Technical Data - Galvanic Corrosion

Table 1 is the galvanic series of commonly used metals when immersed in sea water. This list will vary slightly when a different electrolyte forms the galvanic couple.

Metals which are grouped show negligible corrosion when joined.

For galvanic corrosion to occur the following conditions must be met.

i) Two or more electrochemically dissimilar metals are present and in electrical contact (which is not necessarily physical contact).

ii) The metals must be in contact with an electrolyte.

Quite often other types of corrosion are incorrectly attributed to galvanic corrosion. If the foregoing conditions are met and the corrosion is localized near the junction of the metals, it was probably caused by galvanic effects. Otherwise, look elsewhere.

The best on can do is to try to avoid designs which involve electrically coupled metals. This is not always practical. However the choice of metals can help to lesson corrosive effects. Try to select metals as close together as possible on the galvanic series.

Keep in mind that the least noble or more active metal will deplete during corrosion. Never couple a small anode with a large cathode.

Quite often it is practical to electrically insulate the metals from one another. If it is determined that dissimilar uninsulated metals must be used, make the anodic part of heavier material. Also, design the part for easy replacement.

Useful Corrosion Terminology

- **Bimetallic Corrosion** - Galvanic Corrosion.
- **Corrosion-Erosion** - Corrosion which is increased because of the abrasive action of a moving stream.
- **Crevice Corrosion** - Localized corrosion resulting from the formation of a concentration cell in an crevice formed between a metal and a nonmetal or between two metal surfaces.
- **Fretting Corrosion** - Fretting refers to metal deterioration caused by repetitive slip at the interface between two surfaces.
- **Hydrogen Embrittlement** - Embrittlement of a metal caused by hydrogen.
- **Impingement Attack** - Erosion-corrosion caused by turbulence or impinging flow at certain points.
- **Intergranular Corrosion** - Corrosion which occurs preferentially at grain boundaries.
- **Pitting** - Highly localized corrosion resulting in deep penetration at only a few spots.
- **Scaling** - High temperature corrosion resulting in formation of thick corrosion product layers.
- **Stress Corrosion** - Corrosion which is accelerated by stress.

TABLE 1 Galvanic Series of Commonly Used Metals When Exposed to Sea Water

Active or Least Normal

Magnesium
Magnesium Alloys
Zinc
Galvanized Steel

Aluminum 1100

Aluminum 6053
Alclad

Cadmium

Aluminum 2024 (4.5 Cu, 1.5 Mg 0.6 Mn)

Mild Steel
Wrought Iron
Cast Iron

13% Chromium Stainless Steel
Type 410 (Active)
18-8 Stainless Steel
Type 304 (Active)
18-12-3 Stainless Steel
Type 316 (Active)

Lead-Tin Solders
Lead
Tin

Manganese Bronze
Naval Brass

Nickel (Active)
76 Ni - 30 Mo - 6 Fe - 1 Mn

Yellow Brass
Admiralty Brass
Aluminum Brass
Red Brass
Copper
Silicon Bronze
70:30 Cupro Nickel
G-Bronze
M-Bronze
Silver Solder
Nickel (Passive)
76 Ni - 16 Cr - 7 Fe Alloy (Passive)
67 Ni - 33 Cu Alloy (Monel)

13% Chromium Stainless Steel
Type 410 (Passive)
Titanium
18-8 Stainless Steel
Type 304 (Passive)
18-12-3 Stainless steel
Type 316 (Passive)
Silver

Graphite
Gold
Platinum

Passive or More Noble

Galvanic Corrosion

Technical Data - Corrosion Guide

The sheath materials in the following tables are to be used as a guide only and not as a firm recommendation. Such factors as temperature of solution, percentage of concentration, watt density and contamination are all factors in corrosion rates which make it impossible to make an absolute recommendation. For further information on corrosiveness of a solution, check the supplier of your solution.

Due to the above factors which are beyond our control, CCI Thermal cannot be responsible for electric heater failure due to corrosion.

WARNING - CERTAIN SOLUTIONS, DUE TO THE VISCOSITY OR FLAMMABILITY ARE NOT SUITABLE FOR HEATING WITH DIRECT IMMERSION HEATERS UNLESS SPECIAL PRECAUTIONS ARE TAKEN. CHECK FACTORY IF YOU REQUIRE ASSISTANCE IN THE SELECTION OF A SAFE AND RELIABLE HEATING METHOD FOR YOUR APPLICATIONS.

Legend: A - Good
F - Fair
C - Depends on Conditions
X - Unsuitable

Solution	Iron and Steel	300 Series Stainless	Monel	Incoloy®	Inconel	Copper	titanium	Aluminum	Quartz	Teflon
Aluminum Potassium Sulphate		A-316				A				
Acetic Acid, Crude	X	F	F	C	C	F		F		
Pure			A	C	C	F		A		
Vapor			F	C	C	F	F	C		
150 PSI; 204°C (400°F)			F	C	C	F		C		
Aerated	X	F-316 X-304	X		X	X	A	C		
No Air		C	A		X	F	A	C		
Acetone	C	A	A	A	A	A	A	F	A	
Alboloy Process	A									
Allyl Alcohol		A	A	A	A	A	A	F		
Alcohol	F	A-316	A	A	A	A	A	F	A	
Alkaline Solutions	A	A-304								
Alkaline Cleaners		A-304								
Alkaline soaking Cleaners	A									
Alum										
Aluminum (Molten)										
Aluminum Acetate	X	A-316	F		F	F	A			
Aluminum Bright Dip									A	A
Aluminum Chloride	X	X	X	X	X	X	X	X	A	A
Aluminum Cleaners	C	A	A	A	A	X	F	X	X	
Aluminum Potassium Sulphate (Alum)		C-316 X-304	F		F	A	F	X		
Aluminum Sulphate	X	F	F	X	X	F	A	X	A	
Ammonia	X	X	X	C	F	X	A	C	A	
Ammonia Gas, Cold	A	A	A		A	C	A	A		
Hot	C	C	C		A	X				
Ammonia and Oil	A									
Ammonium Acetate	A	A	A	A	A	X		A		
Ammonium Bifluoride	X	X	X	X	X	X	X	X	X	A

Solution	Iron and Steel	300 Series Stainless	Monel	Incoloy®	Inconel	Copper	titanium	Aluminum	Quartz	Teflon
Ammonium Chloride	C	F	F	C	C	X	A	X	A	A
Ammonium Hyrdoxide	A	A	AC	A	A	X	A	C	X	
Ammonium Nitrate	A	A	C	X	X	X	X	F	A	
Ammonium Persulphate	X	F	X		X	X		X	A	A
Ammonium Sulphate	A	A	A	F	F	F	A	X	A	
Anhydrous Ammonia	A					X				
Aniline	F	A	F	F	F	X	A	F	A	
Aniline, Aniline Oil	A	A	A	F	F	X	A	X	A	
Aniline, Dyes		A	A							
Anodizing Solutions 10% Chromic Acid 36°C (96°F)	C	A					A			
Sodium Hydroxide Alkaline	A			A			A			
Nickel Acetate			A							
Arsenic Acid	X	C	X	X	X	X	X	X	A	A
Asphalt	A	A	X	A	A	X`	A	X	A	
Barium Chloride		F-304 X-316			A			X		
Barium Hydroxide		A		F	F	X	X	X	A	
Barium Sulphate	F	F	F	F	F	F	A		A	
Barium Sulphide		A	A			X				
Barium Sulphite		F-304								
Black Nickel									A	A
Black Oxide		A-304								
Bonderizing	C	A		C	C		A		A	A
Boric Acid	X	C	C	C	C	C	A	X	A	A
Brass Cyanide		A-304								
Bright Nickel							A		A	
Brine (Salt Water)			A		F					
Bronze Plating	A	A-304								
Butanol (Butyl Alcohol)	A	A	A	A	A	A	A	F	A	A
Cadmium Black									A	
Cadmium Fluoborate										A
Cadmium Plating				A	A					
Calcium Chlorate	F	F	F	F	F	C			A	
Calcium Chloride	F	F	F	F	F	F	A	C	A	A
Carbonic Acid, Phenol	C	A	A	F	F	X	A	F		
Carbon Dioxide, Dry	A	A	A	A	A	A	AX	A	A	X
Wet	F	A	A	A	A	F	X	A	A	X
Carbon Tetrachloride	C	C	A	A	A	C	A	X	A	
Carbonic Acid	C	A-304	C	F	A	C	A	C	A	A
Castor Oil	A	A	A	A	A		A	A	A	A
Caustic Etch	A	A	A	X	X	X	A	X	A	X
Caustic Soda (Lye) (Sodium Hydroxide)	X	C-316 X-304	C	C	F	X	C	X	X	A
2%	F	F-316 X-304	A	A	A	F	A	X		
10 - 30 %, 99°C (210°F)	F	A	A	A	A	F	A	X		
76%, 82°C (180°F)	X	F	F	A	A	X	F	X		
Chlorine, Dry	A	A	A	C	F	A	F	X	A	F
Wet	X	X	X	X	X	X	X	X	A	X
Chloroacetic Acid	X	X		C	C	X	A	X	A	A
Chromic Acetate									A	
Chromic Acid	C	A	F	X	X	X	A	X	A	X
Chrome Plating				X	X		A		A	X
Citric Acid	X	A	A	F	F	A	A	C	A	A
Clear Chromate		A-316								
Cobalt Acetate 54°C (130°F)			A	F	F					
Cobalt Nickel									A	
Cobalt Plating		A-304								

Corrosion Guide (cont...)

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Solution	Iron and Steel	300 Series Stainless	Monel	Incoloy®	Inconel	Copper	titanium	Aluminum	Quartz	Teflon
Coconut Oil			F							
Cod Liver Oil		A		A	A			A		
Copper Acid							A		A	
Copper Bright		A								
Copper Bright Acid									A	
Copper Chloride	F	X	F	X	X	C	A	C	A	A
Copper Cyanide	A			X	X			X	A	A
Copper Fluoborate		F	F	F	F					A
Copper Nitrate	X	F	X	X	X	X		X	A	A
Copper Plating	A									
Copper Sulphate	X	A	A	F	F	C		X	A	
Creosote	A	A	A	F	F	A		C	A	
Deionized Water	X	A	A	A	A	X		X		
Deoxidizer (Etching)									A	
Diethylene	F	A	F	F	F	F	A	F	A	A
Diphenyl 149°C - 177°C (300°F - 350°F)	A				A			A		
Disodium Phosphate 25% 82°C (180°F)	A				A		A		A	A
Dowtherm A	A			A						
Electro Polishing									A	
Electroless Nickel							A		A	
Electroless Tin (Acid)									A	
(Alkaline)		A-316					A			
Ethers	A		A	F	F	A	A	F	A	
Ethyl Chloride	A	A	A	F	A	A	A	F	A	A
Ethylene Gycol 149°C (300°F)		A	A	F	F		A	A	A	A

Solution	Iron and Steel	300 Series Stainless	Monel	Incoloy®	Inconel	Copper	titanium	Aluminum	Quartz	Teflon
Fatty Acids	X	A-316	F	F	F	X	A	A	A	
Ferric Chloride	X	X	X	X	X	X	A	X	A	A
Ferric Sulphate	X	F-304 A-316	X	C	C	X	A	X	A	
Flourine Gas, Dry	C	C	A	C	A	X	A	X	C	
Formaldehyde	F	A	A	F	F	F	A	F	A	
Formic Acid	X	F	C	F	C	F	X	X	A	
Freon	C	C	A	A	A	A		A		
Fuel Oil	A	A	A	F	F	A	A	A		
Fuel Oil, Acid	C	C	A	C	C	C	A	X		
Gasoline, Refined	A	A	A	F	F	A		A	A	
Gasoline, Sour	C	A	A	X	X	C		C	A	
Gasoline, Glycerol	A	A	A	A	A	F		A	A	
Gold - Acid	A						A		A	
Gold - Cyanide		A								
Grey Nickel							A		A	A
Hydrochloric Acid < 66°C (150°F)	X	X	C	X	X	X	X	X	A	
> 66°C (150°F)	X	X	C	X	X	X	X	X	A	A
Hydrocyanic Acid (No Air)	X	F	F	F	F	X		F	A	
Hydrofluoric Acid, Cold < 65%	X	X	F	X	X	C	X	X	X	A
> 65%	F	X	A	X	X	F	X	X		
Hot < 65%	X	X	C			X		X		
> 65%	C	X	A	X	X	F	X	X		
Hydrogen Peroxide	X	A	F	F	F	X	A	A	A	
Indium									A	A
Iron Phosphate (Parkerizing)	C	A								
Isopropanol	C		A		A	F				
Kerosene	A	A	A	A	A	A		A		
Lacquer Solvents	C	A	A	F	F	C	A	A	A	
Lard	F									
Lead Acetate	X	A	A	A	A	X	A	X	A	
Lead Acid Salts		A-304								
Lime Saturated Water	F	A-316	F	F	F	F		X	X	
Linseed Oil	A	A	A	F	F	A	A	F		
Magnesium Chloride	F	F	F	F	A	F	A	X	A	
Magnesium Hydroxide	A	A	A	A	A	X		F	A	
Magnesium Nitrate	F	F	F	F	X	F	F	F	A	
Magnesium Sulphate	A	A	A	F	A	A	A	F	A	
Mercuric Chloride	C	X	X	X	X	X	F	X	A	
Mercury	A	A	A	A	F	X	X	X	A	
Methyl Alcohol, Methanol	A	A	A	F	A	A	A	C	A	
Methyl Bromide	C	A	F	F	F	F	A	X	A	
Methyl Chloride	A		A	C	C	A	A	X	A	
Methylene Chloride	X	C	C	C	F	C	A	C	A	
Mineral Oils	A	A	A	A	A	A	A	A	A	
Muriato									A	A
Naptha	A	A	A	A	A	A	A	A	A	A
Napthalene	A			F	F		A	F		
Nickel Acetate Seal		A-316								
Nickel Chloride		F	C	C	F	X	F	X	A	A
Nickel Copper Strike (Cyanide Free)		A								
Nickel Plating, Bright							A		A	A
Nickel Plating, Dull									A	A
Nickel Plating, Watts Solution							A		A	A
Nickel Sulphate	X	A	C	C	C	X		X	A	A
Nitric Acid, Crude	X	C	X	X	X	X		X	A	A
Concentrated	X	F	X	X	X	X		X	A	A
Diluted	X	A	X	X	X	X		X	A	A

Corrosion Guide

Solution	Iron and Steel	300 Series Stainless	Monel	Incoloy®	Inconel	Copper	titanium	Aluminum	Quartz	Teflon
Nitric Hydrochloric Acid	X	X	X	X	X	X	X	X	A	A
Nitric 6% Phosphoric Acid		C-316							A	A
Nitric Sodium Chromate		A-316							A	A
Nitrobenzene	A	A	A	A	A	F	A	A	A	
Oakite No. 20	A									
Oakite No. 23	A									
Oakite No. 24	A									
Oakite No. 30	A									
Oakite No. 51	A									
Oakite No. 67		A-304								
Oakite No. 90 @ 82°C (180°F)	A									
Oleic Acid	C	A	A	F	A	X	F	C	A	A
Oxalic Acid	C	C	A	X	F	C	X	F	A	A
Paint Stripper (High Alkaline Type)	A									
Paint Stripper (Solvent Type)		A-316								
Paraffin	A	A				A		A		
Parkerizing										
Perchlorethylene		A		F	A		A	C	A	
Petroleum Oils, Crude < 260°C (500°F)		A		F	A		A	C	A	
> 260°C (500°F)	A	A	X			X		A		
> 538°C (1000°F)	X	C A-347	X			X		X		
Phenol										
Phenol 85%, 49°C (120°F)	C	A		F	F		A	A		
Phosphate		A-316								X
Phosphate Cleaner		A-304								X
Phosphatizing		A-316								X
Phosphoric Acid, Crude	C	C	X			X		X		
Pure < 45%	X	A	F	A	A	F	X	C		
> 45% Cold	X	A	F	A		F	X	X		
Hot	X	X-304 C-316	C	A	F	C	X	X		
Photo Fixing Bath		A	C							
Potassium Bichromate (Potassium Dichromate)	C	A-316	F	F			F	F	A	A
Potassium Chloride	A	A	A	C	F	A	A	X	A	
Potassium Cyanide	A	A	A	F	F	X	X	X	A	A
Potassium Hydrochloride									A	A
Potassium Hydroxide	C	F	A	C	F	X	X	X	X	A
Potassium Nitrate (Salt Peter)	F	F	F	F	F	F	A	A	A	
Potassium Sulphate	A	F	A	F	F	A	A	A	A	A
Prestone 177°C (350°F)	A		A							
Sea Water	X	C	A	F	F	X	A	X	A	
Silver Bromide	X	X	C			X	A	X	A	A
Silver Cyanide	C	A	F	A		X		X	A	
Silver Nitrate	X	C	X	C	C	X	A	X	A	
Soap Solutions	A	A	A			C		X		
Sodium - Liquid Metal	C	A-304	C	A	A	X		X	X	
Sodium Bisulphate	X	X	C		F	F		C		
Sodium Bromide	F	C	F	F	F	F		X	A	A
Sodium Carbonate < 20%	A			F	F		A	X	C	A
Sodium Chlorate	X	F	A	F	A	A	A	F	A	A
Sodium Chloride	A	F-304 A-316	A	F	A	F	C	X	A	
Sodium Citrate	X	F				X		X	A	A
Sodium Dichromate (Sodium Bichromate)	F	F				X	C	C	A	
Sodium Disulphate	X	X	C		C		C	C	A	
Sodium Hydroxide	A	F	A	A	A	X	A			
Sodium Hypochlorite	X	X	C	X	X	C	A	X	A	A
Sodium Nitrate	A	F-304 A-316	A	A	A	F	A	C	A	
Sodium Peroxide	C	A	A		F			C		
Sodium Phosphate	C	A-316	A	F	A	F	A	X	A	A
Sodium Salicylate	F	F	F	F	F	F			A	A
Sodium Silicate	A	A-316	A	F	F	C		X	A	A
Sodium Stannate	C	F	F	F	F				A	A

Solution	Iron and Steel	300 Series Stainless	Monel	Incoloy®	Inconel	Copper	titanium	Aluminum	Quartz	Teflon
Sodium Sulphate	A	A	A	F	F	A	C	F	A	A
Sodium Sulphide	A	A	F	C	C	X	C	C	C	A
Solder Bath	X	X	X	X	X	X	X	X	X	X
Soybean Oil		A								
Steam < 500°F	A	A	A	A	A	A				
< 260°C - 538°C (500°F - 1000°F)	C	A	C	A	A	C				
> 538°C (1000°F)	X	A	X	A	A	X				
Stearic Acid	C	A	A			C		C	A	
Sugar Solution	A	A	A	A	A	A	A	A	A	A
Sulphur	A	F	X	A	A	X	A	A	A	
Sulphur Chloride	X	C-304 X-316	X	C	F	X		X	A	A
Sulphur Dioxide	X	C-304 X-316	C		F	X		C		
Sulphuric Acid < 10% Cold	X	F	C		X	C		C		
Hot	X	F-316 X-304	C		F	X		C		
10 - 75% Cold	X	X-304 F-316	C		X	X	X	X		
Hot	X	X	C		X	X	X	X		
75 - 95% Cold	C	A	C		X	X	X	X		
Hot	F	X	C			X	X	X		
Fuming	C	C-304 F-316	X	C	C	X		X		
Sulphurous Acid	A	C-316 X-304	X		C	C	A	C		
Tannic Acid		F	A		A	A	A	C	A	
Tar	A	A		A	A			A		
Tartaric Acid		C-304 A-316	C		F		F	C		
Tetrachlorethylene	A		F	A		A	C	A		
Thermoil Grandodine	F									
Tin (Molten)	F	F	X		X	X	A	X		X
Tin-Nickel Plating									A	A
Tin Plating - Acid										A
Tin Plating - Alkaline	A	A-304								
Toluene	A	A	A	A	A	C	A	A		
Triad Solvent	C									
Trichloroethane	A	A-304	F	F	F	F	A	F	A	
Trichlorothylene	C	C	A	A	A	C	A	F	A	
Triethylene Glycol	A	A	A	A	A	A	A	A	A	
Trioxide (Pickle)									A	A
Trisodium Phosphate	A	C	C			C		X	X	X
Turpentine	C	A	A			C		A		
Urea Ammonia Liquor 8°C (48°F)	A									
Vegetable Oil	C	A	A	A		X		F		
Vinegar	C	F-304 A-316	A					C		
Water, Fresh	C		A	A	A	A	A		A	
Distilled, Lab Grade	X	A	C	A	A	X				
Return Condensate	A	A	A	A	A	A				
Whiskey and Wines	X	F-304 A-316	A	A	A	A				
Yellow Dichromate		A-316							A	
X-Ray Solution		A								
Zinc (Molten)		X	X	X	X	X	X	X		X
Zinc Chloride	C	X	A	F	F	X	F	X	A	A
Zinc Plating Acid									A	
Zinc Plating Cyanide	A	A-304								
Zinc Sulphate	C	A	A	A	A	X	A	C		