

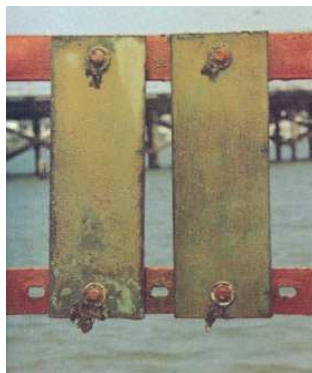
90/10 Copper-Nickel vs. “Sea-Cure” Stainless Steel
A Functional Comparison of Two Condenser Tube Alloys

Condenser tube material selection is one of the most important decisions faced by Electric Utility Engineering personnel. Determination of the “best” material for a given application should be based on an evaluation of a material’s strengths and weaknesses versus the functional requirements of the application. Typical criteria for evaluating condenser tube materials include water side corrosion resistance, condensate side corrosion resistance, heat transfer capability, compatibility with other system materials, condenser design considerations, ease of installation, in-service inspection considerations, and economics.

90/10 Copper-Nickel and “Sea-Cure” Stainless Steel are two condenser tube materials that are generally accepted for use in sea water and brackish water installations. 90/10 Copper-Nickel, with an official alloy designation of UNS C706 00, has a nominal chemical composition of 10% nickel, 1.4% iron, and 88.6% copper. Traditionally known for being a seawater condenser tube alloy, its outstanding resistance to most types of corrosion has led to its widespread use in freshwater systems at a wall thickness of 0.035” (20 BWG). UNS S446 60, more commonly referred to as “Sea-Cure”, has a nominal composition of 26% chromium, 3% molybdenum, 2.5% nickel, and iron as the balance. With its good resistance to corrosion from chlorides, “Sea-Cure” represents a stainless steel that can be used in saline environments; it is typically used at a wall thickness of 0.028” (22 BWG).

The strengths and weaknesses of each of these materials relative to the functional requirements listed above are discussed in the following paragraphs.

Biological Fouling & Bioslime Formation - Copper alloys possess an inherent natural resistance to biofouling, and the more copper there is in an alloy, the greater will be that alloy’s resistance to biofouling. Because of its high copper content, 90/10 Copper-Nickel is the most biofouling resistant of all of the commonly used condenser tube materials. By contrast, passive metals like titanium, aluminum, and stainless steel (including Sea-Cure) exhibit no resistance to biological fouling. This can be seen in the following photographs which were the result of a 3-month study¹ of several metals in seawater. Clearly, the 90/10 Cu-Ni alloy is resisting fouling from algae, mussels, etc. while the passive metal exhibits total susceptibility. For clarification, and contrary to what manufacturers of competitive materials state, the biofouling resistance of copper alloys is due to the copper in the protective oxide film and not from the



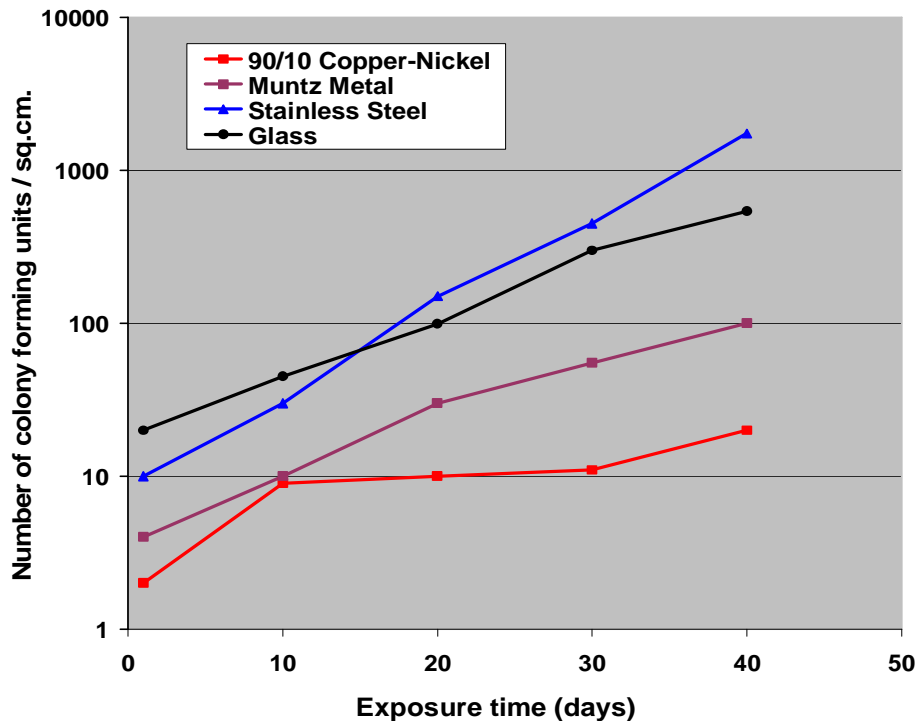
90/10 Copper-Nickel



Passive Metals

leaching of copper ions. This is evident in the photos above in that the steel bolts holding the Copper-Nickel panels exhibit biofouling.

Copper alloys are also highly resistant to bioslime formation. In the following graph ², data is presented for 90/10 copper-nickel, Muntz Metal (60% copper & 40% zinc), S304 stainless steel, and glass. The data is plotted as the number of bacterial colony forming units per square centimeter versus time. Note that the y-axis is a log scale. As can be seen, stainless steel (S304, Sea-Cure, etc) is 100 times more likely to develop a bioslime than is 90/10 copper-nickel.



Most waters are prone to biological fouling, but both biofouling and bioslime formation are more likely to occur in warmer cooling waters than colder cooling waters, and in recirculating cooling water systems versus once-through systems.

Heat Transfer Capability - The thermal conductivities of both 90/10 Copper-Nickel and Sea-Cure are listed below. Admiralty Brass is also listed in this table since it is generally considered to be the standard against which other condenser tube materials are compared. As can be seen, the thermal conductivity of 90/10 Copper-Nickel is 2-1/2 times greater than Sea-Cure.

Tube Material	Thermal Conductivity (Btu's/SqFt/Ft/Hr/F (@ 68F))
90/10 Copper-Nickel	26
Sea-Cure	9.8
Admiralty Brass	64

Other factors contributing to heat transfer resistance include water side and steam side water films, the protective oxide films that form on the ID and OD of the tubes, crystalline fouling (scale), and biological fouling. Lustenader & Staub ³ suggested that these other factors may account for as much as 98% of the overall resistance to heat transfer and that the contribution of the tube material to overall heat transfer resistance could be as small as 2%. However, the thermal conductivity of the tube material is still a significant factor as will be shown in the following paragraphs.

The General Heat Transfer Equation is:

$$Q = U \times A \times \Delta T$$

where: **Q = the Heat Duty in Btu's/Hr**
U = the Overall Heat Transfer Coefficient
A = the Condenser Tube Surface Area
 ΔT = the Log Mean Temp Difference (LMTD)

For the purpose of determining an overall Heat Duty, the Heat Exchange Institute (HEI) ⁴ accounts for the water films and fouling through the use of "Correction Factors" applied to an uncorrected heat transfer coefficient. U, the overall heat transfer coefficient, is calculated by multiplying an uncorrected heat transfer coefficient U_1 by correction factors for water temperature, the tube material and tube wall thickness, and the tube cleanliness:

$$U = U_1 \times F_W \times F_M \times F_C$$

where: **U = Overall Heat Transfer Coefficient**
 U_1 = Uncorrected Heat Transfer Coefficient
 F_W = Water Temperature Correction Factor
 F_M = Material & Gauge Correction Factor
 F_C = Cleanliness Factor

The "uncorrected heat transfer coefficient" values that are used in this equation were determined by the Heat Exchange Institute by testing a tube bundle of new, clean 18 BWG (0.049" wall thickness) Admiralty Brass tubes with a 70°F inlet water temperature. This "uncorrected heat transfer coefficient" adjusts for the steam side and water side films in that the values are for new, clean (unfouled) tubes. Values for the "uncorrected heat transfer coefficient" can be found in Table 1 of the HEI Standards ⁴. From that table, U_1 for a 1" OD tube with a 7 fps water velocity equals 695.8 (this number will be used later in an example calculation).

Values for the "water temperature correction factor" can be found in Table 2 of the HEI Standards ⁴. From that table, F_W equals 1.000 for an inlet water temperature of 70°F (the water temperature that was used to determine the uncorrected heat transfer values) and it equals 0.923 for an inlet water temperature of 60°F (the inlet water temperature that will be assumed in the subsequent example calculation).

Values for the "tube material and gauge correction factor" can be found in Table 3 of the HEI Standards ⁵. Recall that the uncorrected heat transfer coefficients were determined from tests on tube bundles of 18 BWG Admiralty Brass. Therefore, 18 BWG Admiralty Brass was assigned a value of 1.00 in this table with other material & wall thickness combinations being assigned correction factors based on the heat transfer results obtained during tests of tube bundles of those material and wall thickness combinations. 18 BWG 90/10 is assigned a value of 0.93, 20 BWG 90/10 is assigned a value of 0.96, and 22 BWG Sea-Cure is assigned a value of 0.89.

The last component in the overall heat transfer equation is the "cleanliness factor". An 85% cleanliness factor is generally accepted within the industry as a reasonable assumption for clean non-fouling waters. Since stainless steels and titanium have lower thermal conductivities than copper alloys, in an attempt to offset the effect that a lower thermal conductivity has in the overall heat transfer equation (i.e. the tube material and gauge correction factor), the manufacturers of these materials suggest that a 95% cleanliness factor can be used, and they justify their use of a 95% cleanliness factor on the basis that the protective oxide films that form on their materials are very thin and tightly adherent. Unfortunately, as earlier discussed, most waters are prone to biofouling and bioslime formation. For this reason, paragraph 4.2.5 of the HEI standard ⁴ cautions "Non-copper bearing tube materials are more susceptible to biofouling than tubes with high copper content". The use of a 95% cleanliness factor for stainless steel might be justified with a flow velocity in excess of 10 fps, but certainly not for flow velocities below 8 fps, the range for which most condensers are designed.

Since copper alloys exhibit a natural inherent resistance to biological fouling and bioslimes, they stay cleaner; and since 90/10 Copper-Nickel has the highest copper content of all of the commonly used

condenser tube materials, the use of an 85% cleanliness factor is justified. Determining what cleanliness factor to use for Sea-Cure is a little more difficult as the tendency for bioslime formation will vary with geography and cooling water temperature. As a general statement, Sea-Cure will behave like any other stainless steel. The best source of information is from other units at the same site, if they happen to be tubed with a stainless steel. The next best source of information is from neighboring utilities that utilize the same cooling water source. Industry meetings, magazine articles, etc can also provide insights. As an example, it was reported in Power Engineering Magazine ⁶ that, when Alabama Power replaced 90/10 Copper-Nickel with S304 stainless steel in unit 9 at their Gorgas station, the cleanliness factor dropped from 85% to 35-45%. Similar experiences have been reported for other parts of the United States. For example, at a two-unit plant in the Midwest (identical 600 MW units), the EtaPro plant monitoring system reported that one unit tubed with Admiralty Brass achieved a cleanliness factor in the range of 70-75% with a back pressure of 2.16" Hg, while the sister unit tubed with stainless steel achieved a cleanliness factor in the range of 55-65% with a back pressure of 3.18" Hg. The unit tubed with stainless steel has a sponge ball continuous cleaning system, both units are chlorinated for two hours per day, and shock chlorination is employed at least twice per year. Intermittent chlorination coupled with periodic shock treatments is generally effective at controlling biofouling with non-copper alloys but, as is the case at this plant, there is still an adverse effect on heat transfer and back pressure from the presence of bioslimes.

Overall heat transfer coefficients can now be calculated for 90/10 Copper-Nickel and for Sea-Cure to evaluate the heat transfer capability of each material relative to the other material. For these calculations, a maintenance retubing will be assumed. 90/10 Copper-Nickel is typically used at a wall thickness of 20 BWG (0.035" wall) for fresh water installations and at both 18 BWG (0.049" wall) and 20 BWG for salt water installations. Sea-Cure is typically used at a wall thickness of 22 BWG (0.028" wall) regardless of the water type. Calculations will be presented for these three options. As previously discussed, the uncorrected heat transfer coefficient U_1 is determined based on the tube OD and water velocity. For the example calculations, a tube OD of 1.000" and a water velocity of 7.0 fps will be assumed. For the 18 BWG 90/10 Copper-Nickel, the value to be used from Table 1 of the HEI standards is 695.8. Since a maintenance retubing has been assumed, and since 20 BWG 90/10 and 22 BWG Sea-Cure both have a larger internal volume than the 18 BWG 90/10, the water velocity for both of these options will be reduced since it is unlikely the circulating water pumps will be replaced. The flow velocity for the 20 BWG 90/10 is calculated to be 6.58 fps and the flow velocity for the 22 BWG Sea-Cure is calculated to be 6.39 fps. From Table 1 of the HEI standards, the value for U_1 for the 20 BWG 90/10 is 675.6 and the value for 22 BWG Sea-Cure is 664.8. The water temperature correction factor for all three options will be 0.923 (for 60°F inlet water). As previously stated, from Table 3 in Addendum 1 of the HEI standards, the tube material and gauge correction factors to be used are 0.96 for 20 BWG 90/10, 0.93 for 18 BWG 90/10, and 0.89 for 22 BWG Sea-Cure. The cleanliness factors to be used in these example calculations will be 75% for the Sea-Cure and 85% for the 90/10, although the above discussion of cleanliness factors might suggest the use of a lower value for the Sea-Cure.

Example Calculations:

$$U = U_1 \times F_w \times F_M \times F_C$$

$$U \text{ for 18 BWG 90/10} = 695.8 \times 0.923 \times 0.93 \times 85\% = 507.68$$

$$U \text{ for 20 BWG 90/10} = 675.6 \times 0.923 \times 0.96 \times 85\% = 508.84$$

$$U \text{ for 22 BWG Sea-Cure} = 664.8 \times 0.923 \times 0.89 \times 75\% = 409.59$$

As can be seen, there is a significant difference between the Sea-Cure and either of the 90/10 options. On a percentage basis, the Heat Transfer Penalty for Sea-Cure calculates to be:

Heat Transfer Penalty for Sea-Cure

19.3 % vs. 18 BWG 90/10

19.5% vs. 20 BWG 90/10

This Heat Transfer Penalty is entirely due to the lower thermal conductivity of Sea-Cure relative to 90/10 and the fact that Sea-Cure is susceptible to biofouling and bioslimes. In this example, if Sea-Cure is specified, the unit will either need to be de-rated, or more fuel will be required.

One might ask “what is the cost of this reduced heat transfer?”

- Using the Midwestern utility discussed above as a guideline, the back pressure increase with Sea-Cure will be in the range of 0.31 – 0.68 “Hg.
- Per Table 3-1 of EPRI CS-4554 “Heat Rate Improvement Guidelines”, a back pressure increase of 1” of Hg is equivalent to a heat rate increase in the range of 42-269 Btu’s/kWh (204 Btu/kWh average).
- Also in EPRI CS-4554 (page 9), for a 500 MW plant, a 400Btu/kWh heat rate increase translates to an annual increased fuel cost of \$4 million.
- Thus, if a back pressure increase of 1” Hg equals a heat rate increase of 204 Btu’s/kWh, and if a heat rate increase of 400 Btu/kWh equals an increased fuel cost of \$4 million/year, then a back pressure increase of 1” of Hg costs about \$2,000,000/year.

Thus, for our example, a back pressure increase of 0.31-0.68” Hg for the Sea-Cure would result in an annual fuel cost increase in the range of \$610,000-\$1,390,000.

General Corrosion Resistance – Both materials would be rated as “Excellent”, but condenser tubes never fail prematurely from general corrosion. Rather, premature failure occurs because of a selective form of corrosion attack. A summary of each alloy’s resistance to various forms of selective attack is provided in the table below and as discussed in the paragraphs which follow.

Type of Corrosion Attack	90/10 Cu-Ni	Sea-Cure
General Corrosion Resistance	Excellent	Excellent
Erosion-Corrosion Resistance	Very High	Excellent
Resistance to Sulfide-Related Pitting	Poor	Excellent
Resistance to Crevice-Related Pitting	Excellent	High
Steam Impingement Resistance	Good	Excellent
Resistance to Condensate (Ammonia) Attack	Very High	Excellent
Resistance to Stress Corrosion Cracking	Excellent	Excellent

Erosion-Corrosion Resistance – The potential for erosion-corrosion is directly related to cooling water velocity. Both materials are good, but Sea-Cure is better. 8 fps is recommended as the maximum design water velocity for 90/10 Copper-Nickel in seawater, and 10 fps max is recommended for fresh water. There is no practical upper limit for Sea-Cure.

Sulfide-Related Pitting Attack is the “Achilles Heel” of all copper alloys. The reader is cautioned against the use of 90/10 Copper-Nickel in cooling waters containing greater than 0.5 ppm sulfides.

Crevice-Related Pitting Attack has historically been the “Achilles Heel” for stainless steel alloys. The high chromium and molybdenum content of Sea-Cure greatly enhances the resistance of this alloy to this type of corrosion attack, but exposure to temperatures above 104° F for any period of time (as might occur during an extended wet lay-up) should be avoided as the alloy’s resistance to crevice attack falls off dramatically above this temperature.

Steam Impingement Resistance – Virtually all copper-nickel and stainless steel alloys exhibit very good resistance to this type of corrosion.

Resistance to Ammonia Attack – Both 90/10 Copper-Nickel and Sea-Cure are considered suitable materials for the air removal section of the condenser.

Resistance to Stress Corrosion Cracking – Typical environments in which stress corrosion can occur include ammonia (for copper alloys) and chlorides (for stainless steels). However, 90/10 Copper-Nickel and Sea-Cure are both considered essentially immune to stress corrosion in these environments.

Other factors to consider when selecting a condenser tube material include the following:

Compatibility with other System Materials – Galvanic corrosion is a possibility whenever two dissimilar materials are in contact with one another as is the case with condenser tubes and tubesheets. Traditionally, tubesheet materials have been produced from copper alloys such as Muntz Metal, Naval Brass, Aluminum Bronze, and Nickel Aluminum Bronze. 90/10 Copper-Nickel is compatible with all of these materials. By contrast, Sea-Cure ranks with titanium as being one of the most noble (cathodic) of all of the commonly used condenser tube materials. When coupled to one of the less noble tubesheet materials mentioned above, galvanic corrosion of the tubesheet can be expected. For this reason, a more highly alloyed tubesheet is required with Sea-Cure. In general, the tubesheet must be more highly alloyed in chromium, molybdenum, and nickel⁷. Specific recommendations include Incoloy Alloy 825, Alloy 904L, 254 SMO, 25-6 Mo, AL-6XN, 1925 hMo, Inconel Alloy 625, and Alloy C276. In the case of a maintenance retubing, replacing the tubesheets may not be practical. One alternative is to install an impressed current cathodic protection system. With this alternative, there is the risk that too large of a negative potential will result in hydrogen embrittlement of the Sea-Cure tubes. Another alternative is to epoxy coat the tube sheets. For a unit with 10,000 tubes, the cost of epoxy coating the tubesheets would be at least \$250,000.

Condenser Design Considerations – The potential for mid-span collision is primarily a function of support plate spacing and the condenser tube material's modulus of elasticity. In a properly designed condenser, mid-span collision will generally be a consideration only if there is a change in tube material. Consultation with the condenser manufacturer is highly recommended if a high modulus material is being replaced with a lower modulus material.

Ease of Installation – Sound, leak-free joints can be obtained with 90/10 Copper-Nickel when generally accepted rolling-in procedures are practiced. Sound, leak-free joints can also be obtained with Sea-Cure, but welding of the tubes to the tubesheet is recommended by the manufacturer⁷.

In-Service Inspection – Sea-Cure is not readily inspected using standard eddy-current test equipment; 90/10 Copper-Nickel is.

Economics – The price of a condenser tube is comprised of manufacturing cost and metal value, and metal values change constantly as the "supply & demand" relationships change. However, based on the metal values in effect as this comparison is being written, Sea-Cure appears to cost 20-30% more than 90/10 Copper-Nickel at the wall thicknesses that are commonly specified for each material, i.e., 0.028" wall (22 BWG) for Sea-Cure and 0.035" wall (20 BWG) or 0.049" wall (18 BWG) for the 90/10 Copper-Nickel. However, it is strongly recommended that quotations be obtained for both alloys before final material decisions are made.

Conclusion – Assuming normal standard operating parameters, economics and heat transfer capability favor the selection of 90/10 Copper-Nickel.

- The initial purchase cost of 90/10 Copper-Nickel tubes is less than that of Sea-Cure tubes
- The cost of operating a 500 MW unit tubed with Sea-Cure could be as much as \$1.5 million more than 90/10 Copper-Nickel depending on the tendency of the cooling water to form bioslimes
- Epoxy Coating of the Tubesheets or a Cathodic Protection System will increase initial installation costs by as much as \$250,000
- Increased Downtime for Mechanical Cleaning and/or the installation of a Continuous Cleaning System may be required with Sea-Cure tubes.

Should 90/10 be the alloy of choice, the reader is cautioned to review cooling water flow rates versus the recommended design velocities for the alloy, and to evaluate the cooling water for the presence of sulfides. Should Sea-Cure be the alloy of choice, the reader is cautioned to avoid exposure to temperatures above 104° F (e.g., during a temporary lay-up) in addition to the concerns stated above.

Bibliography

1. *The Interrelation Of Corrosion and Fouling Of Metals In Seawater*, K.D. Eford, NACE Corrosion/75
2. Biofilm Formation, Chapter 1, *Microbiologically Influenced Corrosion*, Little & Lee, 2007, John Wiley & Sons.
3. *Development Contributions to Compact Condenser Design*, Lustenader & Staub, INCO Power Conference, Wrightsville Beach, NC, May 1964
4. *Standards for Steam Surface Condensers*, 9th Edition, Heat Exchange Institute, 1995.
5. *Standards for Steam Surface Condensers*, 9th Edition, Addendum 1, Heat Exchange Institute, 2002.
6. *Gorgas Team Battles Condenser Tube Problems*; Swiney, Reed, Huguley, and White; Power Engineering; May 1999
7. *SEA-CURE – Common Practice for Welding Stainless Tubes Into Clad or Monolithic Tubesheets*, Plymouth Tube Technical Data Sheet.