Reinhold Environmental Ltd.

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Corrosion Issues in Scrubbers

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2007 APC/PCUG Conference

Workshop Outline

- Basics of Corrosion
- Corrosion History of Scrubbers
- Guidelines for Scrubbers
- Material Selection:
  - Alloys
  - FRP
  - Other materials

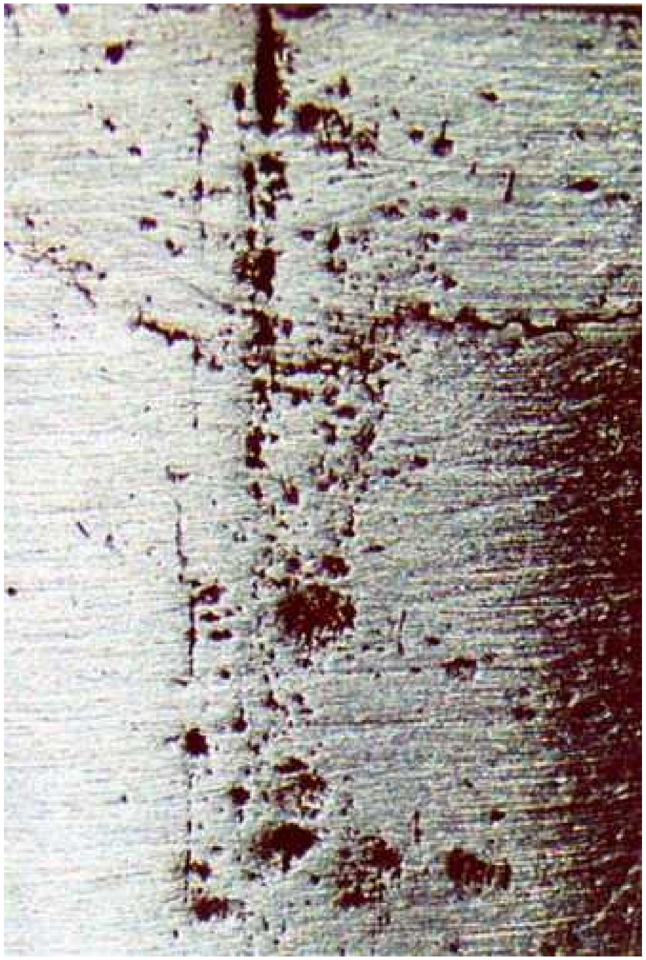
Corrosion Basics

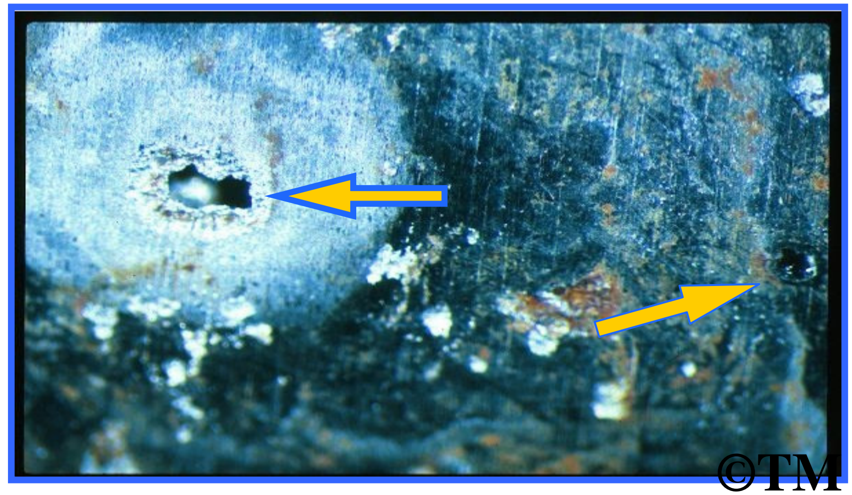
- Definition – Corrosion is defined as a dissolution of a material due to reaction with the surrounding environment
- Almost anything can corrode:
  - Glass
  - Plastics
  - Ceramics
  - Steels and steel alloys
  - Other Metals

8 Forms of Corrosion

- General corrosion
- Galvanic corrosion
- Intergranular corrosion
- *Pitting & crevice*
- *Stress corrosion cracking*
- Erosion corrosion
- Selective leaching

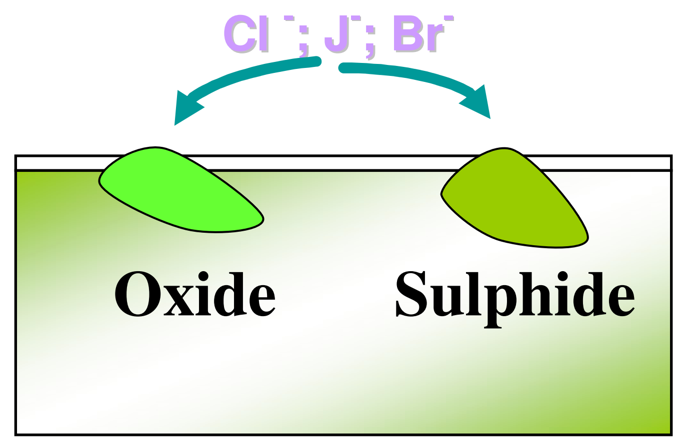
Examples of Pitting Corrosion



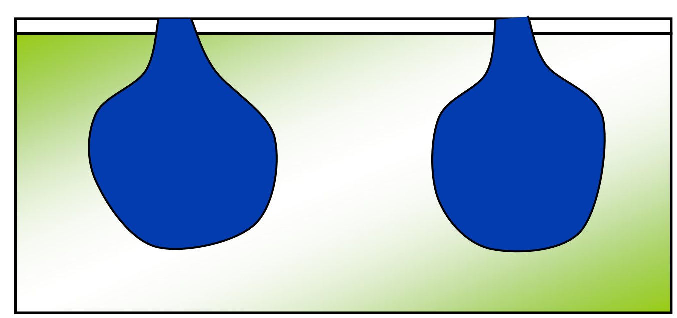


Basic Mechanism for Pitting

- Occurs in metals that require presence of passive film for corrosion protection
- Requires simultaneous presence of oxidizing agent and chloride ion
- Occurs at location of damage (scratches), embedded iron or sulphide inclusion



Damage Appearance



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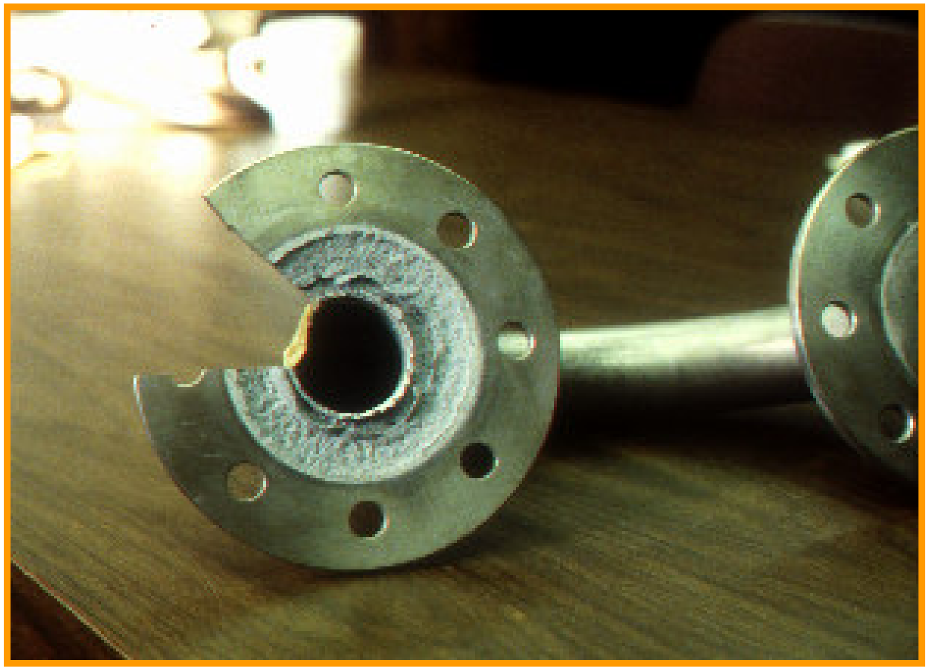
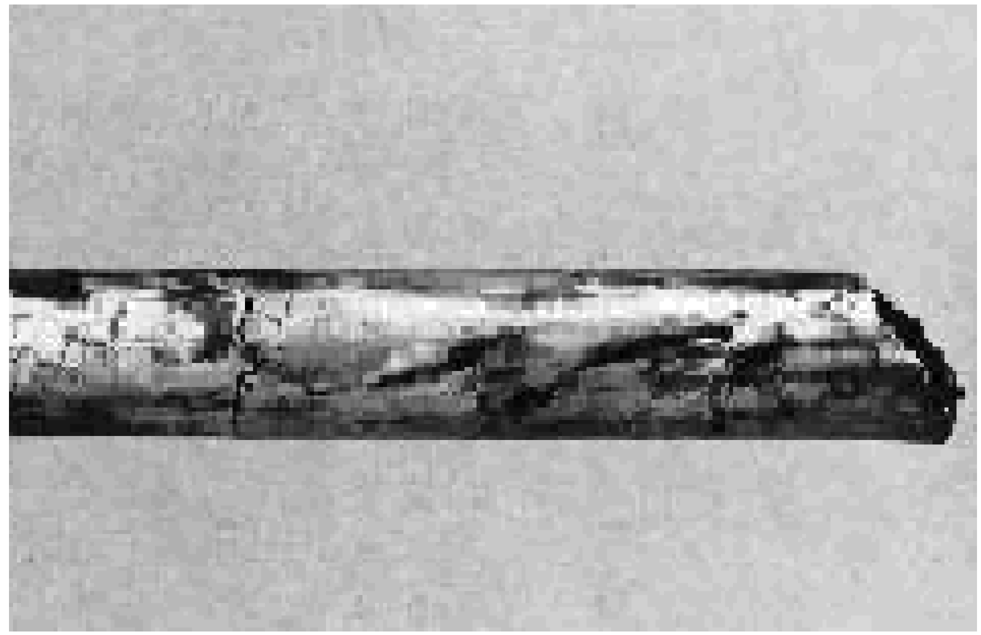
Crevice Corrosion



Mechanism for Crevice Corrosion

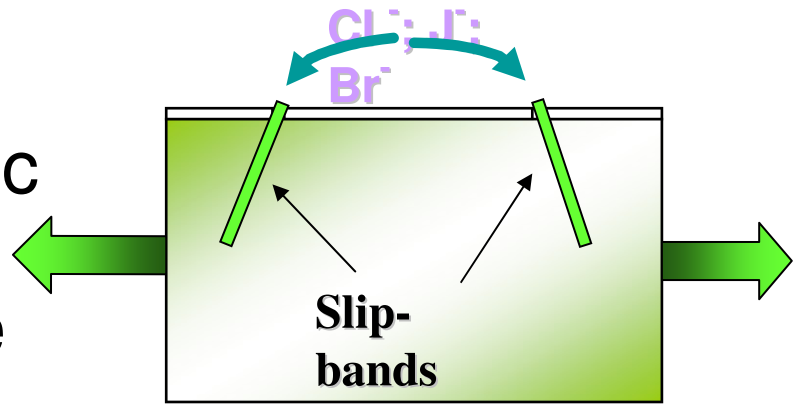
- Result of formation of an oxygen concentration cell on the surface of an otherwise passive metal (e.g., SS)
- Crevice can be created by metal-to-metal contact (e.g., bolt head), or nonmetal-to-metal contact (e.g., gasket)
- The tighter the crevice the more severe the corrosion

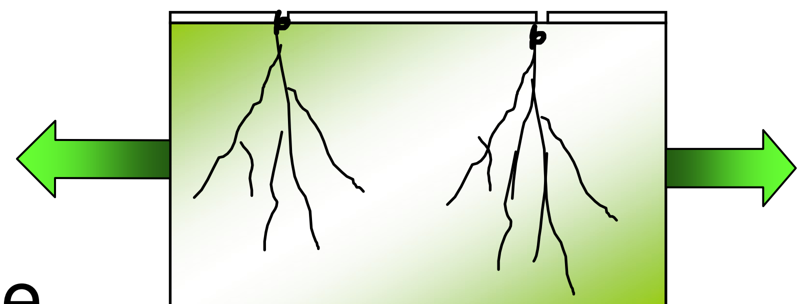
Stress Corrosion Cracking



Stress Corrosion Cracking

- Responsible for most corrosion related catastrophic failures
- Requires presence of tensile stress:
  - Residual welding stresses
  - Forming stresses
  - Operating stresses
  - Frictional stresses
- In general austenitic SS more susceptible





Damage appearance: irregular and branched

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Early History

- First generation scrubbers ('70s and '80s):
  – General underestimation of corrosion severity.
  – Carbon steel or carbon steel lined with non-metallic coating common
  – Many failures occurred especially in outlet ducts due to acidic condensate
  – Repairs made by new applications of non-metallic coating, or lower Mo containing alloys
  – Significant development effort for improved non-metallic coatings
  – Lower Mo containing alloys experienced high failure rate due to pitting/crevice corrosion

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Wallpaper Concept

- First used at R.D. Morrow in early ’80s
- Thin (typically 1.6 mm) sheets of high Ni-Cr-Mo alloy applied over carbon steel to provide the needed corrosion resistance
- Original alloy used was C-276

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Second Generation Scrubbers

- Wide spread use of “wallpapering” and “cladding” of alloy liners
  - Wallpapering refers to attaching thin sheets (typically 1.6mm) of an alloy liner to a metal substrate, typically CS. The sheets are cut to fit and skip-welded to the substrate. Subsequent sheets overlap the first sheet and are seal welded to prevent leaks
  - Cladding refers to bonding of a corrosion resistant alloy plate to a CS backing plate. The alloy is either hot-roll or explosion bonded to the backing plate. Typical thicknesses are 1.6mm for the alloy plate and 4.8mm for the CS plate

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Second Generation Scrubbers (continued)

- Other materials used include rubber lined carbon steel (RLCS), lined carbon steel (LCS) including organic-based and epoxy resins and flaked glass, foamed borosilicate glass block, ceramic tile, and fiberglass reinforced plastic (FRP)

Current Design Trends

- No spare absorber
- 100% of flue gas is scrubbed
- No reheat
- High reliability requirements
- Many system operated to produce wallboard-grade gypsum. As a result, chloride levels run much higher
- Widespread use of alloy, FRP and ceramic tile for construction materials

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Factors Influencing Corrosion in Scrubber

- Sulfur content of flue gas
  - Will affect acidity of condensate
- Temperature
- pH
- Chloride
- Fluoride (?)
- Solid deposits can lead to localized corrosion attacks by concentrating chlorides and by providing oxygen-deprived crevice conditions
- Corrosion and erosion often go hand-in-hand

Guidelines for Scrubber Zone

Zone	Description	Factors	Preferred Materials
Gas Inlet Duct	Inlet duct upstream of where moisture forms	Hot (250 to 330 F) dry gas	Unlined CS
Inlet Quench Zone	Absorber inlet at point where gas first contacts slurry	Fluctuating temperature. Wet/dry interface. Potential for solid deposits.	Alloys Ceramic tile
Reaction Tank	Includes reaction tank and slurry piping	Temperature well modulated. Potential for erosion Potential for scale growth Floors subject to mechanical damage pH typically 5 to 6 but low pH excursion possible Chlorides range site specific	Alloys Ceramic tile FRP RLCS LCS

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Guidelines for Scrubber Zone (continued)

Zone	Description	Factors	Preferred Materials
Absorber and Spray Zone	Area from inlet to absorber downstream of quench to inlet of mist eliminator	Moderate temperature which are well modulated pH typically 3.5 to 5.5 Erosion may be a problem Scaling may be a problem	Alloys Ceramic tile FRP RLCS LCS
Absorber Outlet Duct, Wet	Extends from outlet of absorber to either stack breaching or beginning of reheat zone	Wet, saturated gas Acidic (pH 1 to 2) condensate on walls and floor Solid deposits possible	Alloys Ceramic tile FRP RLCS LCS Foamed borosilicate glass block

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Guidelines for Scrubber Zone (continued)

Zone	Description	Factors	Preferred Materials
Absorber Outlet Duct With Reheat	Outlet duct from reheater to stack breaching	Reheat rarely achieves complete dryness due to short residence time Tends to concentrate aggressive ions due to evaporation of water film Acidic condensate less likely Temperature range 140 to 190 F	Alloys Ceramic tile LCS Foamed borosilicate glass block
Absorber Outlet Duct With Bypass Reheat	Extends from mixing zone between treated gas and bypass gas to stack breaching	Extremely aggressive corrosion zone due to highly acidic condensate High temperature areas possible due to thermal gradients	High Ni alloys (e.g., C276) Ceramic tile Foamed borosilicate glass block

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Guidelines for Scrubber Zone (continued)

Zone	Description	Factors	Preferred Materials
Stack	Stack breaching to discharge	Without reheat gas will be wet and saturated Acidic condensate likely on walls which will need to be collected With reheat thermal gradients possible resulting in conditions which range from wet to dry	Acid brick Alloys FRP (wet stack) LCS Foamed borosilicate glass block CS (if gas is dry)
Reagent and Storage Tanks	Interiors of tanks and associated piping	Ambient or near ambient temperature pH range from slightly acidic to alkaline Chloride level will determine corrosivity	Alloys Ceramic tile FRP RLCS LCS CS

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Characteristics of Alloys

- Corrosion resistance results from formation of thin passive surface-oxide film. Common for alloys containing at least 12% Cr
- Pitting Resistance Equivalent Number (PREN) used to rank pitting and generally corrosion resistance of alloys

PREN = %Cr + 3.3*%Mo + 1.65*%W + 16*%N

- Corrosion resistance improves with increasing Cr, Ni, Mo, and N content
  - Cr provides passive surface film
  - Mo and N improve resistance to pitting and crevice corrosion
  - Ni improves fabrication and weldability and also assists in renewing damaged passive surface film

Composition and PREN Values For FGD Alloys

Trademark	UNS	C	Cr	Ni	Mo	N	Others	PREN
316L	S31603	< 0.030	17	11	2.0	0.02	-	24.5
316LM	S31653	< 0.030	18	15	4	0.06		32
317LMN	S31703	< 0.030	18	14	4.2	0.15	-	33
2205	S31803	< 0.030	21.0 23.0	4.5 6.5	2.5 3.5	0.08 0.20	-	34
2205	S32205	< 0.030	22.6	6	3.3	0.18	-	36
904L	N08904	< 0.020	20	25	4.3	0.13	Cu = 1.5	37
255	S32520	< 0.030	25	7	3.5	0.25	Cu = 1.5	41
6Mo	N08926	< 0.020	20	25	6.2	0.2	Cu = 1	43
C625	N06625	< 0.020	22	61	9	-		51
C276	N10276	< 0.020	16	56	16	-	T=3.5	75

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Alloy Selection Guide

		Mild	Moderate		Severe		Very Severe		
	Chlorides:	500	1,000	5,000	10,000	30,000	50,000	100,000	200,000
Mild	pH - 6.5	Type 316L SS						Nickel Alloy 625 etc.	
Moderate	pH - 4.5		Type 317LMN or 22% Cr Duplex SS				6% Moly Superaust. SS		
Severe	pH - 2.0	Type 317LM SS		22% Cr Duplex SS	25% Cr Super Duplex SS			Nickel Alloy C276 etc.	
Very Severe	pH - 1.0	Type 317LMN SS		6% Moly Superaustenitic SS		Nickel Alloy 625 etc.			

Source: NiDI

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Alloy Summary

- Proper selection of alloy critical for good performance
- Good strength and mechanical properties. Able to span absorber without intermediate supports allowing self-supporting spray headers
- Good fabrication characteristics

Fiberglass Reinforced Plastics (FRP)

- Have been used for many applications:
  - Process piping
  - Internal recycle spray systems
  - Ductwork
  - Stack liners
  - Storage tanks
  - Absorbers (JBR)
- FRP is a composite material which is built by layering different materials (resins, glass fibers) to achieve required properties

Application of FRP Materials

- Process piping needs to include corrosion/erosion resistant liner at least 0.1" thick. Internal spray headers need liner on both inside and outside
- FRP thermally expands at a different rate than steel. FRP is also inherently inflexible. As a result, detailed pipe stress analysis should be performed to verify design and placement of supports

FRP Summary

- FRP materials (piping, tanks, equipment) have been used successfully in FGD service for many years
- Provide good corrosion resistance
- Piping does not have structural strength of alloy
- Inherently inflexible, easily damaged if stressed (e.g., pipe hammer)
- Significantly lower cost than alloy
- Failures usually result of improper material selection, bad design, or faulty installation

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Other Materials

- Stebbins tile lining
- Stebbins tile/concrete
- RLCS
  - Prone to cold wall effects and water permeation
  - Correct application in controlled environment critical
- LCS
  - Includes organic-based and epoxy resins, and flake-glass
  - Correct application in controlled environment critical
  - Susceptible to mechanical damage

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