	<2	<2	14	"	<100/100 ml
7	Nitrifying Bacteria	<1	<1	1	"	N.S.
8	Ammonia Producers	7	6	28	"	N.S.
9	Slime Formers: (Pseudomonas aeruginosa)	31	49	350	"	N.S.
10	Iron Bacteria	N.D.	N.D.	N.D.	P/A	<2

# Aqueous Corrosion

## Corrosion of Mild Steel under Aqueous conditions:

Corrosion is a form of oxidation i.e.; it involves removal of electrons from the metals. An atom of iron becomes oxidized, when it leaves its neutral metallic states and enters solution as a positively charged ion:



This separation of charge constitutes an electric current, the magnitude of which is a measure of the rate of corrosion. For the continuation of current, the electrons liberated by the oxidation process must be absorbed in a compensating reduction reaction in which oxygen or water is reduced.



The oxidation and reduction reactions may occur close together or at widely separated sites on the metal surface, the electric circuit being completed by a flow of electrons in the metal and by transport of charged ions in the solution. Negative ions migrate to balance the positive metal ion released at the anodic site of oxidation and positive ions travel the other way to balance the negative hydrogen ions at the cathodic site of reduction.

# Aqueous Corrosion

## Corrosion of Mild Steel under Aqueous conditions:

Driving force for the corrosion reactions is the difference between the free energies of the starting materials (iron & oxygen or water) and those of the corrosion products (oxides and ionic species such as  $\text{Fe}^{2+}$  and  $\text{OH}^-$ ). This difference is normally experienced as an electrical potential. It varies with the materials, the temp. and the solution composition-especially with pH.

## Aqueous Corrosion:

The aqueous corrosion of iron under aerobic conditions can be represented as:



The product, ferrous hydroxide is further oxidized to magnetite ( $\text{Fe}_3\text{O}_4$ ) or hydrated ferric oxide  $\text{Fe}(\text{OH})_3$  i.e. rust. The above reaction (a) can be re-written as:

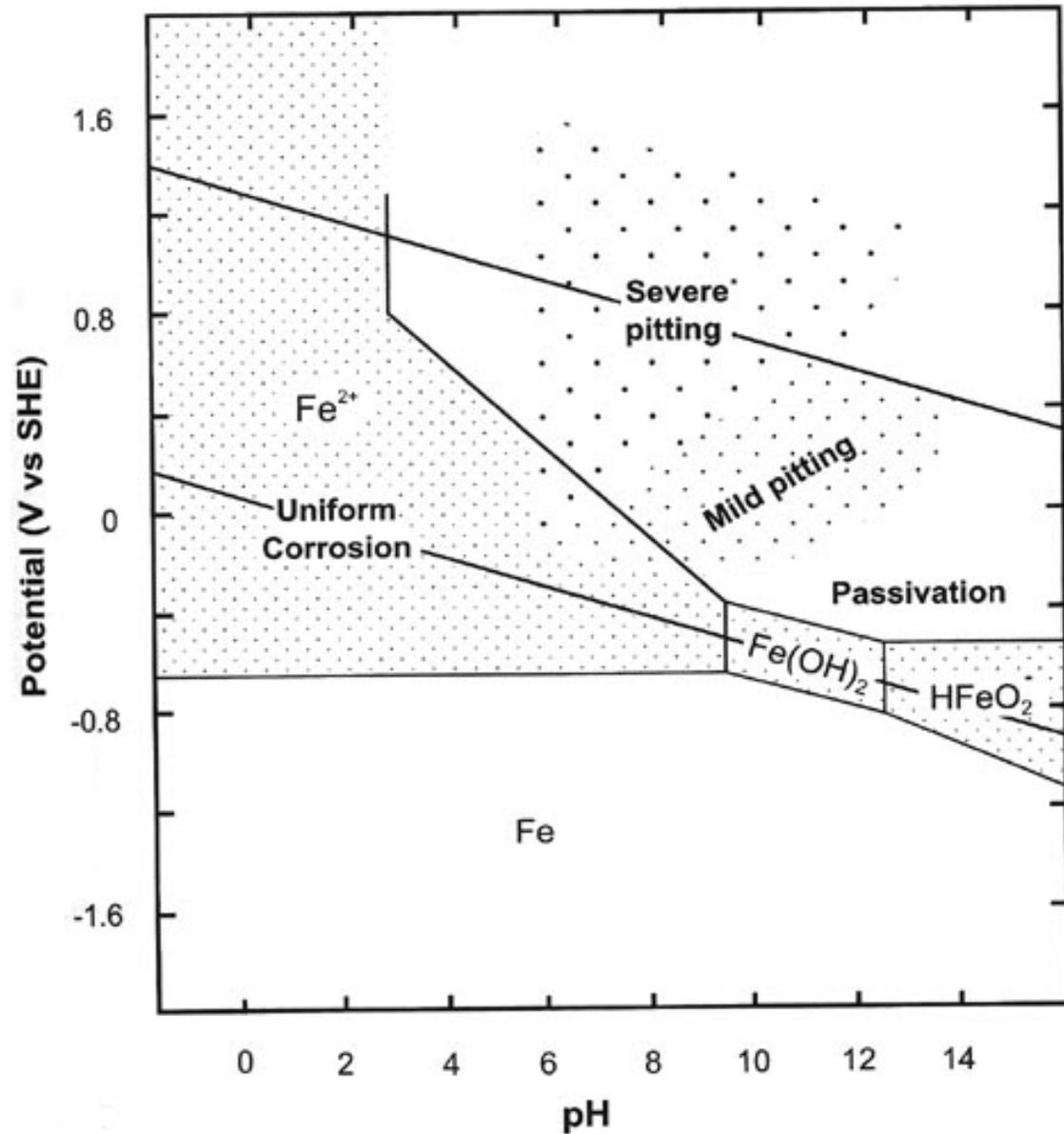


# Soil Corrosion

Predicting  
Corrosivity:

Soil

Stability Diagram for  
Iron:



# Soil Corrosion

## Predicting Soil Corrosivity:

### What Factors Affect Soil Corrosivity?

- Chloride level
- Moisture content
- Oxygen content/Redox potential
- Soil permeability/texture
- pH/Acidity
- Temperature
- Soil resistivity
- Drainage characteristics
- Sulfate and Sulfite ion concentrations
- Microbiological activity
- Stray currents, Electrochemical Potential Fields
- Spillage of corrosive substance/pollution
- Agricultural chemical activities

# Aqueous Corrosion

## **Corrosion of Mild Steel under Aqueous conditions:**

The consumption of metal & release of electrons is termed as "anodic reaction", whereas consumption of electrons and dissolved species in the environment is termed as "cathodic reaction ". In case electrons are withdrawn from metal surface through electrical forces, then reaction (b) will speed up and reaction (c) will slow down. However, if additional electrons were supplied to the metal surface, the cathodic reaction would speed up and the anodic reaction would be inhibited. This is the basis of protection of metals by cathodic protection.

During the corrosion process, electrons are transferred through the metal from one site of the metal surface to another (electronic conduction). The current flowing round the circuit is proportional to the corrosion rate.

## **KEY FACTORS AFFECTING CORROSION OF IRON IN WATERS:**

Key water quality parameters that are expected to influence corrosion of iron in waters include pH, alkalinity, and buffer intensity.

# Aqueous Corrosion

## KEY FACTORS AFFECTING CORROSION OF IRON IN WATERS:

**Role of pH:** Weight loss is generally found to increase with increasing pH in the range 7 to 9, as is the degree of tuberculation. In contrast, by-product release was decreased at higher pH. Again; this is consistent with increased corrosion by-products being incorporated into the scale layer. However, one study found that both weight loss and iron concentration decreased as pH was raised from 8.5 to 9.2.10

**Alkalinity:** Increasing alkalinity generally leads to lower weight loss and corrosion rate. Also, fewer customer complaints of red water were received when the alkalinity was maintained at greater than 60 mg/L as  $\text{CaCO}_3$ .

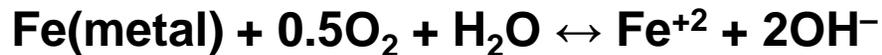
**Buffer Intensity:** Higher buffer intensity is often associated with increased alkalinity, although the two parameters are not exactly equivalent. However, their effect on iron corrosion seems to be similar. Several studies found the maximum weight loss for cast iron samples occurred at the minimum buffer intensity (pH 8.4) presumably because higher buffer intensity attenuates pH changes due to corrosion reactions at anodic and cathodic areas. However, one study found the opposite effect: weight loss for iron coupons in stagnant water increased with increasing buffer intensity.

# Aqueous Corrosion

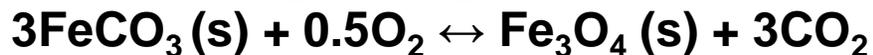
## KEY FACTORS AFFECTING CORROSION OF IRON IN WATERS:

### Dissolved Oxygen:

Dissolved oxygen (DO) is an important electron acceptor in the corrosion of metallic iron:



DO can also play a role in the oxidation of ferrous iron (Fe+2) or iron scales, for example:



Thus, oxygen concentration can have varying effects on iron corrosion. As expected, the corrosion rate increases with increasing DO. However, effects on iron concentration and tuberculation may be mixed depending on the type of scale formed. Higher turbidity (a surrogate for iron concentration) was seen at lower oxygen saturation, but it is also reported that water free of DO will not tuberculate. DO is also responsible for the ability of buffering ions, including phosphates, to inhibit corrosion.

# Aqueous Corrosion

## KEY FACTORS AFFECTING CORROSION OF IRON IN WATERS:

For example, in water with DO < 1 mg/L, solutions with phosphates had a higher corrosion rate compared to waters with no phosphates; in water with 1–6 mg/L DO, this trend was reversed. Thus some DO is required for inhibitors to function.

### Biological Activity

Microbes are present in many distribution systems, and they can influence iron corrosion in a number of ways. Bacteria have been found in iron tubercles. Growth of a bacterial biofilm on a pipe wall may serve as a barrier to corrosion, but biofilms can also produce a differential aeration cell, leading to localized changes in oxygen concentration and electrical potential. The biopolymers in the biofilm may also uptake soluble metals. Various bacteria can affect iron speciation by reducing  $\text{Fe}^{+3}$  or oxidizing  $\text{Fe}^{+2}$ . Bacteria also may consume oxygen, cause localized pH gradients, and produce corrosive metabolites such as  $\text{H}_2\text{S}$  or iron phosphide. Thus, the role of biological activity in a water pipe can be mixed, but is generally considered to be detrimental to most aspects of iron corrosion. In cases where such activity is dominant, it is not surprising that biocides such as chlorine effectively reduce overall corrosion problems despite their oxidative properties.

# Aqueous Corrosion

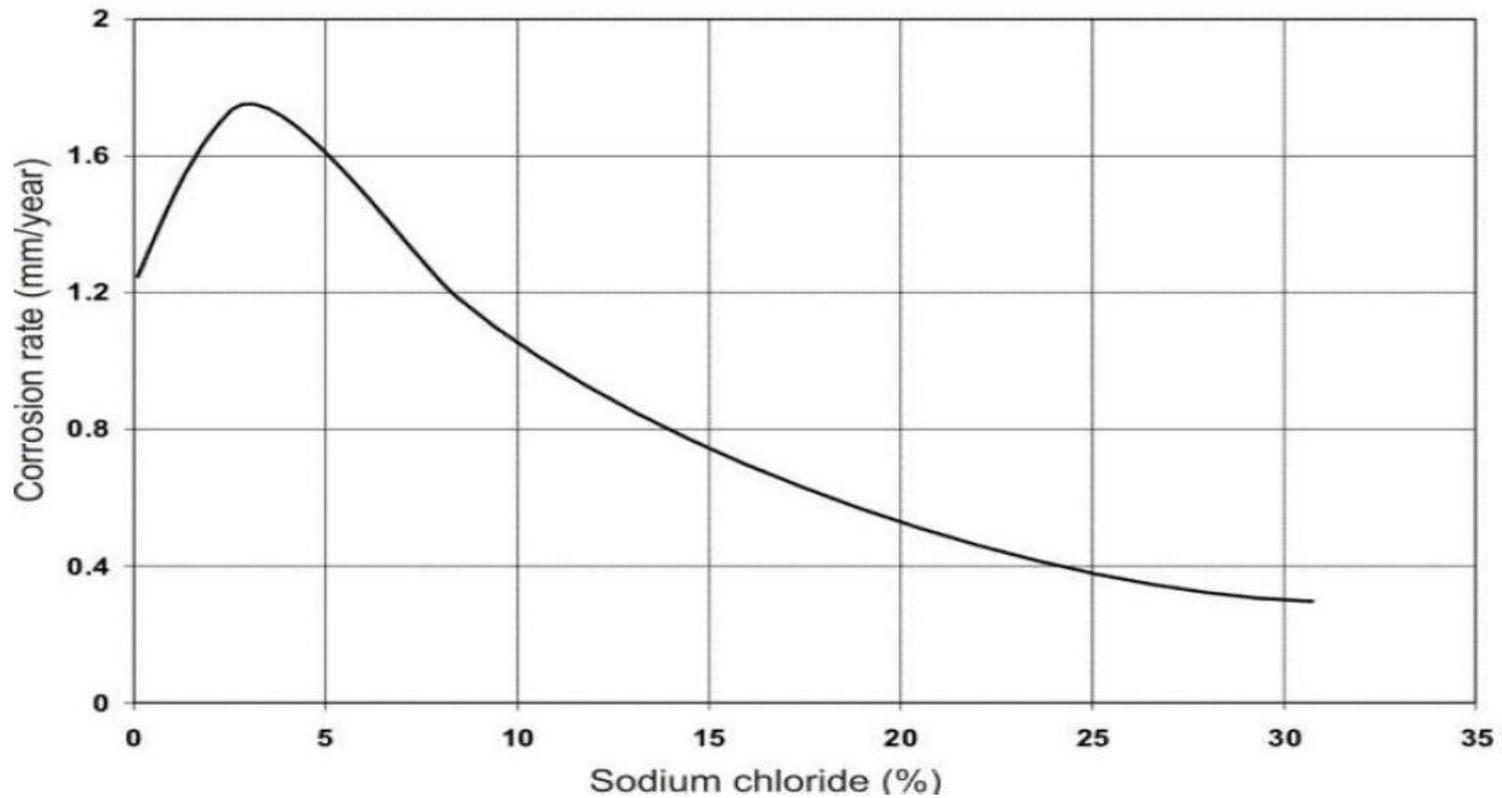
## KEY FACTORS AFFECTING CORROSION OF IRON IN WATERS:

### Temperature

The effect of temperature on iron corrosion is often overlooked. Many parameters that influence corrosion can vary with temperature: dissolved oxygen (DO) solubility, solution properties (e.g. viscosity and ion mobility), ferrous iron oxidation rate, thermodynamic properties of iron scale (leading to formation of different phases or compounds), and biological activity. Moreover, heterogeneous iron scale formed on pipes may have large differences in physical properties such as scale density and coefficients of thermal expansion. If the scale is exposed to temperature gradients or cycling, these differences can cause mechanical stresses in the scale, leading to spalling or crack formation.

Only a few studies have examined the role of different temperatures in distribution system corrosion. In one study, weight loss decreased for iron samples held at 13°C versus 20°C. Other studies found lower iron concentrations and fewer customer complaints of red water during the colder winter months. Finally, two pilot scale studies saw peaks in turbidity and metal concentrations that appeared to correlate with temperature changes.

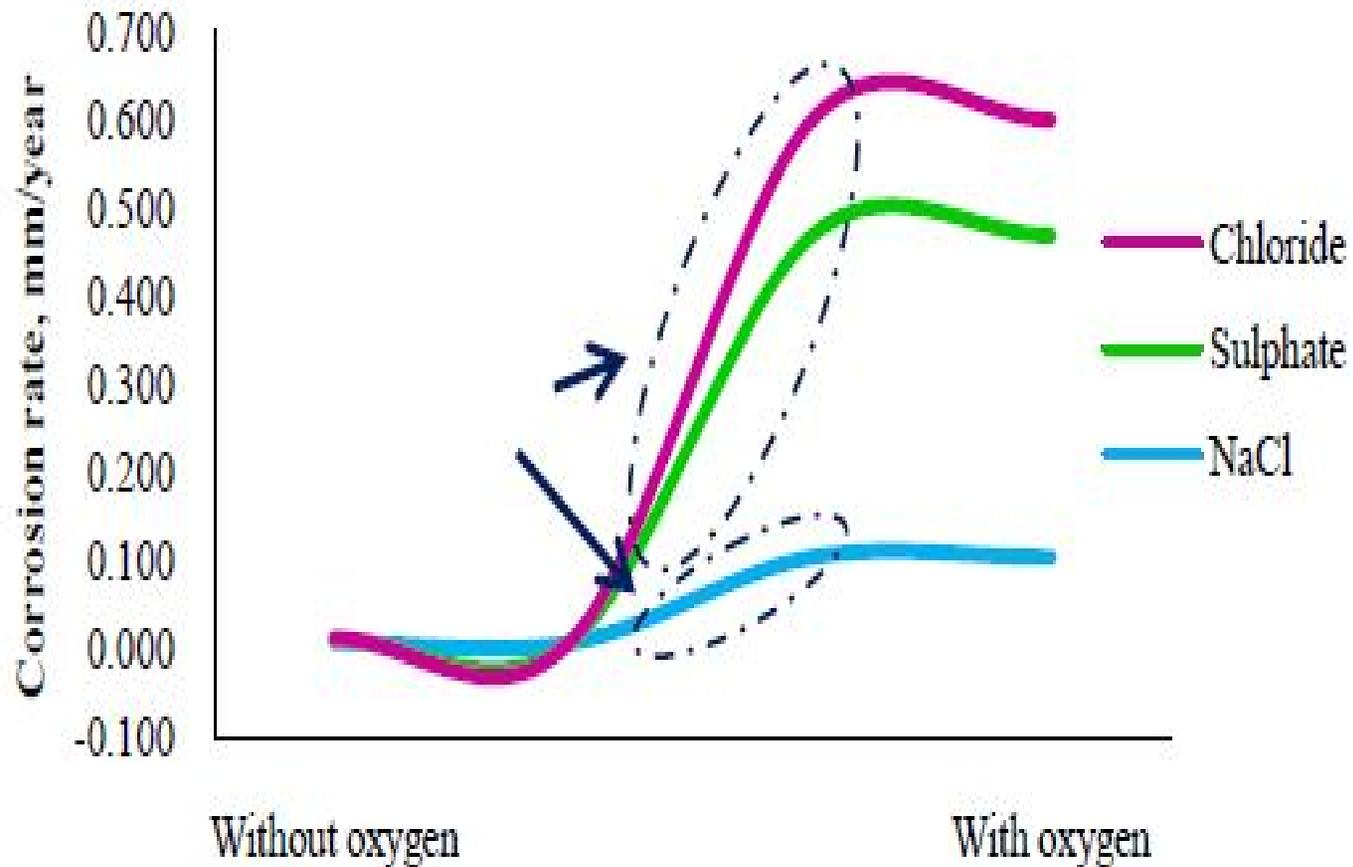
## Effect of Chloride on Corrosion of MS



Corrosion of steel in various sodium chloride solutions. Note the peak in corrosion rate at approximately 3% salt.

**Effect of concentration of chloride on Corrosion rate of Carbon Steel**

# Effect of Chloride and Sulphate on Steel Corrosion



**Critical Corrosion of Steel**

# Corrosivity of Steel in Service Water

SNo	Parameter	Unit	Seawater		1 <sup>st</sup> Stage RO Permeate		2 <sup>nd</sup> Stage RO Water	Raw Water (fresh)	RO Water
1	pH		8.0	8.03	6.6	6.92	6	8	6.35
2	Conductivity	µmhos/cm	57400	56800	1000	940	25	464	13.2
3	Total hardness	ppm as CaCO <sub>3</sub>	6500	7502	12	22	8	162	2
4	CaH	ppm as CaCO <sub>3</sub>	1100	1146	6	3	4	100	1
5	MgH	ppm as CaCO <sub>3</sub>	5400	6356	6	19	4	62	1
6	P alk.	ppm as CaCO <sub>3</sub>	0	0	0	0	0	0	0
7	M alk.	ppm as CaCO <sub>3</sub>	120	130	6	8	4	165	5
8	Chloride	ppm as Cl	22000	21300	360	306	30	41	1.8
9	Turbidity	NTU	450	17.20	0.1	0.50	0.1	0.24	0.1
10	SiO <sub>2</sub>	ppm as SiO <sub>2</sub>	0.235		0.01			12.2	0.544
11	Sulphate	ppm as SO <sub>4</sub>	3248	3164	50	6	6	0	0.1
12	Iron	ppm as Fe	0.02	1.1	0.01	0.003		0.02	0.001
13	RSI		5.20	5.16	13.44	13.49	14.46	6.68	15.36
14	LSI		1.42	1.44	(-) 3.44	(-) 3.28	(-) 4.23	0.66	(-) 4.36
15	<b>Larsen Skold Index</b>		<b>516.01</b>	<b>480.50</b>	<b>170.67</b>	<b>61.35</b>	<b>17.4</b>	<b>1.75</b>	<b>0.712</b>

# Corrosivity of Steel in Service Water

## Larsen Skold Index:

$$\text{Larson-Skold index} = (\text{epm Cl}^- + \text{epm SO}_4^{2-}) / (\text{epm HCO}_3^- + \text{epm CO}_3^{2-})$$

Index  $\ll$  0.8 chlorides and sulfate probably will not interfere with natural film formation.

0.8  $\ll$  index  $\ll$  1.2 chlorides and sulfates may interfere with natural film formation. Higher than desired corrosion rates might be anticipated.

Index  $\gg$  1.2 the tendency towards high corrosion rates of a local type should be expected as the index increases.

## Effect of different water chemistry parameters on iron corrosion

Parameters	Iron released to water		Iron corrosion rate (weight loss)	
	O <sub>2</sub> -saturated	low O <sub>2</sub>	O <sub>2</sub> -saturated	low O <sub>2</sub>
NOM	↑	---	---	---
Ca <sup>2+</sup>	Short term ↑, long term ↓	---	↑	---
Phosphate	Short term ↑, long term ↓	---	↓	---
Mg <sup>2+</sup>	↓	↓	---	Slightly ↓
Zn <sup>2+</sup>	↓	↓	↓	↓
Free Cl <sub>2</sub>	↓	↓	↓	---
Chloramines	Short term ---, long term ↓	↓	---	---

Note: ↑: increase, ↓: decrease, --- no significant effect

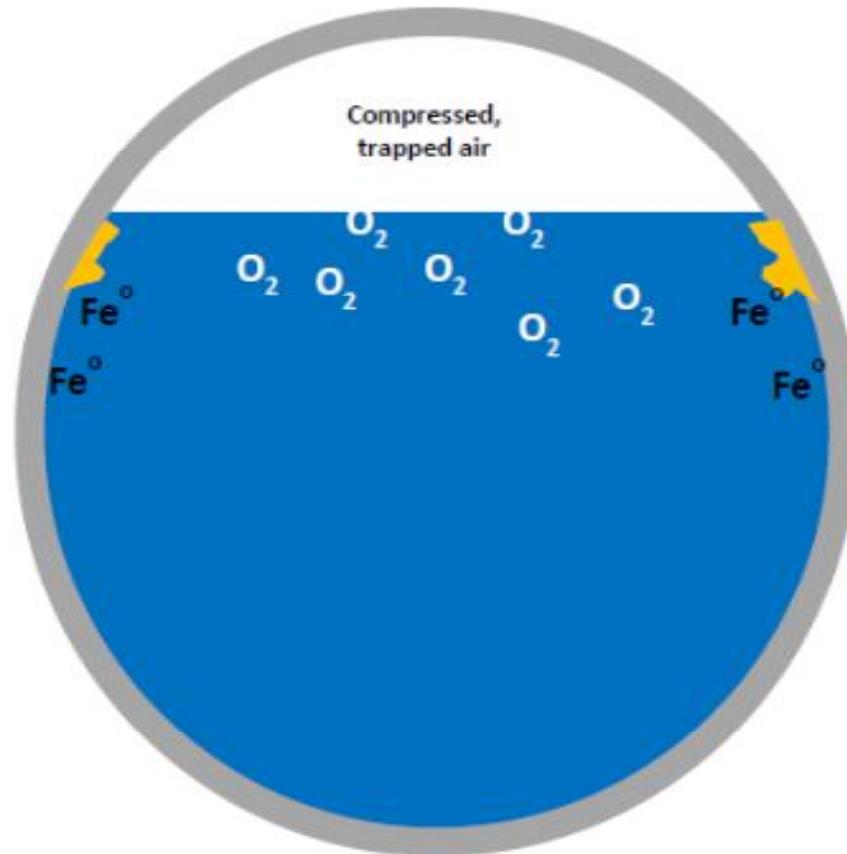
## Effect of Different Variables on Erosion-Corrosion

<b>EROSION-CORROSION</b>	
<b><u>Variable:</u></b>	<b><u>Increase if Variable Is:</u></b>
Fluid velocity	Higher
Fluid pH level	Lower
Fluid oxygen content	Lower
Fluid temperature	250-400°F
Component geometry	Such as to create much more turbulence
Component chromium content	Lower
Component copper content	Lower
Component molybdenum content	Lower

## Effect of different water chemistry parameters on iron corrosion

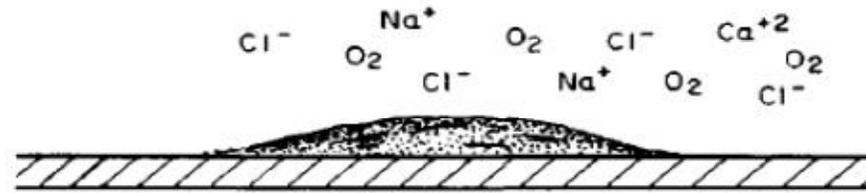
Chemical control usually must be considered as a supplement to proper choice of materials and protective coatings, not as a substitute. Chemical control cannot be expected to over-come improper flow conditions, poorly designed distribution systems, defective materials, grossly faulty coatings, and under-design of copper pipe.

## Effect of Trapped Air Pocket

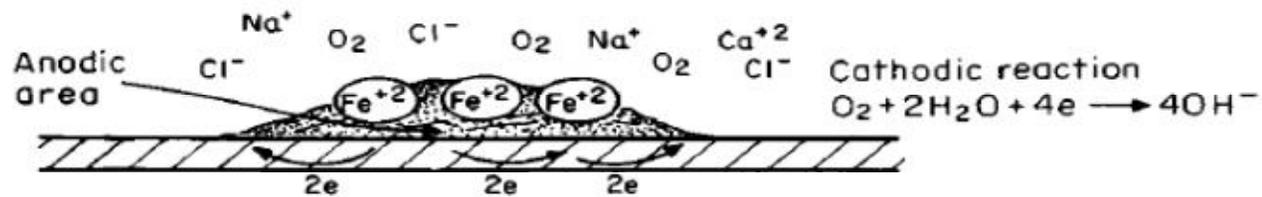


**Corrosion Reaction at the Trapped Air Pocket**

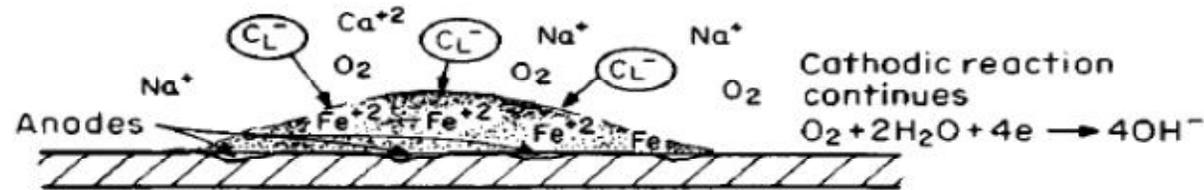
# Corrosion of Steel by Dissolved Oxygen



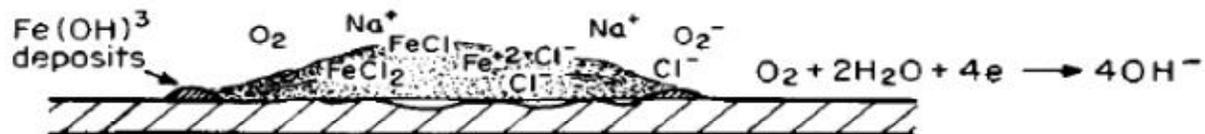
(a) Debris settles on metal surface



(b) Oxygen can reach metal only at open surface.



c) Oxygen continues to depolarize the cathodic area while chloride diffuses into the porous deposit.



d) The iron within the deposit remains soluble as  $Fe^{+2}$  in the absence of  $O_2$ ; and corrosion increases as ionic strength in the deposit increases.

# Microbiologically Influenced Corrosion (MIC)

## TUBERCLES

Tuberculation refers to the formation of a corrosion product and deposit mound above a corroded area, usually on a steel or cast iron surface. Figure shows a heavily tuberculated supply line from a steel mill. Beneath each tubercle, a depression is present. (See Figure) These structures form a friable outer crust of brown ferric oxide and other deposited material, as shown in Figure Just beneath, a hard, black, brittle crust of magnetite-rich oxide forms.

Some investigators feel that the magnetite shell is a good electrical conductor and, hence, is cathodic in an active tubercle. The hydroxyl ion generated at the top of the shell aids in the precipitation of carbonate and other species exhibiting decreasing solubility with increasing pH.

As ferrous ion generated within diffuses out of the tubercle, ferric hydroxide is also generated and deposited on top of the shell. Certain iron-oxidizing bacteria also assist in the iron deposition process. Tubercles formed under flowing conditions may be elongated in the direction of flow and show sharply sculptured contours. Under more quiescent conditions, tubercles are rounded mounds. Beneath the shell, ferrous ions are always generated; other compounds such as siderite can form.

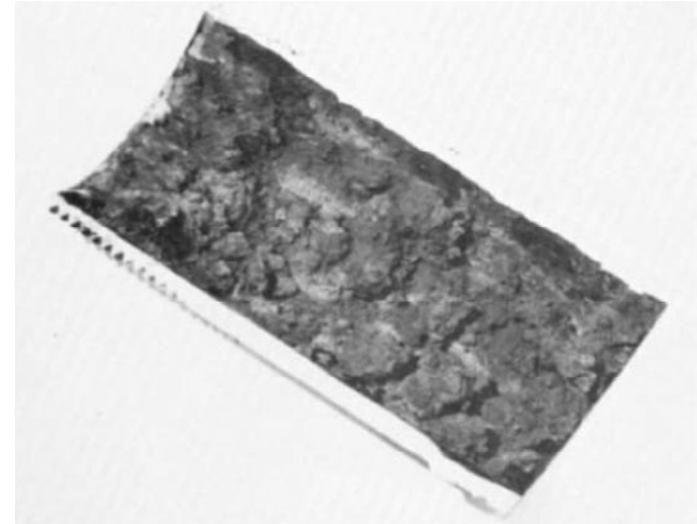
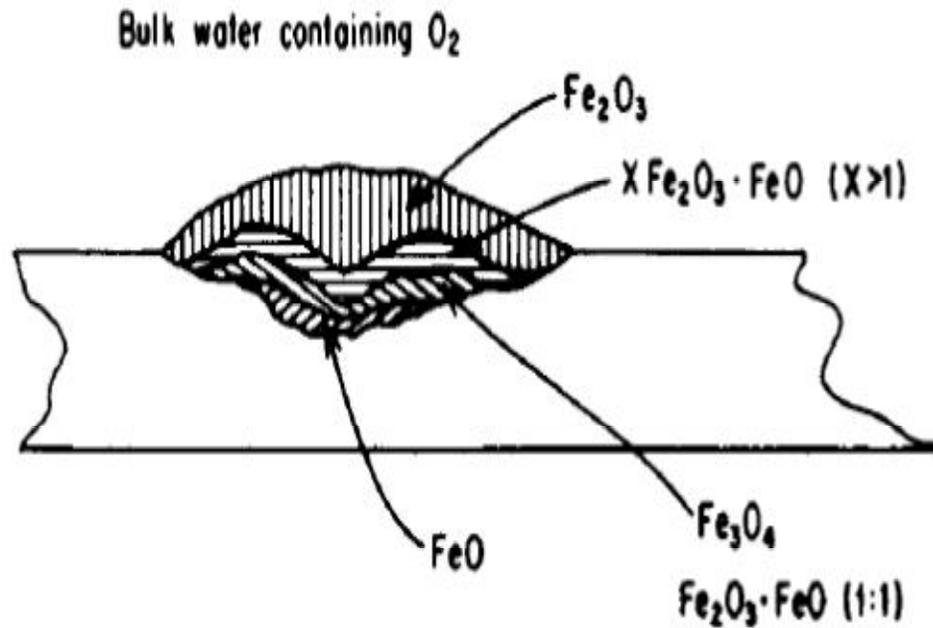
# Microbiologically Influenced Corrosion (MIC)

## TUBERCLES

Chloride and sulfate migrate into the tubercle, lowering pH. The internal environment is usually acidic regardless of the pH of the bulk water. If pH falls below about 4, hydrogen evolution begins, providing a secondary cathodic reaction and thus, accelerating attack. Many incipient tubercles are shown in Figure. When the brittle oxide caps are removed, small pit-like depressions are revealed. In early stages of formation, tubercles can show concentric growth rings, as in Figure. Many tubercles contain hollow chambers. The metal surface usually has an undulating-to-smooth contour beneath a tubercle. Evidence of low pH conditions is often present. Striated surfaces result from preferential attack along microstructural irregularities formed during steel manufacture. As the tubercles increase in size, the rate of ingress of chloride and sulfate can decrease, ultimately reducing corrosion rates. Anions such as oxygen also find the tubercle less permeable, and oxygen concentrations decrease.

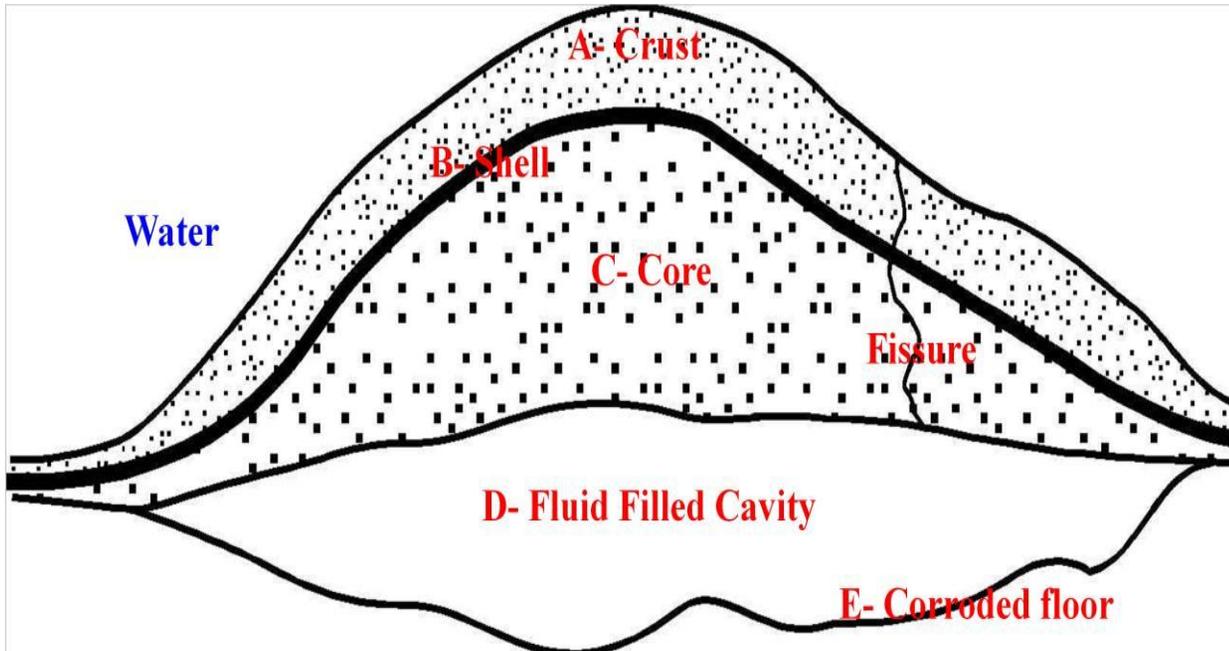
If oxygen concentration falls to sufficiently low levels, anaerobic microbiological activity may occur.

# Tuberclation



Formation of tubercle

# Tuberclation



Schematic drawing illustrating five common structural features of non-MIC tubercles

# Biofouling/MIC

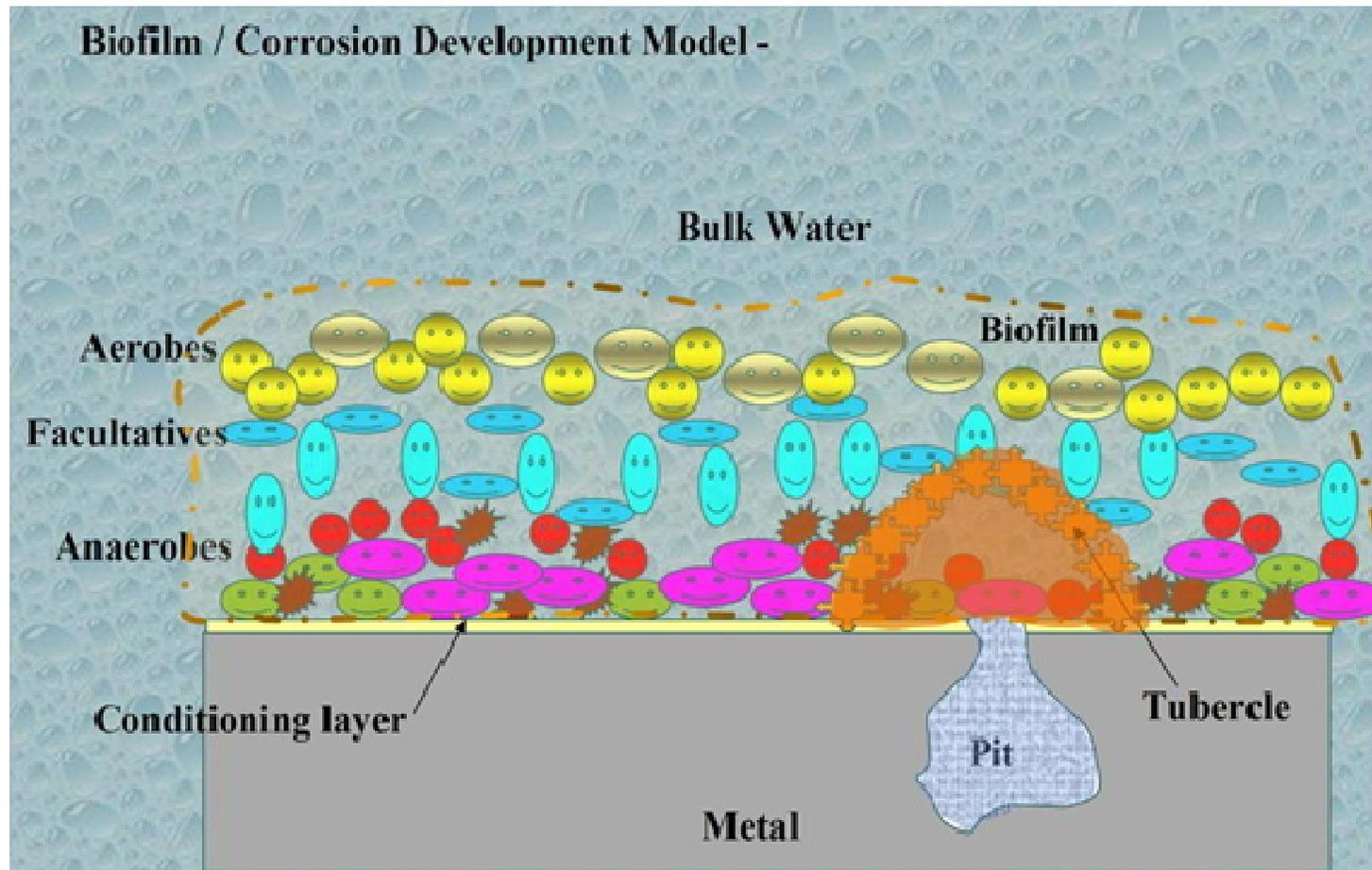
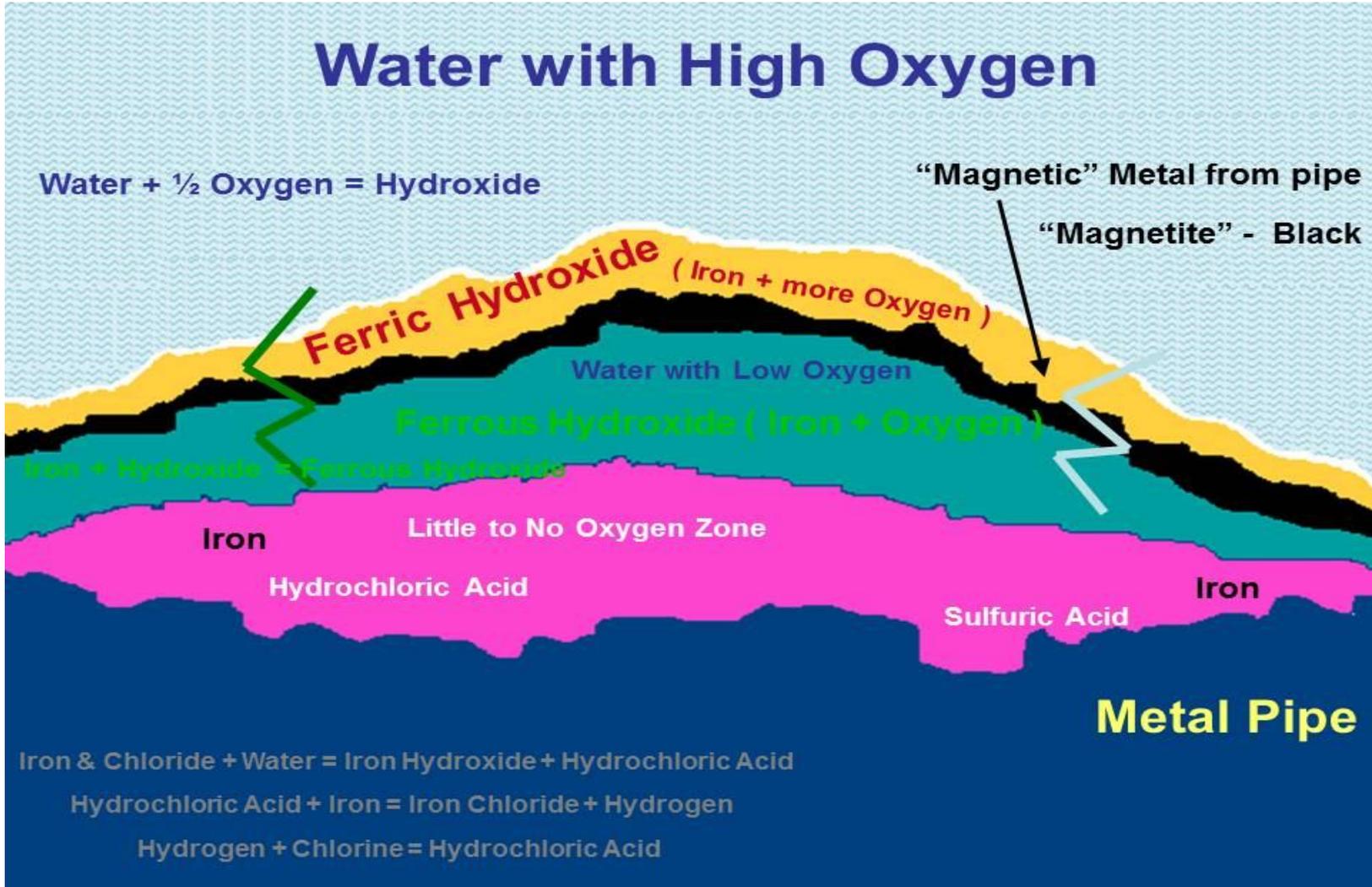


Illustration of the biofilm/microbiologically influenced corrosion development model.

# Microbiologically Influenced Corrosion (MIC)



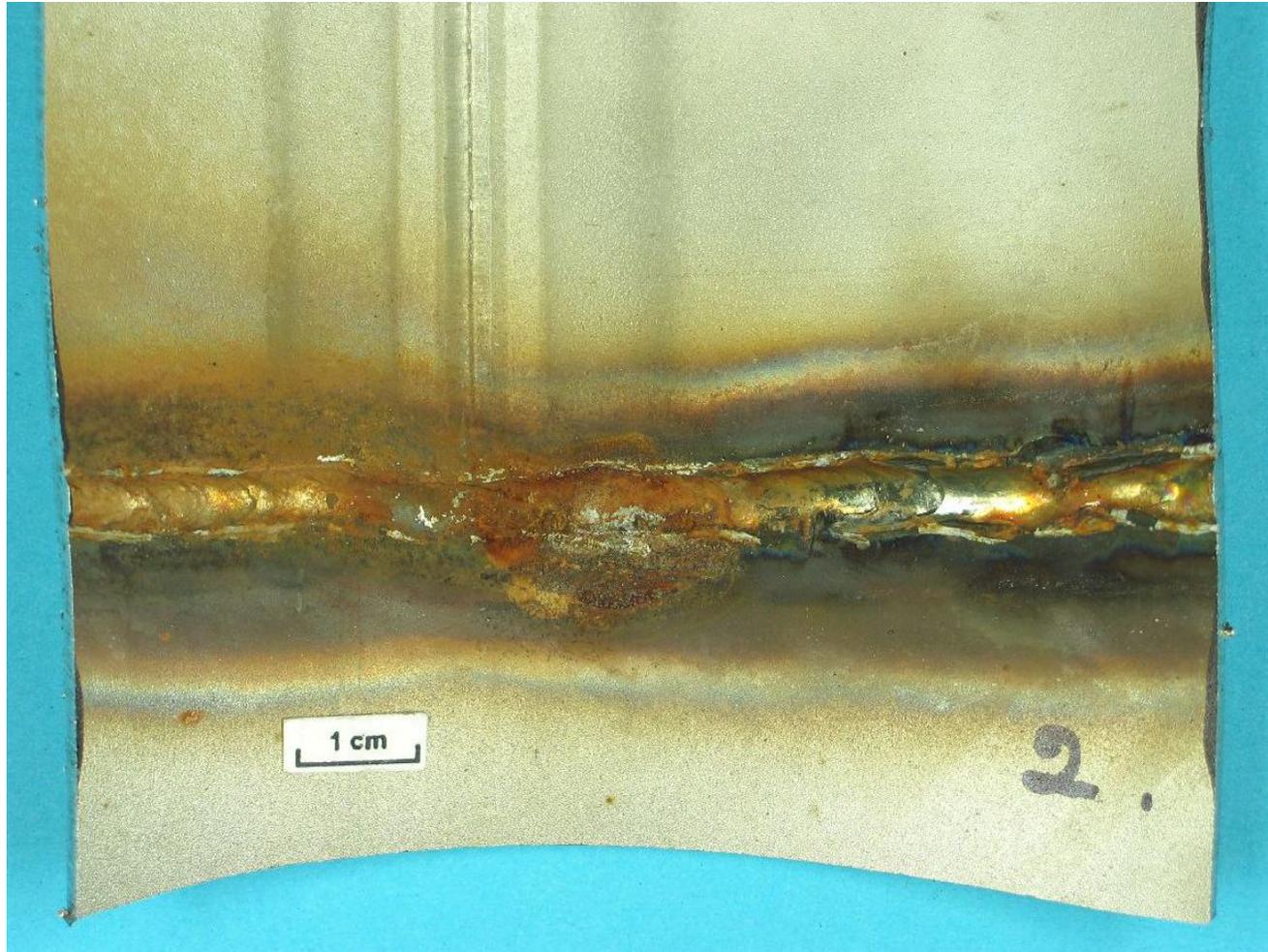
# Microbiologically Influenced Corrosion (MIC)

## MIC at Welds



# Microbiologically Influenced Corrosion (MIC)

## MIC at Welds



# Corrosion and Fouling Issues in Water Systems

## Summary of Causes of Corrosion, Fouling, Deposition and Biofouling in Water Distribution Systems:

- Design Limitations – Limited Recirculation, Limited Draining, Limited Flushing, Limited Air Relief systems, sudden changes in Pipe geometry, Improper Pipe Supports, etc.
- Improper material selection, Use of un-annealed welded pipes, Galvanic Coupling, Uncoated Pipes and other components, .
- Poor Cleaning and Passivation practices of newly installed systems.
- Poor Lay-up practices.
- Low Flow, Stagnant Water, Dead Legs, Temperature variations, etc
- Improper Water Treatment and Monitoring, Poor provision of cleaning of makeup water tanks, etc
- Continuous makeup of water to the systems adding dissolved oxygen, silt, dust, microbes, etc resulting in Corrosion, Fouling, Deposition and Biofouling/Microbiologically Induced Corrosion.
- Improper maintenance practices (patch welding, putting nails/wooden blocks in leaks), Poor painting practices, Poor Flushing Schedules, etc

## Control Measures – Internal Water Side

A treatment program to control corrosion and fouling may involve not only chemical treatment, but also other operational procedures such as maintenance cleaning, routine flushing, makeup water pretreatment, and in some cases, system design modifications.

System design can be a major limitation in developing an effective control program. A thorough understanding of the system flow is necessary to determine how critical areas can be flushed/cleaned and how chemically treated makeup water can reach the critical areas.

The use of potable water, when available, is desired because it usually denotes that any required pretreatment has been done. When potable water sources are not available for FPS makeup, separate pretreatment of the raw water at the source may be justified as a means for preventing corrosion and fouling. Pretreatment may include clarification, hardness reduction, pH adjustment, and biocide addition.

Summary of control measures suggested are given below:

## Control Measures – Internal Water Side

- Attempts shall be made to reduce the makeup to the fire water system as far as possible.
- Provision of Air Relief valves, pressure gauges, drain points/flushing arrangement at suitable locations in all water distribution systems.
- Replace all Service Water, Clarified Water, CW/ACW Pipes, Raw Water, SWRO 1<sup>st</sup> Stage Permeate water, etc pipes by non-metallic pipes such as CPVC, HDPE, GRP/FRP (if required in phased manner).
- For Fire Water Systems Internally Coated Pipes may be used (as permitted by NFPA 13) and the pipes may be laid over-ground. Galvanic coupling should be avoided or if necessary metals with close potentials may only be used.
- A suitable chemical treatment program including dosing of biocide may be developed for metallic pipes including installation of suitable monitoring equipment (at least for critical heat exchangers).
- If the system is fouled with tuberculation/silt/deposition same shall be removed/cleaned by appropriate mechanical/chemical means.
- A schedule of recirculation/flushing/Draining of treated water from all possible sources shall be adopted.

## Control Measures – Internal Water Side

- During shut down of units it shall be ensured that every-alternate day circulation of water in the system is carried out.
- During every opportunity the heat exchangers should be inspected and if required mechanical/chemical cleaning should be adopted so as to ensure that systems are kept clean and treatment chemicals reach all the area.
- All large diameter pipes and pumps/valves shall be protected on internal side by suitable coating and supplemented by cathodic protection especially for seawater and brackish water systems.
- Suitable isolation shall be adopted for preventing galvanic corrosion.
- In case of leaks, patch welded repairs to be avoided instead readymade clamps can be used for repairing the leaks and as and when opportunity arises pipe length can be replaced.
- Seam welding shall be if possible annealed and position of seam weld shall not be at 6 o'clock position

## Corrosion Control Measures – External Surfaces

Application of suitably selected Coatings and Cathodic Protection for Buried Pipelines.

Application of Coatings as per ISO 12944 C4, C5 I/M and as per NORSOK M501 System 7 for areas susceptible to cooling tower drifts to control Atmospheric Corrosion.

Modified Pipe Support to avoid Corrosion between pipe-support and pipes.

Covering critical flanges of pipes/pumps with Petro-lactum tapes as per NACE Standard.



# Control Measures



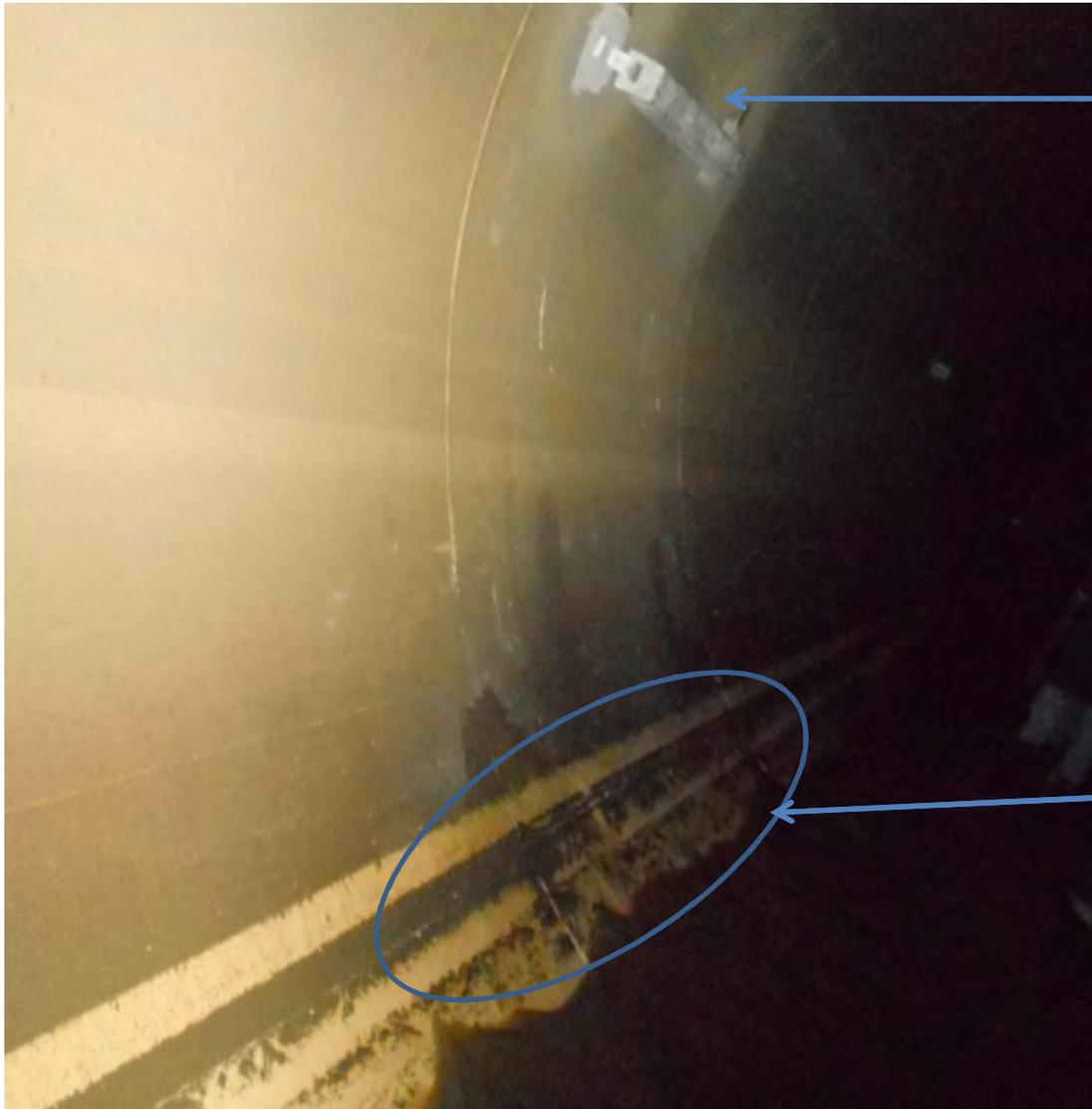
**Replacement of Steel Service Water Pipes with CPVC Pipes**

# Control Measures



**Internally coated fire water pipelines**

# Control Measures



Anode Installed

Severely corroded

**Cathodic Protection of CW Duct**

# Corrosion of ACW Pipelines



**Coated ACW Valves**

## Corrosion of ACW Pipelines



**Al based anodes for fixing in ACW Pipes**

# Oxygen Removal

## Removing Trapped Oxygen

Air Vents automatically vent the trapped air in the wet fire sprinkler/water systems. This eliminates the corrosion oxygen trapped in the line.



**Air Vent**

# Nitrogen Purging

Nitrogen generators provide on-site reliable nitrogen production (can be used for small systems)



# Control Measures



**Repair Clamps and tapes**

# Conserve Resources



**Thank You**

## Effect of different water chemistry parameters on iron corrosion

### Types of Corrosion:

**Uniform corrosion** is recognized as taking place at a generally equal rate over the surface. The loss in weight is directly proportional to the time of exposure and the rate of corrosion is constant. ***This type of corrosion is usually associated with acids or with water having a very low pH and very few protective properties.*** Mild steel in neutral, low-calcium, and low-alkalinity salt water corrodes at a rather uniform rate.

**Pitting corrosion** is non-uniform and more generally observed than uniform corrosion. It occurs in an environment which offers some but not complete protection. The pit develops at a localized anodic point on the surface and continues by virtue of a large cathodic area surrounding the anode. Chloride ions are particularly notorious for their association with this type of corrosion of steel. Even stainless steel is subject to pitting corrosion with relatively high chloride solutions. Pits may be sharp and deep or shallow and broad, and can occur without chlorides. In water containing dissolved oxygen, the oxide corrosion products deposit over the site of the pitting action and form tubercles.

# Effect of different water chemistry parameters on iron corrosion

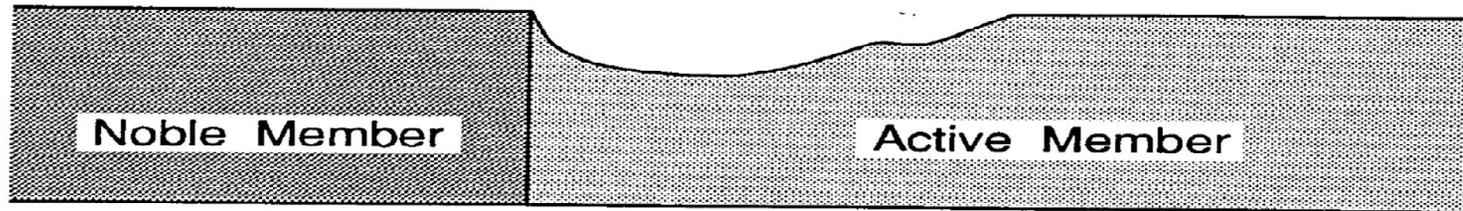
## Types of Corrosion:

Pitting corrosion may also be associated with galvanic corrosion, concentration-cell corrosion, and crevice corrosion, particularly during low flow or stagnant conditions.

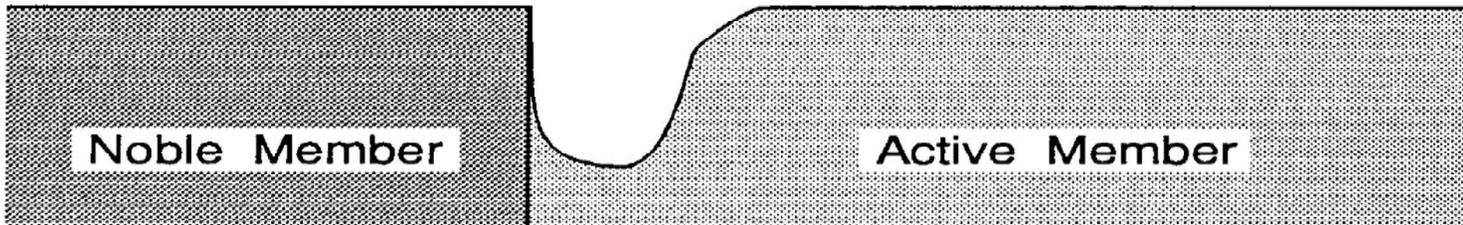
**Galvanic corrosion** is associated with the contact of two different metals or alloys in the same environment. The rate of galvanic corrosion is increased by greater differences in potential between the two metals. It is increased by large areas of cathode relative to the area of the anode. It is generally increased by closeness of the two metals and also by increased mineralization or conductivity of the water.

**Concentration-cell corrosion** is perhaps the most prevalent type of corrosion, and because it is difficult to ascertain by field measurement, it is usually deduced by inference. This type of corrosion occurs when there are differences in the total or the type of mineralization of the environment. Differences in acidity (pH), metal-ion concentration, anion concentration, or dissolved oxygen cause differences in the solution potential of the same

# Effect of different water chemistry parameters on iron corrosion



Galvanic Effect/High Conductivity Waters



Galvanic Effect/Low Conductivity Waters

## Effect of different water chemistry parameters on iron corrosion

### Types of Corrosion:

metal. Differences in temperature can also induce differences in the solution potential of the same metal.

Oxygen concentration cells develop at water surfaces exposed to air, accelerating corrosion a short distance below the surface. The dissolved oxygen concentration is replaced by diffusion from air and remains high at and near the surface, but does not replenish as rapidly at lower depths because of the distance for diffusion. Therefore, the corrosion takes place at a level slightly *below* the surface rather than at the surface.

Dirt and debris or local chemical precipitates on a metal surface hinder oxygen diffusion by covering the metal at local areas. Thus, corrosion takes place under the deposit.

Thus it is evident that any nonadherent deposition on metal can start a chain of circumstances which result in an oxygen concentration cell.

## Effect of different water chemistry parameters on iron corrosion

### Types of Corrosion:

**Crevice corrosion** might be classed as a form of concentration-cell corrosion because when oxygen is spent on corrosion in a crevice, it is difficult for more oxygen to reach the metal by diffusion into the depths of the crevice. The crack, crevice, or uneven joint between two surfaces of the same metal bound together face to face behaves as a pit where oxygen can reach the exposed surface but becomes deficient in the crevice, thus forming an oxygen concentration cell where corrosion takes place.

**Dezincification** is the result of removal of zinc from its alloy with copper (brass). Copper remains at the surface of the brass as the zinc is dissolved. Soft unstable waters, especially those with a high CO<sub>2</sub> content, are particularly aggressive to Muntz metal and yellow brass.

**Graphitization** is a form of corrosion of cast iron in highly mineralized water or waters with a low pH, which results in the removal of the iron silicon metal alloy making up one of the phases of the cast iron microstructure.

## Effect of different water chemistry parameters on iron corrosion

### Types of Corrosion:

**Stress corrosion** results from tensile stress, usually of external origin, on the metal or alloy. The corrosion usually (but not always) takes place selectively at the microstructure grain boundaries in the metal. Repeated rupture of a protective film on the surface provides a continuously anodic region.

**Corrosion fatigue** resulting from alternate stress conditions is usually more rapid than steady-state stress corrosion. The alternation of the stress disturbs such protective film as may develop at the anode site and enhances the rate of corrosion.

**Erosion corrosion** results from the removal of the protective film of corrosion products which serves as a barrier to corrosive attack of some metals. The erosion, generally at high velocity, may take place through removal of the film by abrasive, suspended material. Friction between two adjoining surfaces may also permit corrosion to continue.

## Effect of different water chemistry parameters on iron corrosion

### Types of Corrosion:

***Cavitation corrosion*** is usually associated with high velocity and sudden changes in velocity direction which causes gas-bubble formation at low pressure points and resolution of the gases at high pressure points. ***The attack occurs downstream from the direction change caused by a constriction such as a valve or protrusion at a joint.*** Carbon dioxide in the gas bubbles develops an acidic film at the water surface. ***If oxygen is present, its concentration at the water surface is also greater than in the body of the water and further accelerates corrosion.***

# EPRI Guidelines for Cooling Waters

Water Quality		EPRI Guidelines	Remarks
Parameter	Units		
Ca	Mg/l CaCO <sub>3</sub>	900 (max)	
Ca X SO <sub>4</sub>	(Mg/l) <sup>2</sup>	500000	
M Alkalinity	Mg/l CaCO <sub>3</sub>	30 – 50 220 - 250	Without Inhibitor With Inhibitor Scale Scale
Mg X SiO <sub>2</sub>	Mg/l CaCO <sub>3</sub> X Mg/l SiO <sub>2</sub>	35000	
SO <sub>4</sub>	Mg/l		
SiO <sub>2</sub>	Mg/l	150	
PO <sub>4</sub>	Mg/l		
Fe (Total)	Mg/l	< 0.5	
Mn	Mg/l	< 0.5	

Cu	Mg/l	< 0.1	
Al	Mg/l	< 1	
S	Mg/l	5	< 0.25 ppm for Copper Alloys
NH <sub>3</sub>	Mg/l	< 2	For copper based alloys present in the system
pH		6.0 – 7.2 7.8 – 8.4	Without Inhibitor With Scale Inhibitor (Higher operating pH is possible with new alkaline treatments)
TDS	Mg/l	70000	
TSS	Mg/l	< 100 < 300	For Film type Fill Splash type Fill
BOD	Mg/l		
COD	Mg/l		
LSI		< 0	
RSI		> 6	
PSI		> 6	

Desirable: BOD < 5 ppm, Turbidity < 2 NTU, Sulphide < 0.1 ppm (for Cu based systems), Chloride < 200 ppm for SS 304 (upto 500 ppm short duration & < 500 ppm for SS 316 (3000 ppm short duration))

# Microbiological Parameters for Cooling Waters

PARAMETERS	LIMITS	UNIT	PROTOCOL
Total Bacterial Count	<1 x10 <sup>4</sup> * <2 x10 <sup>3</sup> **	CFU/mL	Standard Method for Examination of water and waste water 20 <sup>th</sup> Edition, Part 9215-B  IS 5402 (latest edition)
Total Fungal Count	<10	CFU/ mL	Standard Method for Examination of water and waste water 20 <sup>th</sup> Edition, Part 9610-B  IS 5403 (latest edition)
Sulphate Reducing Bacteria	<100	MPN/ 100 mL	ASTM Standard, 1990. D 4412 - 84 (latest edition)
Sulfur Oxidising Bacteria: a.Thiobacillus thiooxidans b.Thiobacillus thiooparus	<2	“	Standard Method for Examination of water and waste water 20 <sup>th</sup> Edition, Part 9240-D  IS 1622 (CL 3.8) Latest edition
Acid Producing Bacteria	<100	“	NACE Standard TM0194-194
Gas Producing Bacteria	<100	“	NACE Standard TM0194-194
Nitrifying Bacteria	Not desirable	“	Microbiology of Cooling Water, James W Mccoy
Ammonia Producers	N.S.	“	Microbiological Methods-Collins and Lyne's, 7 <sup>th</sup> Edition
Slime Formers: a.Pseudomonas aeruginosa b.Enterococcus Sp.	N.S.	“	Standard Method for Examination of water and waste water 20 <sup>th</sup> Edition, Part 9213-F  IS 13428 (Annexure 1 CL 6.1.5)
Iron Bacteria	<2	P/A	Standard Method for Examination of water and waste water 20 <sup>th</sup> Edition, Part 9240-B  IS 1622 (CL 3.6)
Manganese Bacteria	<2	P/A	Standard Method for Examination of water and waste water 20 <sup>th</sup> Edition, Part 9240-D

## Acceptable Performance Criteria for Cooling Water Systems

1. Cumulative corrosion rate of Mild Steel: < 2.0 mpy with no pitting.
2. General corrosion rate of Stainless Steel: < 0.10 mpy. (No visible sign of localized corrosion should be on SS tubes).
3. Corrosion rate of Cu-Ni: < 0.10 mpy with no pitting.
4. Scale deposition rate: <15 mg/dm<sup>2</sup>/year.
5. Total Viable Count (TVC): Not to exceed 10000 counts/ml in cooling water. Complete Microbiological analysis – once in 3 months.
6. Sulphate Reducing Bacteria (SRB): Not to exceed 100 organisms/100 ml in cooling water.
7. Heat Transfer not to vary more than 5 % from the time of starting the treatment program
8. The system should be free from deposits & fouling.
9. The system should be free from Algae & Fungi growth on towers, basins, sumps etc.
10. Scaling: Hard scales should not be there only scaling in traces & loose in nature, which can be cleaned by water jet on deposit monitor, can be there.
11. Magnesium Cycle - To be consistent with cycle of concentration.
12. Silica Cycle - To be more than or equal to Magnesium cycle.