Advanced Energy

Galvanic Corrosion Prevention Guide for Water Cooling Systems

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Water Cooled Devices

Created by

Helen E. Kane, Advanced Energy Industries, Inc.

Abstract

This report details best practices for reducing the risk of galvanic corrosion in water cooling system designs. Galvanic corrosion will manifest if the following conditions exist:

1. Electrically dissimilar metals in contact (or both in contact with the same water)
2. Electrolyte present (could be as simple as condensation)

Time is another critical factor. The mean time to failure can be short or long, depending on the combination of conditions 1 and 2. This report provides the galvanic series for general metals and compatibility. In addition, it lists preventative measures to avoid issues in open loop cooling water systems.

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Summary and Background

This report details best practices for reducing the risk of galvanic corrosion in mechanical and electro-mechanical cooling system designs. Galvanic corrosion, sometimes called bimetallic or dissimilar metal corrosion, is when one metal in a system experiences corrosion due to an electro-chemical reaction with a different metal and an electrolyte in the same system. Galvanic corrosion has been experienced in designs with dissimilar metals used in Advanced Energy products that use water cooling. Because conditions that promote galvanic reactions can exist inside Advanced Energy units due to the environment and running conditions, some simple best practices will help reduce the risk of galvanic corrosion failure.

Research Findings

Galvanic corrosion will occur when cathodic and anodic metals are in contact in humid, salty, or outside environments, or in and around water systems. The potential for different metals to be an anode verses a cathode is listed in Table 1. The larger the difference between two materials in this list, the larger the potential for galvanic corrosion. Testing for a material's anode potential is generally done in saltwater; however, reactions will occur in simple humid environments as well.

Table 1A: Galvanic Series in Flowing Seawater[1]

Anodic or Active End

Alloy	Voltage Range of Alloy vs. Reference Electrode*
Magnesium	-1.60 to -1.63
Zinc	-0.98 to -1.03
Aluminum Alloys	-0.70 to -0.90
Cadmium	-0.70 to -0.76
Cast Irons	-0.60 to -0.72
Steel	-0.60 to -0.70
Aluminum Bronze	-0.30 to -0.40
Red Brass, Yellow Brass, Naval Brass	-0.30 to -0.40
Copper	-0.28 to -0.36
Lead-Tin Soldier	-0.26 to -0.35
Admiralty Brass	-0.25 to -0.34
Manganese Bronze	-0.25 to -0.33
Silicon Bronze	-0.24 to -0.27

Alloy	Voltage Range of Alloy vs. Reference Electrode*
400 Series Stainless Steels **	-0.20 to -0.35
90-10 Copper-Nickel	-0.21 to -0.28
Lead	-0.19 to -0.25
70-30 Copper-Nickel	-0.13 to -0.22
17-4 PH Stainless Steel †	-0.00 to -0.15
Silver	-0.10 to -0.20
Monel	-0.04 to -0.14
300 Series Stainless Steels ** †	-0.00 to -0.15
Titanium and Titanium Alloys †	+0.06 to -0.05
Inconel 625 †	+0.10 to -0.04
Hastelloy C-276 †	+0.10 to -0.04
Platinum †	+0.25 to +0.18
Graphite	+0.30 to +0.20

Cathodic or Noble End

* These numbers refer to a Saturated Calomel Electrode.
** In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V.
† When covered with slime films of marine bacteria, these alloys may exhibit potentials from +0.3 to +0.4 V.

Table 1B[2]

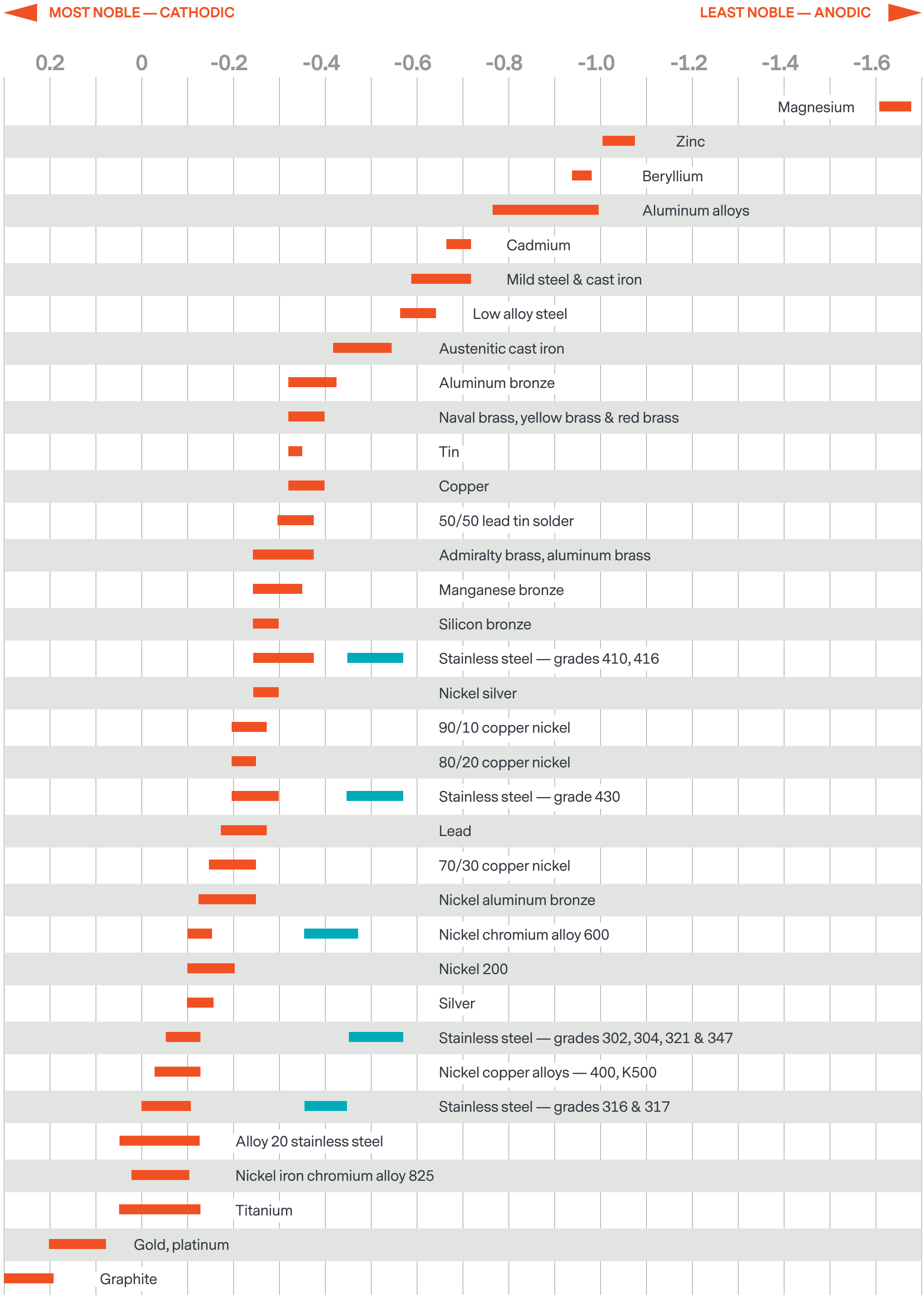
MOST NOBLE — CATHODIC
LEAST NOBLE — ANODIC
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
Magnesium
Zinc
Beryllium
Aluminum alloys
Cadmium
Mild steel & cast iron
Low alloy steel
Austenitic cast iron
Aluminum bronze
Naval brass, yellow brass & red brass
Tin
Copper
50/50 lead tin solder
Admiralty brass, aluminum brass
Manganese bronze
Silicon bronze
Stainless steel — grades 410, 416
Nickel silver
90/10 copper nickel
80/20 copper nickel
Stainless steel — grade 430
Lead
70/30 copper nickel
Nickel aluminum bronze
Nickel chromium alloy 600
Nickel 200
Silver
Stainless steel — grades 302, 304, 321 & 347
Nickel copper alloys — 400, K500
Stainless steel — grades 316 & 317
Alloy 20 stainless steel
Nickel iron chromium alloy 825
Titanium
Gold, platinum
Graphite

Table 2[3]

Metallurgical Category	Anodic Index (V)
Gold, solid and plated, gold-platinum alloy	0.00
Rhodium plated on silver-plated copper	0.05
Silver, solid or plated; monel metal. High nickel-copper alloys	0.15
Nickel, solid or plated, titanium alloys, Monel	0.30
Copper, solid or plated; low brasses or bronzes; silver solder; German silvery high copper-nickel alloys; nickel-chromium alloys	0.35
Brass and bronzes	0.40
High brass and bronzes	0.45
18% chromium type corrosion-resistant steels	0.50
Chromium plated; tin plated; 12% chromium type corrosion-resistant steels	0.60
Tin-plate; tin-lead solder	0.65
Lead, solid or plated; high lead alloys	0.70
Aluminum, wrought alloys of the 2000 Series	0.75
Iron, wrought, gray or malleable, plain carbon and low alloy steels	0.85
Aluminum, wrought alloys other than 2000 Series aluminum, cast alloys of the silicon type	0.90
Aluminum, cast alloys other than silicon type, cadmium, plated and chromate	0.95
Hot-dip-zinc plate; galvanized steel	1.20
Zinc, wrought; zinc-base die-casting alloys; zinc plated	1.25
Magnesium & magnesium-base alloys; cast or wrought	1.75
Beryllium	1.85

Extensive research and experimentation show galvanic corrosion occurring in metals with an anodic index difference of as little as 0.15V depending on the environment, and some metals have been known to corrode with potentials of -0.5V. It should also be noted that if the dissimilar metals are simultaneously in contact with the same water, and that water is electrically charged, corrosion will occur. In addition, in very highly energetic interactions between copper and aluminum in water, the small amounts of nitrate and sulphate in the water can be reduced to ammonia and sulphides that will attack the copper, thereby causing the copper to corrode despite it being the cathode in the system.

It is important to note that some non-metallic materials have been found to promote galvanic reactions as well: cellulosic reinforced plastics, carbon or metal loaded resin materials and asbestos-cement composites. These non-metallic materials should be avoided.

The galvanic series chart created by the organization Preservation Science (shown in Table 3), rates the interaction between specific base metals and different fastener materials. This chart can be referenced to determine the best fasteners to use to reduce the risk of galvanic corrosion.

Table 3: Fastener Effects[4]

The following chart can be used to guide the selection of fasteners based on galvanic action:

	Fastener Metal					
Base Metal	Zinc & Galvanized Steel	Aluminum & Aluminum Alloys	Steel & Cast Iron	Brasses, Copper, Bronzes, Monel	Martensitic Stainless (Type 410)	Austenitic Stainless Steel (Type 302/304, 303, 305)
Zinc & Galvanized Steel	A	B	B	C	C	C
Aluminum & Aluminum Alloys	A	A	B	C	Not Recommended	B
Steel & Cast Iron	AD	A	A	C	C	B
Teme (Lead Tin) Plated Steel Sheets	ADE	AE	AE	C	C	B
Brasses, Copper, Bronzes, Monel	ADE	AE	AE	A	A	B
Ferritic Stainless Steel (Type 430)	ADE	AE	AE	A	A	A
Austenitic Stainless Steel (Type 302/304)	ADE	AE	AE	AE	A	A

Key:
A. Corrosion of the base metal is not increased by the fastener.
B. Corrosion of the base metal is marginally increased by the fastener.
C. Corrosion of the base metal is markedly increased by the fastener material.
D. Plating on the fasteners is rapidly consumed, leaving the bare fastener metal.
E. Corrosion of the fastener is increased by the base metal.

Best Practice Recommendations

Due to extensive research on galvanic corrosion over the years, galvanic series lists and best practices for prevention are well documented. The best practices for reducing the risk of galvanic corrosion are listed below.

1. **Select metals/alloys as close together as possible in the galvanic series.**
    a. Galvanic corrosion can occur in metals that are 0.15V different on the galvanic series. Remember that in a water system any two metals that share contact with the same water will be susceptible to corrosion, if notably dissimilar or in a charged environment.
    b. For fasteners, use the same metal or a more cathodic metal than the part being fastened.

2. **Design interface metals such that the area of the cathode is much smaller than the area of the more anodic metal.** For example, use a stainless steel screw in aluminum but not the reverse. The amount of galvanic corrosion is proportional to the cathode/anode area ratio. A small anode and large cathode will result in large galvanic corrosion.

3. **Insulate dissimilar metals wherever practical.**
    a. Use compatible gaskets or washers between dissimilar metals prior to fastening.
    b. Do not use non-metallic materials that have salts, acid or alkaline materials, carbon or metallic particles, are subject to bio-deterioration, support fungal growth, or absorb or wick water.

4. **Apply coatings with caution. If coatings must be used, coat the cathode with a metal compatible with the anode.**
    a. Coatings must be inspected and maintained.
    b. Apply corrosion-inhibiting pastes or compounds under small screw heads of dissimilar metal surfaces, even if plated.
    c. Seal all faying edges to prevent the entrance of moisture.
    d. Coat external joints of dissimilar metals when possible, to prevent exposure to moisture.

5. **Avoid threaded joints for materials far apart in the galvanic series.**
    a. Threading creates small contact areas that corrode quickly.
    b. Coatings are damaged by the act of threading the joint together.

6. **Do not use deionized/distilled water**
    a. While deionized/distilled water carries very little charge, it is known to be highly corrosive to copper as well as several other metals.
    b. Deionized water will rip Cu ions from any copper in the system, contaminating the water and corroding any copper in the system. The Cu ion tear-off process is accelerated by the higher temperatures and water speeds that exist locally inside the power generator cooling systems.

7. **Ground power supplies per manufacturer recommendations to avoid charging the cooling water.**
    a. Improper grounding of a unit can result in corrosion from stray current.
    b. Ways to prevent stray current corrosion:
        i. Find the source of the stray current and stop leakage by proper grounding and insulation.
        ii. Offset the corrosion effects of the current by installing an impressed cathodic protection system.

8. **Avoid condensation inside system generators.**
    a. Condensation is enough electrolyte to promote corrosion.
    b. Cooling water flowing through a power supply while the unit is not providing output can cause condensation to form inside the unit. Condensation can cause internal device shorts as well as corrosion.
    c. Shutting down the water flow while units are not running via a solenoid, or some equivalent method, will protect against condensation-caused corrosion.

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