APPLICATION SERIES

INFORMATION ON CENTRIFUGAL PUMPS

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Why NICKEL ALUMINUM BRONZE for Sea Water Pumps

Proper selection of a centrifugal pump handling sea water begins with initially limiting material selections to reasonably priced metal alloys that can be manufactured to the requirements of a good pump design. A centrifugal pump properly designed will impose substantial yet tolerable demands on its material of construction. However; a less efficient, compromised design dictated by manufacturing limitations of another, sometimes more expensive, alloy having "superior" physical characteristics might not stand up nearly as well due to the highly destructive energy losses (wasted HP) that are being incurred. Below, Figure 1 of a closed impeller in bronze construction compared to an open impeller in Alloy 20 provides and actual case of this comparison.

FIGURE 1 — Compare the open impeller after 3 months, and the closed design after 3 full years of pumping the same slurry at identical speed, capacity and bead. Open impeller, badly worn on vane faces, had lost so much capacity it had to be replaced.

To increase the life expectancy of a pump, a good design must not only include streamlined flow patterns, but also sound mechanical features such as closed impellers, wear rings, splash plates, large radii (eliminates sharp crevices), and thru tapping, along with of course a suitable material of construction for the specific application.

The basic topic in this article will be practical pump materials of construction for sea and brackish waters. It is vital that one also be aware of the inter-relationship within the pumps mechanical and hydraulic designs in selecting a proper material.

While copper with its ability to withstand the corrosive effects of salt and brackish water is well known, specific identification, physical properties and application areas are not nearly as readily available as that of the ferrous materials. In many quarters, confusion appears to have arisen from the rather *loose terminology which is used in referring to copper alloys.*

There is an accepted alloy designation for wrought and cast copper and copper alloy products administered by the Copper Development Association, Inc. Within the two categories, the compositions are grouped into the following families of copper and copper alloys. In this article, we will primarily cover castings as provided in centrifugal pumps.

1. **COPPER** – Metal which has a designated minimum copper content of 99.3% or higher. Used primarily for electrical and electronic services.

2. **HIGH COPPER ALLOYS** (cast) – Metal with a minimum copper content of 94% to which silver may be added for special properties. Used in corrosion services where high strength is not required.

3. **BRASSES** (cast) – These copper alloys contain zinc with or without other designated elements such as iron, aluminum, nickel and silicon. Also included in this category is a family of alloys known as "Manganese Bronze" because zinc is the major alloying

element. Limited use on water applications due to dezincification – a type of corrosion which selectively removes the zinc, leaving a weak, porous copper shell with limited physical properties for today's fluid machinery.

4. **Bronze** – cast alloys have four main families:
   - **A. Tin Bronzes**
   - **B. Leaded Tin Bronzes**
   - **C. Nickel Tin Bronzes**
   - **D. Aluminum Bronzes**

Within the Aluminum Bronze family is included a Nickel Aluminum Bronze known as CDA (Copper Development Association) Copper Alloy C95800. The Ampco designation for this alloy is Ampco 483. Other specifications meeting this criteria include: ASTM B-148, B-271, C95800: Federal QQ-C-390 C958: MIL C-15345 Alloy 2B, B-24480, B-21230 Alloy 1, C22229 Alloy 958: and SAE J426B C95800.

The addition of aluminum to copper and its alloys is a relatively recent accomplishment dating back to the early 1900's. Aluminum originally was added to give strength to the copper, while maintaining the corrosion resistance of the base metal. In addition, it was found that aluminum bronzes were more resistant to direct chemical attack because of aluminum oxide plus copper oxide formed on the metal surface thereby giving the alloy superior corrosion resistiveness.

As the speeds and size of marine rotating equipment such as ship propellers and pump impellers increased during the 1950's, a more durable copper material was required.

The limited physical properties of the tin bronzes (Gun Metal) coupled with their castability problem relative to sound pressure tight boundary parts were no longer acceptable. At the request of the U.S. Navy a new copper alloy was developed for critical sea water service with the ability to withstand higher stresses while maintaining its resistance to the corrosion-erosion effects of rapidly moving sea water. This alloy is the nickel aluminum – bronze known as CDA 95800 (Ampco 483). Other designations are "alpha nickel aluminum" and "propeller bronze." This alloy combines high strength, corrosion resistance and fatigue strength with good castability and repairability features. The high strength enables thin sections of blade to be used so improving the propeller and impeller efficiencies.

The composition of Ampco 483 is 79.0% min. Cu, .05% Pb, 3.5-4.5% FE, 4.0-5.0% Ni, 8.5 – 9.5% AL, 0.8 – 1.5% Mn, .10% Si, .10% Sn. The microstructure as cast generally consists of continuous equiaxed alpha crystals with small areas of metastable Beta phase. Kappa phase precipitates are found in the Alpha phase, in grain boundaries and in the Beta areas. A quench and temper thermal treatment results in refinement and redistribution of the Kappa phase throughout a matrix of tempered Beta martensite and Alpha Kappa eutectoid. Ampco 483 castings are all given this thermal treatment to enhance corrosion resistance and eliminate the potential of any de-alloying of this non-magnetic material.

De-alloying of aluminum bronzes commonly known as de-aluminification years ago caused some concern but no longer is a significant problem, because of today's heat treatment standard. De-aluminification can be likened to the familiar dezincification of Cu-Zn (Brass) alloys. The attack leaves a porous copper structure in place of the phase attacked. While the nickel addition helps, it is the fast rate of cooling given the cast nickel-aluminum bronze metal from a specific annealing temperature (1250F) that insures the ideal structure of this alloy.

The U.S. Navy has been using the nickel-aluminum-bronze alloy MIL-B-24480 (CDA 958) for more than 40 years and except for a brief period of time, there has always been a mandatory temper anneal given the case material. This same treatment is given to all Ampco Pumps bronze commercial pressure boundary parts, such as the casting and cover.

Let us now look in some depth at some comparable pertinent points against other materials being utilized in pumping sea water including:

- **A. Physical Properties**
- **B. Corrosion Resistance**
  - **1. Uniform Corrosion**
  - **2. Pitting Corrosion**
  - **3. Crevice Corrosion**
  - **4. Galvanic Compability**
  - **5. De-Alloying**
  - **6. Stress Cracking**
- **C. Cavitating Erosion**
- **D. Wear Erosion**
- **E. Fouling**

A. Physical Properties

Contrary to common belief, Ni-Al-Br compares very favorable against other noteworthy corrosion resistant material per Table 1; particularly in terms of strength and hardiness.

TABLE 1

Physical Properties

	AMPCO 483	316 STAINLESS STEEL	ALLOY 20	70/30 COPPER NICKEL	GUN METAL
Tensile (psi) x 1000	92	80	69	68	52
Yield (psi) .5% elong x 1000	39	42	32	37	26
BHN (3000 kg)	174	156-170	130	84	70
Coef. of Expansion	$9x10^{-6}$	$9.2x10^{-6}$	$8.6x10^{-6}$	$9.2x10^{-6}$	$10.0x10^{-6}$
Density	.276	.290	.287	.323	.316
Thermal Cond.	.086	.038	.05	.07	.18
Sp. Gr.	7.65	8.04	8.02	9.02	8.7
Modulus of Elas. x 100	16	29	24	20.9	15
Elong 2"	24	50	48	20	28
Sp. Heat	—	.12	.12	.09	—

As a point of interest for design engineers, note that the effect of cross-sectional thickness on mechanical properties is minimal on the aluminum bronzes while other copper alloys such as the tin bronzes in thickness from 3/8 to 2 inches can expect over a 50% less yield tensile strength over this range as the thickness increases.

B. Type of Corrosion

Metals can be attacked in a corrosive manner in several ways ranging from a uniform dissolution to highly localized pitting or cracking. The focus here will be on the resistance of aluminum bronzes and competing material in sea water applications to the different forms of attack.

1. Uniform Corrosion

General overall surface penetration by chemical reaction causes a uniform reduction of the pump casting's wall thickness. The amount of metal removed by general corrosion in sea water or fresh water is insufficient to cause significant damage during operation to components in any of the non-ferrous metals, alloys or austenitic stainless steel in normal commercial use. Refer to table 2 below.

TABLE 2

Resistance of Cast Copper Alloys to Impingement Attack and General Corrosion in Sea Water

	Composition % (Bal. Cu)					Depth of Impingement Attack (mm)		General Corrosion Weight Loss (mg/cm^2 per day)	
						28-day Jet Impingement 20°C	14-day Brownsdon & Bannister 20°C	Water in Slow Motion	Water Speed 10 m/s
	Al	**Fe**	**Ni**	**Mn**	**Zn**				
Aluminum Bronze	8.2	1.7	—	—	—	0.04	0.19	0.15	0.17
Nickel Aluminum Bronze	8.2	2.9	4.3	2.4	—	0.00	0.32	0.04	0.10
Nickel Aluminum Bronze	8.8	3.8	4.5	1.3	—	0.00	0.28	0.04	0.16
Manganese Aluminum Bronze	7.6	2.8	3.1	10.0	—	0.01	0.24	0.04	0.11
High Tensile Brass	0.8	0.8	0.2	0.5	37.0	0.03	0.08	0.09	0.73
	Sn	**Zn**	**Pb**						
Gunmetal	9.7	1.4	0.6			0.02	0.32	0.14	0.74
Gunmetal	5.1	5.0	4.3			0.23	0.39	0.22	1.66

Table 2 data is from a paper, "The Resistance of Copper Alloys to Different Types of Corrosion in Sea Water," by Sigmund Bog of the Ship Research Institute of Norway, 1975

Be aware that sea water's corrosiveness varies about the earth being particular higher in warmer climates and specific local areas such as the Dead Sea.

2. **Pitting Corrosion**
   Extremely localized attack which often develops during stagnation periods (downtime). This type of corrosion can be devastating at the immersion line where deep cavities can rapidly develop in an irregular pattern.

FIGURE 2 — Pitting

Pitting corrosion is important because it can result in perforating a wall of a pump casting or other vessel in a relatively short period. All common metals and alloys are subject to pitting corrosion to a greater or less extent under certain conditions. Austenitic stainless steels including CN7M (alloy 20) are subject to crevice attack as well as pitting. Pitting in copper alloys will not normally be significant in sea water service.

3. **Crevice Corrosion**
   Intense localized corrosion which occurs within crevices and other shielded areas is categorized as crevice corrosion. It is associated with oxygen shielding or starvation in pockets, under gaskets, crevices under bolt heads, etc. Stagnant salt water promotes such attacks. This is one area where a good pump design can eliminate a good portion of the problem. Practically all metals and alloys develop accelerated local corrosion either within or just outside crevices or "shield areas" where two segments of the part are in close contact with one another but where a thin film of liquid can penetrate between and cause a reaction.

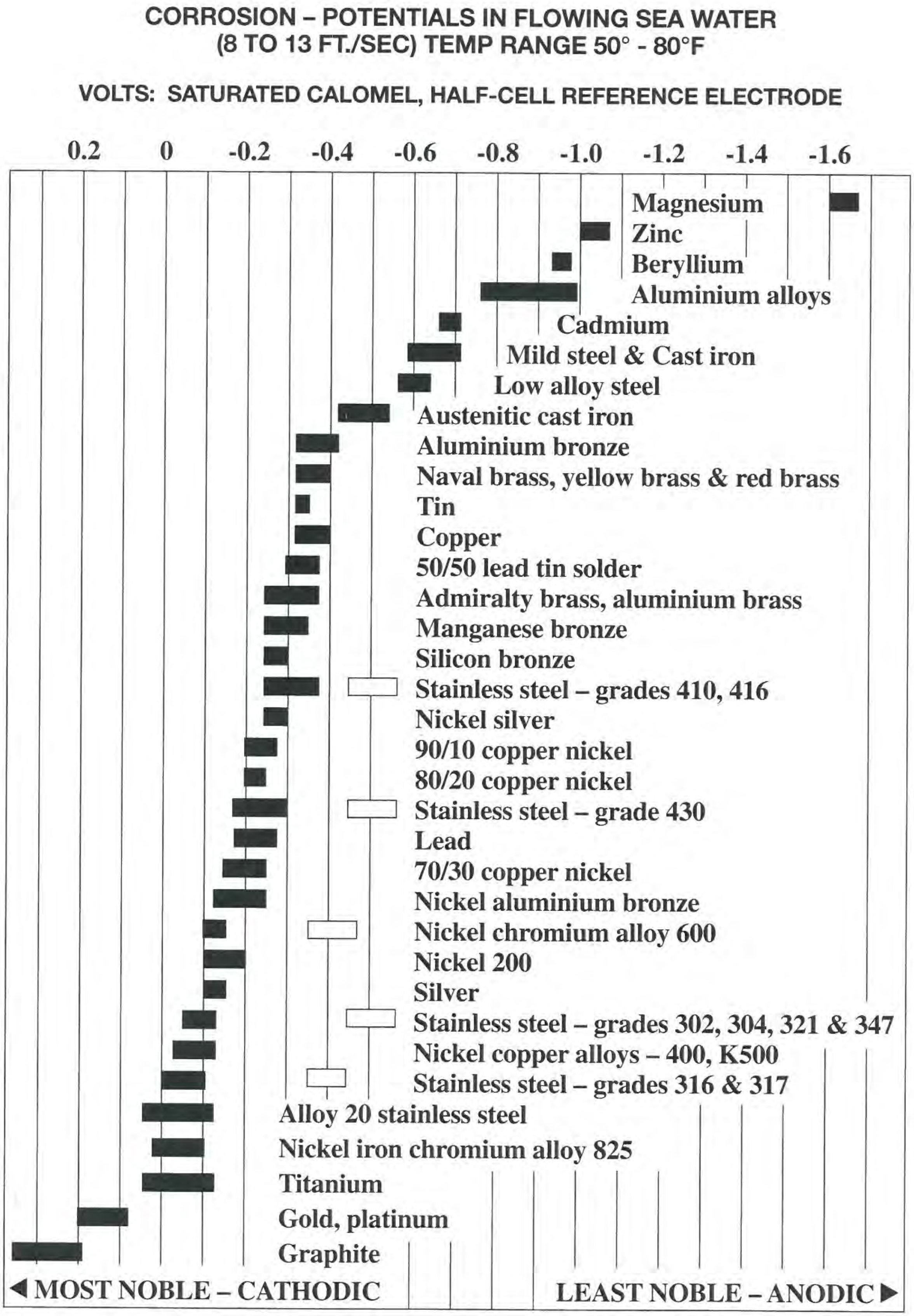
Crevice corrosion of stainless steels usually takes the form of pitting as described previously. Crevice corrosion of aluminum bronzes tends to be limited within the crevice only. None of the aluminum bronzes is seriously affected by crevice corrosion in the way that stainless steels may be since the attack does not produce pitting or serious roughing of the surface.

4. **Galvanic Corrosion**
   Extreme care must be used in making pump component selection for a sea water application to prevent or reduce galvanic corrosion.

Galvanic corrosion occurs when two different metals are exposed to a conductive solution (such as sea water). The result is an increased corrosion rate of one metal and decreased corrosion rate of the second metal. To avoid this action, select combinations of metals in close proximity in the galvanic series. The application engineer can turn galvanic effects to advantage by making certain that smaller components like sleeves, wear rings and shaft are more noble and protected by the larger, heavier walled casing.

Years ago, we were surprised when stainless steel seals substituted for special Ampco bronze seals in an Ampco alloy pump withstood the rigors of petroleum field salt waters. Later studies by others verified the success s being a kind of galvanic (cathodic) protection. The stainless type 316 steel must be of area less than that of the aluminum bronze components.

Corrosion potentials in flowing sea water are shown in Figure 3 on the following page.



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near +0.5 volts.

FIGURE 3

(Taken from "Guidelines for Selection of Marine Materials," INCO 12-83)

5. **Dealloying**

A form of corrosion that affects some copper alloys results in the specific removal of the major alloying element leaving a fragile porous copper structure of low strength. The most common example of dealloying occurs in some brasses where the attack takes the form of dezincification with removal of the zinc leaving the formation of a weak copper structure. A similar type of corrosion known as dealuminification occurs when the aluminum element is removed in some of the aluminum bronzes usually because of no or improper heat treatment of the affected casting. In severe services nickel (4%) – aluminum bronze castings properly heat treated should be more than adequate.

6. **Stress Corrosion**

Stress Corrosion is a highly localized attack occurring under the simultaneous action of tensile stress and an appropriate environment. The total degree of corrosion is light but cracking occurs in a direction perpendicular to that of the applied stress can cause rapid failure. The environments conducive to stress corrosion cracking vary for different types of alloy. Stainless steels suffer stress corrosion cracking in hot chloride solutions. Several copper alloys are subject to cracking when stressed in certain corrosive media. They vary however in their degree of susceptibility the brasses being the most susceptible and copper-nickel alloys the least. Aluminum bronzes also have a low susceptibility, especially the nickel-aluminum bronzes.

C. **Cavitating Erosion**

In the late 19th century, the developments of significant rotating speeds as a means of transmitting energy resulted in a new phenomenon – CAVITATION. In a centrifugal pump, the suction entry area of the impeller immediately beyond the vane tips is most susceptible to this type of attack.

Physical damage will vary depending on the material being attacked and the stage of cavitation exposure. As cavitation exposure continues, actual metal removal begins to occur. Pitting is caused solely by the mechanical action of collapsing bubbles. Effect varies with impeller material and degree of cavitation. The instant stress developed at the precise point of collapse has been theoretically determined to be as high as 100,000psi. Selected observations of certain types of cavitation has shown forming and collapsing rates of nearly 2,000,000 per second in a one-inch diameter area.

FIGURE 4 — Cavitation

Material selection as a means of minimizing cavitation damage has been done in an empirical manner based on experience, lab testing and actual performance in the field. Results have shown both nickel-aluminum bronze and 316 stainless steel to have good resistance to cavitating erosion as shown on Figure 4. Both are far superior to other common pump material such as gray iron, carbon steel, brass and 70-30 copper nickel.

TABLE 3

HOW METALS RATE IN RESISTANCE TO CAVITATON EROSION	
(Typical Hydraulic Equipment Materials)	
Alloy	**Weight Loss After 24 Hr. Mg**
a. Rolled Stellite	0.6
b. Welded Aluminum Bronze	3.2
c. Cast Aluminum Bronze	5.8
Welded Stainless Steel (2 layers, 17 Cr-7% Ni)	6.0
Hot Rolled Stainless Steel (26 Cr-13% Ni)	8.0
Tempered, Rolled Stainless Steel (12% Cr)	9.0
Cast Stainless Steel (18 Cr-8% Ni)	13.0
Cast Stainless Steel (12% Cr)	20.0
Cast Manganese Bronze	80.0
Welded Mild Steel	97.0
Plate Steel	98.0
Cast Steel	105.0
Aluminum	124.0
Brass	156.0
Cast Iron	224.0

a. Despite the high resistance of this material to cavitation damage, it is not suitable for ordinary use because of its comparatively high cost and the difficulty encountered in machining and grinding.
b. Ampco-Trode 200: 83Cu – 10.3 A1 – 5.8% Fe
c. Ampco 20: 83.1 Cu – 12.4 A1 – 4.1% Fe

(Taken from "Avoid Cavitation Damage," by William J. Rheingans, Mgr., Hydraulic Dept., Allis-Chalmers/Materials in Design Engineering, 9-58 article).

Materials having high resistance can be attributed to tough homogenous structure, high corrosion fatigue limit, high tensile strength and good hardness.

The soundness of the casting has a very significant bearing on resistance to cavitation erosion and impingement attack. Maximum resistance cannot be expected from a casting produced by bad foundry practice. Cavitation pitting is also accentuated in cracks, scratches and other surface flaws.

Proper pump selection based on hydraulic flows can substantially reduce or even eliminate the cavitation factor.

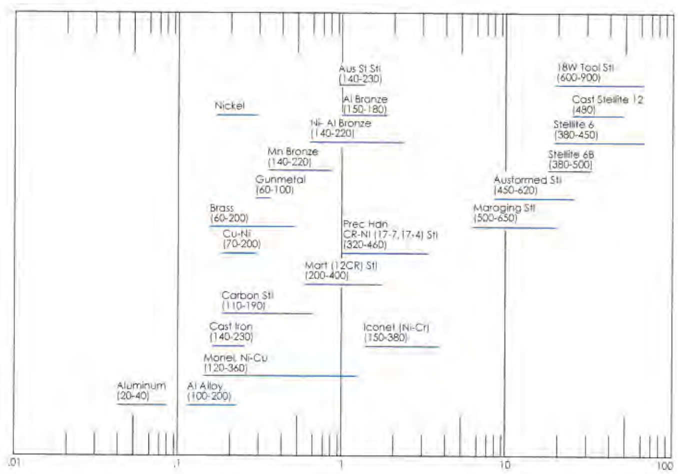
D. Wear-Erosion

Erosion is defined as diminishing or destroying by degree. In the design and application of Centrifugal pumps converting mechanical energy into hydraulic energy through centrifugal action there are several areas throughout the pump where erosive actions may occur.

While no common denominator has yet evolved as exact measurement of erosion resistance based on individual properties such as hardness, grain size, matrix characteristics, work hardening, etc., there are other factors that may outdo them all and that is the pump's design (efficiency) and the actual point of operation.

To provide a general indicator of erosion resistance you are referred to Figure 5. This data published by Westinghouse Electric compares normalized erosion resistance of several materials to austenitic stainless steels. Note that nickel aluminum bronze in this test is rated as being superior to the harder stainless alloys thus explaining why this material is so often used in pump impellers.

FIGURE 5 — Normalized erosion resistance relative to 18-8 stainless steel (170 DPH). Hardness of various materials (in parentheses) is in Brinell or Vickers hardness numbers.



Taken from "Erosion By Liquids," by F.J. Heymann, Large Turbine Division Westinghouse Electric/Machine Design 12-10-70 article.

Even developers of special austenitic stainless steels have written in their literature that Nickel Aluminum Bronze has given excellent service in pump impellers, stating – "The Stainless Steel alloys have somewhat better resistance to the most severe velocity conditions, but in many designs nickel aluminum bronze can approach the durability of stainless steel and is resistant to pitting during down periods.

E. Inter-relation of Corrosion and Fouling of Metals in Sea Water

Fouling of metals can affect performance and life expectancy. Sea organisms attached to metal particularly in slow moving or "down" conditions can drastically affect a pumping system's efficiency and promote severe crevice corrosion.

Metals alloys can be divided into three categories relative to their tolerance for crevice effects be it caused by design features of the pump or fouling (marine organism attached to a metal surface).

FIGURE 6 — The five-year sequence of fouling on 90-10 Cu-Ni (CA 706) in sea water. Exposure periods are (from left to right): top—3 months, 9 months, months; bottom—36 months, 48 months, 60 months.

(From The interrelation of corrosion and fouling in sea water, 1975)

1. **Corrodible Metals** – such as carbon steel, which will begin to corrode immediately without having any surface protection.

2. **Passive Metals** – materials such as the stainless steels, titanium, some aluminum and members of nickel base alloys. Occurrence of organism attachment can accelerate localized corrosion attacks on alloys that are highly susceptible to oxygen concentration cells.

3. **Protective Film Formers** – materials such as copper, copper alloys and other metals. The copper-base alloys remain fouling resistant because of the heaviness of the buildup layer which is quite removable off the initial film. Film forming metals such as beryllium and lead are not anti-fouling when immersed in sea water.

Years ago the leaching theory for anti-fouling resistance of copper-based alloys in sea water supposedly required a minimum 0.7 mpy loss rate to prevent fouling. More recently collected data following a 5 year exposure of copper and two copper-based alloys provided rates from 0.3 to .01 mpy as being adequate. Today's consensus holds that the toxic properties are not due to a release of poisonous ions into the seawater but to the toxic surface layer on the metal.

SUMMARY

Great strides have been made in the twentieth century relative to effective materials of construction for handling salt water. In pumps, metal technology has gone from brass fitted cast iron units in the first half of this century to extremely costly titanium today. In this overall view you can be assured backed by empirical data and 40 years of sea water application that the moderately priced Nickel Aluminum Bronze alloy (Ampco 483) pump units properly employed should be successful in this state-of-the-art field.

Note that proper pump design and application together with the excellent properties of Ampco 483 are necessary to provide the ideal pump for handling sea water. The costs of a pump unit in Ampco 483 construction will run less in initial cost and require less maintenance than an austenitic stainless steel pump properly designed requiring fresh water flushing and complete draining during extended down times to reduce immersion line pitting. That today there is a bronze alloy that provides not only the excellent corrosion resistiveness properties of copper but by alloying with other elements primarily aluminum, nickel and iron results in a material that resists the immense stress caused by cavitation, wear due to the high velocities developed by the rotating impeller and a sound pressure boundary having a high yield stress limit.

For additional information, contact Ampco Pumps Company or visit www.ampcopumps.com.

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