



Stainless Steel versus Copper Tube Air Cooled Heat Exchangers: The Science Behind the Material

Abstract

The air-cooled heat exchanger market relies primarily on two tube materials: copper and stainless steel. EVAPCO uses Type 304L stainless steel tube with aluminum fins to deliver robust, long-life industrial equipment. This paper reviews the heat transfer performance, corrosion resistance, mechanical properties, and manufacturing differences between stainless steel and copper, showing why stainless steel tube offers the greatest life cycle cost benefit for air-cooled applications.

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EVAPCO, a global leader in heat rejection solutions, supplies equipment to the industrial, data center, power, refrigeration and HVAC markets. Committed to the highest quality standards and peak thermal performance, EVAPCO standardizes on stainless steel tubes across all air cooled heat exchanger product lines serving all of these demanding markets. In addition, EVAPCO coil bundles meet stringent ASME B31.5 and IIAR-2 manufacturing standards, and our eco-Air line of air cooled heat changers (i.e. dry and adiabatic fluid coolers) are independently certified by the Cooling Technology Institute (CTI) for thermal performance. These EVAPCO standards surpass what is typically provided by copper tube heat exchanger manufacturers.

Thermal Performance

It is true that copper exhibits increased thermal conductivity when compared to stainless steel:

- Copper’s thermal conductivity is 386 W/m*K
- Type 304L stainless steel’s thermal conductivity is 16.2 W/m*K

However, a thermal conductivity difference in tube material is not directly proportional to the total tube and fin heat exchanger providing greater thermal capacity. Let’s break this down to basic thermodynamic equations.¹

$$Q = U * A * LMTD$$

Q = Heat Transfer Rate

A = Heat Transfer Surface Area

U = Heat Transfer Coefficient

LMTD = Logarithmic Mean Temperature Difference

For comparison purposes between two different tube materials, parameters A and LMTD are held constant. As such, the U value is the remaining variable expressed by the following equation.

$$U = \frac{1}{\left(\frac{1}{h_{IF}} + \frac{L}{\lambda} + \frac{1}{h_{EF}}\right)}$$

h_{IF} = Overall Interior Heat Transfer Film Coefficient

h_{EF} = Overall Exterior Heat Transfer Film Coefficient

L = Thickness of the Wall

λ = Thermal Conductivity



Figure 1: Stainless Steel Coil Bundle

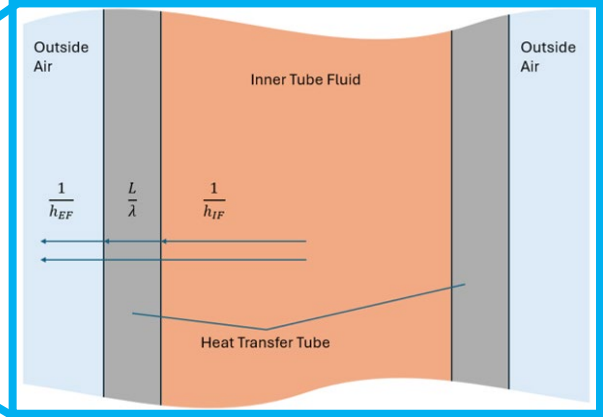


Figure 2: Heat Transfer Diagram

There are several variables that can influence the overall heat transfer film coefficients, such as coil manufacturing, fouling, thermodynamic resistances, and others. The “U” equation captures and simplifies all into three characteristics. In testing, h_{IF} ranges from 3,000 to 15,000 $W/(m^2 * K)$ and h_{EF} ranges from 35 to 60 $W/(m^2 * K)$ which dominate the total equation. For the purpose of this example h_{IF} of 7,000 and h_{EF} of 60 was chosen as it is closest to typical conditions for tube and fin in heat rejection applications:

$$U_{SST} = \frac{1}{\left(\frac{1}{7000} + \frac{0.00508}{16.2} + \frac{1}{60}\right)} = 58.40$$

$$U_{Cu} = \frac{1}{\left(\frac{1}{7000} + \frac{0.00508}{386} + \frac{1}{60}\right)} = 59.44$$

$$\frac{U_{Cu}}{U_{SST}} = \frac{59.44}{58.40} = 1.0178 \approx 1.8\% \text{ increase}$$

In exhaustive laboratory testing, EVAPCO has confirmed a 1-3% thermal capacity increase when testing EVAPCO manufactured copper vs stainless steel coils in equivalent circuiting and heat transfer surface area. In the market, stated capacity differences are often stated in excess of 20% which contradicts what thermodynamics would reasonably support.

EVAPCO is the only manufacturer, at the time of publication, to have CTI 201RS certified air-cooled fluid coolers. This is the most likely reason for large differences in market capacity ranges, with non-certified manufacturers commercially rating their equipment. CTI certification levels the playing field by requiring manufacturers to publish certified capacities tested per established CTI test codes, guaranteeing that end-users are getting the capacity purchased.

Corrosion Resistance

Stainless steel has superior corrosion resistance in comparison to copper when exposed to environmental factors that could be seen in typical industrial heat rejection applications. Comparing industry accepted chemical resistance properties from the National Association of Corrosion Engineers² and others, for Type 304L stainless steel and copper, show that stainless steel will outperform copper against an assortment of common chemicals/refrigerants. The standard meanings of each term are outlined beneath the table.

Chemical	Type 304L Stainless Steel	Copper
Hard Water	Excellent	Good
Glycols	Excellent	Good
Sodium Hydroxide	Good	Poor
Ammonia/Bleach	Good	Poor
Amine Corrosion Inhibitors	Excellent	Good
Dilute Sulfuric Acid	Fair	Moderate
Dilute Nitric Acid	Excellent	Poor
Bromine Biocides	Moderate	Poor
Peracetic Acid	Moderate	Poor
Potassium Hydroxide	Good	Poor
Deionized Water	Excellent	Poor
Ammonia	Excellent	Poor
Carbon Dioxide	Excellent	Good

Table 1: Corrosion Resistance for Type 304L Stainless Steel and Copper

Table Key:

Excellent – The material exhibits little to no corrosion in the given environment and is highly suitable for long-term use without protective measures.

Good – Some minor corrosion may occur over time, but the material is still an acceptable choice for the environment with minimal concerns.

Moderate – The material shows noticeable corrosion, and its use may require mitigation strategies like coatings, inhibitors, or more frequent inspections.

Fair – Significant corrosion is expected, and the material may only be used if protective measures are applied, or if a shorter service life is acceptable.

Poor – The material corrodes rapidly in the environment and is not recommended for use.

Additionally, stainless steel will naturally form a passive chromium oxide layer that self-heals and doesn't impact performance. Copper, by contrast, forms a "patina" layer that reduces heat transfer efficiency. Over time, this patina degrades external tube wall, accelerated by acidic water or temperature swings - conditions common in industrial applications, creating maintenance tasks. Corrosion inside the copper tubes can lead to leaks undetectable from visual inspection and is difficult to prevent. This is showcased in the useful life of products with stainless steel tubes when compared to copper. Stainless steel air-cooled products should last more than 30 years if maintained properly, copper typically lasts 12-15 years.



Figure 3: Stainless Steel Tubes

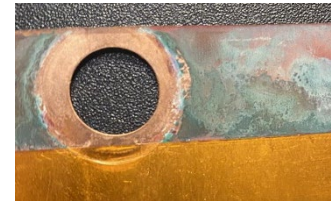


Figure 4: Patina Copper

Burst Pressure

While the process design pressure in fluid cooler systems is typically below 250psi (1.72 MPa), there is merit to having a material that could withstand higher pressures if the need arises. As indicated in the equation below, stainless steel has a higher burst pressure than copper, for the same diameter and wall thickness:³

$$P_{Burst,SST} = \frac{2 * S * t}{D} = \frac{2 * (485 * 10^6) * (0.000508)}{0.015875} \approx 31.12 \text{ MPa (4,514psi)}$$

$$P_{Burst,Cu} = \frac{2 * S * t}{D} = \frac{2 * (207 * 10^6) * (0.000508)}{0.015875} \approx 13.26 \text{ MPa (1,923psi)}$$

P_{Burst} = Burst Pressure S = Tensile Strength t = wall thickness D = Outer Diameter

This means that under higher internal stress, like tubes freezing during the winter, there is about 2,610psi (18MPa) safety in choosing stainless steel tubes. No one ever expects coils to freeze, but the robust solution of stainless steel will add resiliency and reduce risk in the heat transfer equipment. As a quality assurance initiative, EVAPCO burst pressure tests a stainless steel tube every 30 minutes, a good burst test is shown, where the failure is in the base material and not at the

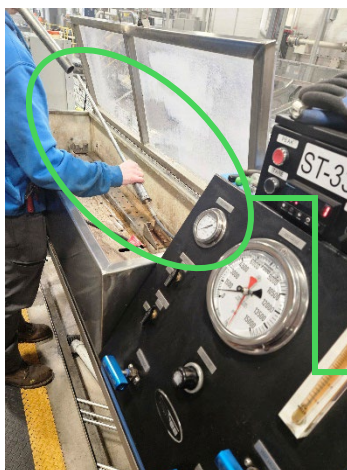


Figure 5: Tube Burst Test

welded seam. This continuous testing ensures that consistent, quality welds are maintained in all EVAPCO equipment.

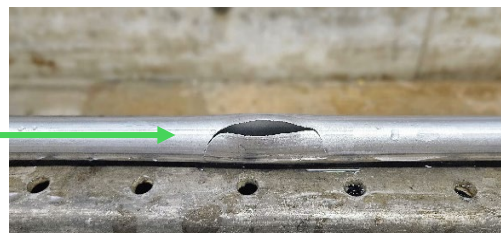


Figure 6: Burst Stainless Steel Tube

Robustness

The last material property that will be discussed is tensile strength, rigidity, and hardness of stainless steel in comparison to copper. The three material properties that determine a material's "robustness" or ability to take force, stress, scratching, or damage without permanently deforming.⁴

Metric	Type 304L Stainless Steel	Copper
Tensile Strength	485 MPa (70,343psi)	207 MPa (30,023psi)
Rigidity (Young's Modulus)	205 MPa (29,793psi)	121 MPa (17,542psi)
Hardness (Brinell)	215	80

Table 2: Material Properties of Type 304L Stainless Steel and Copper

Stainless steel is more resistant against maximum stress causing failure, it is more resistant to bending and deformation under load, and it is more resistant to surface indentation and scratching. These values support that stainless steel is a more robust material that can be more easily handled and has less risk of being damaged during installation and operation of the units, thus proving to be the optimal material.

Methods of joining components differ significantly between copper and stainless steel coils. Copper components are typically joined via brazing, a process that melts a filler material to bond parts via capillary action without melting the base materials. The filler material being used always has a lower melting point than the materials being joined which means the parent materials do not melt during the joining process. While brazing is effective at joining materials, it creates a joint with lower tensile strength than the base materials and introduces a potential failure point, as the filler material may corrode over time. In contrast, stainless steel coils are joined through welding, which involves melting the base materials (with or without additional filler) to create a unified structure. Welded joints are significantly stronger and more dependable than brazed joints, as they eliminate the risks associated with filler material and result in a robust, corrosion-resistant bond. This difference in joining methods directly impacts the structural integrity and longevity of the coils. While stainless steel coil bundles generally cost more than copper, the higher price reflects the superior strength and durability of the material. From raw tubing to final assembly, end users are investing in a longer-lasting, higher-performing product that justifies the added expense.



Figure 7: Induction Brazing of Copper Tubes

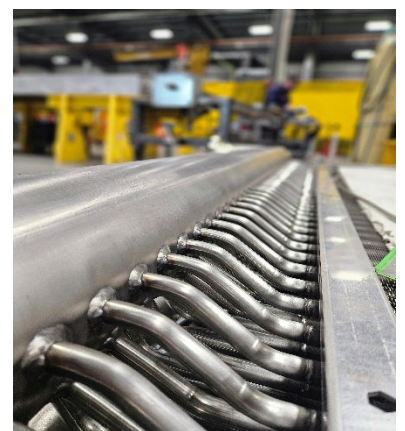


Figure 8: Welded Stainless Steel Coil

Higher Tube Velocities

Internal tube erosion is a consideration when designing heat exchangers that carry working fluids and needs to be evaluated when using higher flows to promote heat transfer.

Stainless steel allows for higher velocities through the tubes than copper (11fps vs 8fps) due to stronger internal microstructures and higher hardness. This enables EVAPCO to apply higher limits on tube velocities, which in turn creates more turbulent flow and yields greater heat transfer without compromising material integrity.

While this may seem like a minor increase in flow, stainless steel material extends the fluid velocity operating range, generating more heat transfer. As the Reynolds number, the value responsible for determining laminar or turbulent flow, is directly proportional to the velocity of the fluid (as shown below), the flow is 37% more turbulent.¹

$$Re = \frac{\rho v D}{\mu} \qquad \frac{Re_2}{Re_1} = \frac{v_2}{v_1} = \frac{11}{8} \approx 1.37 = 37\%$$

Re = Reynolds ρ = fluid density v = velocity D = tube diameter μ = dynamic viscosity

The Reynolds number is proportional to the heat transfer coefficient and thus overall heat transfer by the following equations.

$$h \propto Re^n$$

Where, for the purpose of turbulent flow in heat exchangers, we could assume an (n) value of 0.8. This yields a higher heat transfer coefficient with higher flow and thus a higher overall heat transfer rate as Q and h are proportional.

$$\frac{h_2}{h_1} = \left(\frac{Re_2}{Re_1}\right)^{0.80} \approx (1.37)^{0.80} = 1.29 = 29\% \text{ increase} \qquad Q = h * A * \Delta T$$

With all things being equal, and while maximizing flow, a stainless steel tube has the capacity to theoretically increase heat transfer rate from the process fluid by up to 29%.

EVAPCO Value

Commercial manufacturers favor copper due to its lower material and fabrication cost. However, this choice sacrifices long-term durability and resilience. EVAPCO controls its process from raw stainless steel tube production to final coil assembly by manufacturing their stainless steel tubing. This vertical integration ensures tight quality control, optimized design, and superior lifecycle value. Rather than comparing materials in isolation, EVAPCO redefines the benchmark by engineering entire systems around stainless steel's strengths and delivering the most robust and cost-effective solutions for demanding industrial and data center environments.

Conclusion

Stainless steel tubes have distinct advantages in industrial air-cooled products:

Thermal Performance:

- Commercialized unit ratings in excess of 20% higher than CTI Certified eco-Air ratings cannot be explained by material difference alone.
 - Unit thermal performance difference is not proportional to the difference in thermal conductivity between copper and stainless steel.
 - Copper tubes only improve the air-cooled heat exchanger performance by 1-3%

Quality & Longevity:

- Stainless steel offers superior corrosion resistance with a self-replenishing passivation layer.
- EVAPCO coils withstand a minimum of 4,500psi burst pressure – much higher than copper – reducing leak risk.
- Welded joints provide greater strength than brazed copper connections.
- Stainless steel tubes and return bends resist internal erosion, increasing equipment longevity

While copper offers slightly higher thermal conductivity, its real-world advantage in air-cooled heat exchangers is minimal. The life cycle benefits of stainless steel cannot be overstated - superior corrosion resistance, higher burst strength, structural durability, and consistent long-term performance. It withstands aggressive water chemistries, withstands internal and external erosion, and accommodates higher tube velocities without sacrificing integrity. Unlike copper's brazed joints, stainless steel's welded construction ensures mechanical reliability and longevity. EVAPCO's vertically integrated manufacturing and steadfast focus on stainless steel allow every coil bundle to deliver industry-leading quality, resilience, and service life. For industrial applications that demand reliability, resilience, efficiency, and durability, stainless steel is not just the better material, it's the right one.

Resources

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2. NACE Corrosion Engineer's Reference Book. Edited by Robert Baboian and R. S. Treseder, Houston, Tx, Nace International, 2002.
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4. ASM Handbook, Volume 1: Properties and Selection: Irons, Steels, and High-Performance Alloys, 15th ed., ASM International, 2020.