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Selection of heat exchanger tube material for power plant

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ABSTRACT

An experimental study was carried out this article expresses and provides an overview on the factors affected to known cause of failure of the tube and pipe materials. The limitations of material are crucial during the selection for a specific application. This paper helps to identify the factors that need to be considered when selecting a material. Properties compared in this article include corrosion resistance, stress corrosion cracking potential, thermal and mechanical properties, erosion resistance, vibration potential, and temperature limitations. The comparison guides are intended to be quick tools to assist the user in selecting a cost-effective material for a specific application. From the above important consideration, even though the material cost may be slightly higher side but the system will run in long life. So we need the materials selection process in such a manner that the property of the material will be withstand as much as for the above said requirements and also consider other financial aspects. This article is intend to prepared in such a way that to consider all comparable elements and try to give a solution for the tube selection of condenser tube for Nuclear Power Plants as well as Thermal Power Plants.

Keywords: Tube, Condenser, Power plant, Heat Exchanger

INTRODUCTION

This article expresses and provides an overview on the factors affected to known cause of failure of the tube materials. The limitations of material are crucial during the selection for a specific application. This paper helps to identify the factors that need to be considered when selecting a material. Properties compared in this article include corrosion resistance, stress corrosion cracking potential, thermal and mechanical properties, erosion resistance, vibration potential, and temperature limitations. The comparison guides are intended to be quick tools to assist the user in selecting a cost-effective material for a specific application. From the above important consideration, even though the material cost may be slightly higher side but the system will run in long life. So we need the materials selection process in such a manner that the property of the material will be withstand as much as for the above said requirements and also consider other financial aspects. This article is intend to prepared in such a way that to consider all comparable elements and try to give a solution for the tube selection of condenser tube for Nuclear Power Plants as well as Thermal Power Plants.

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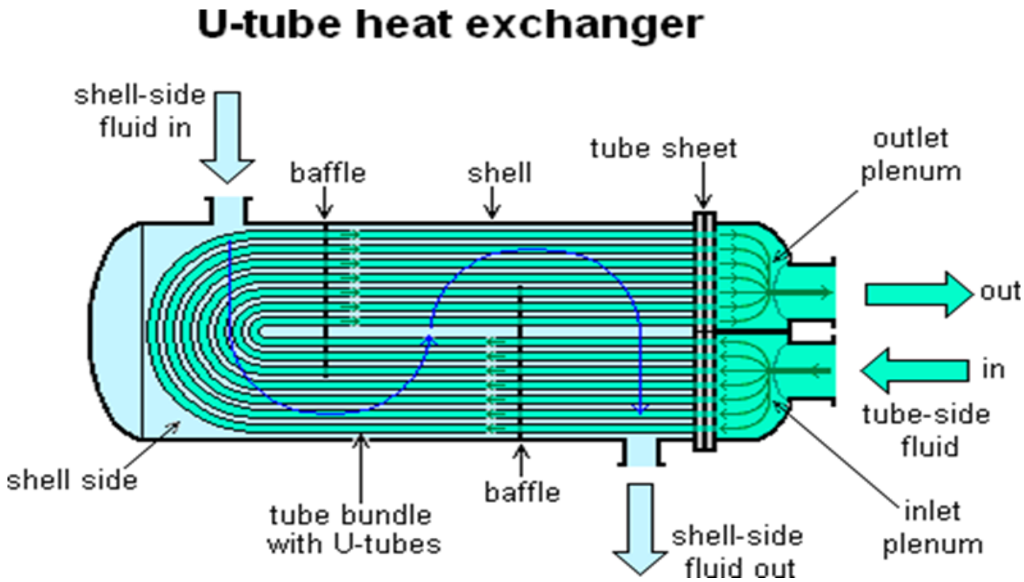

Figure 1

Corrosion

Corrosion is the one of the main factor affecting the performances of the system and it may be grouped into two broad categories, the first type of corrosion is called General corrosion and the next one is Localized corrosion which is accelerated by an electrochemical mechanism. The latter group of corrosion has further divided into several well-known specific mechanisms.

General corrosion

General corrosion is the progressive dissolution of surface metal. The two common encountered are the rusting of carbon steel and the wall thinning of copper alloys. General corrosion is a not catastrophic. With proper planning and execution, a heat exchanger can be designed to accommodate general corrosion, and in many instances, an alloy susceptible to this type of corrosion may be a cost-effective design. Heat exchanger commonly adds a "corrosion allowance" to a high-pressure carbon steel feed water heater to allow for a period of 25 year lifetime.

Copper and its alloys are often chosen for condensing and BOP heat exchangers, and 25- year lifetimes. In some applications, copper alloys are slowly dissolve to maintain some resistance to bio fouling as the copper ion can be toxic to the micro organisms that attach to the tube wall. Unexpected thing on the steam side of the tubing, copper transport to other locations due to this slow dissolution may cause some more problems. The copper can affect on turbine blades, resulting in a loss of efficiency, or on boiler tubes, resulting in short time failures. Although the discharge values on the cooling water side may be in the ppb concentration range, total copper metal discharge for a medium-sized condenser over the tubes' lifetime can exceed several hundred thousand pounds per unit.

Electrochemically driven mechanisms

Many corrosion-related mechanisms are electrochemically driven, and these can be very. Hence, they cannot be selected by design. These failure mechanisms usually have two stages: an incubation or initiation period, and a propagation mode. The time of initiation can be un expected. It could happen in a few days or last for years. Once it was initiated, the second mode can occur rather quickly, driven by the electro potential between the two regions. Conductivity of the water may be a dominant factor of the system. Higher conductivities allow higher current densities. Higher current densities are proportionately related to metal removal rates.

Pitting: Pitting corrosion is also a highly localized corrosion attack and that can result in through-wall penetration in short periods of time. Failures may occur in few weeks. Once a pit is initiated, the environment in the pit is usually more aggressive than the bulk solution because of the pit's stagnant nature. Even if the bulk solution has a neutral or basic pH, the pH in a pit can drop below two. When this occurs, the surface under the pit becomes active. The potential difference between the pit and the surrounding area is the driver for the galvanic attack. As the surface area of the anode is small and the cathode is large, a very high current density in the pit is possible. This drives and leads to the very high corrosion rates. Chlorides are the most common cause of pitting of stainless steels in the power industry. Alloying elements, such as chromium, molybdenum, and nitrogen, is creating chloride resistance in this group of alloys. As per the Rockwell formula to determine the total stainless steel resistance to chloride pitting (1): PREn = % Cr + 3.3 (% Mo) + 16 (N) (1) PREn represents the "Pitting Resistance Equivalent" number. Using this formula, stainless steels can be ranked based upon their chemistry. In this formula, nitrogen is 16 times more effective and molybdenum is 3.3 times more effective than chromium for chloride pitting resistance. The higher the PREn, the more chloride resistance an alloy will have. It is interesting to note that nickel, a very common stainless steel alloying element, has little or no effect on chloride pitting resistance.

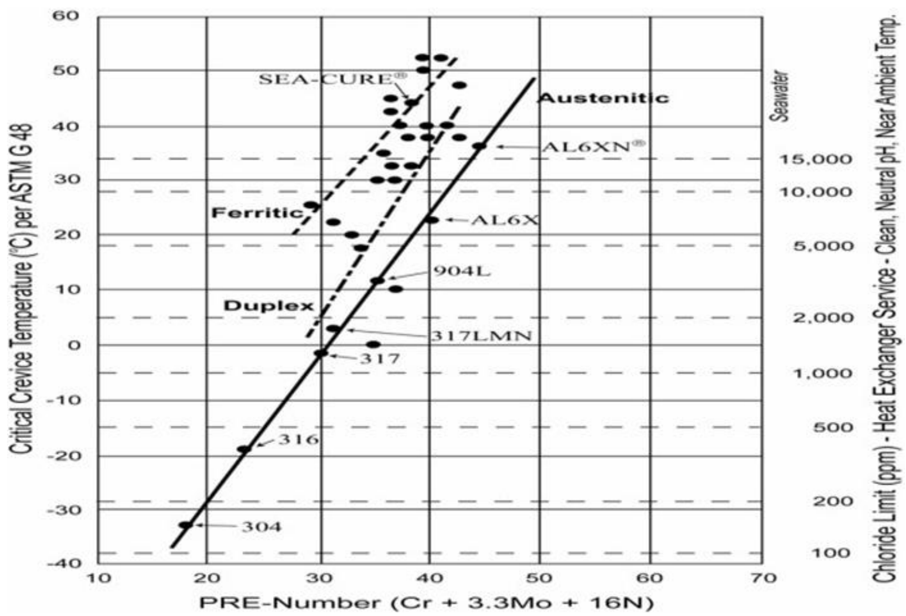

Figure 2 Critical Crevice Temperature and Maximum Chloride Levels Versus PREn of Various Stainless Steels

Crevice Corrosion: Crevice corrosion is similar to pitting corrosion. However, since the tighter crevice allows higher concentrations of corrosion products (less opportunity to flush with fresh water), it is re insidious than pitting. This drives the pH value lower. The end result is that crevice corrosion can happen at temperatures 30°-50° Centigrade lower than pitting in the same environment

Ferrite stainless steels are found to have the highest CCT for a particular PREn, followed by the austenitic. To Plot the known alloys results in three separate and almost parallel correlations. After chemistry is determined, the PREn can be calculated.

Maximum chloride levels

Factors include pH, temperature, presence and type of crevices, and potential for active biological species. Figure 1 to help in this decision. It is based upon having a neutral pH, 35o Centigrade flowing water (to prevent deposits from building and forming crevices) common in many BOP and condensing applications. Once an particular chemistry is selected, the PREn can be determined and then intersected with the appropriate sloped line. When using this guide, additional caveats need to be considered:

1. If the temperature is higher than 350c, the chloride level needs to be lowered.

2. If the pH is lower than 7 and then also the chloride level should be lowered. The chloride levels are approximately 50% of what was considered.

Normally the ASTM stainless steel composition limits, TP 304 had a chromium level of approximately 19%, and TP 316 had a molybdenum content of typically 2.6%. These earlier alloys had a higher PREn than today's versions, and thus, the higher chloride limits were acceptable.

Microbiological influenced corrosion (mic)

Microbiological Influenced Corrosion (MIC) is often problem and due to sea water this could happen and it always related with pitting corrosion and generally occurs in water normally considering. The term "influenced" is used since the bacteria it does not create the corrosion. Usually, the bacterium forms a crevice that isolates the water chemistry on the metal surface from the bulk water chemistry or has a waste product that can be very aggressive.

Table 1 Bacteria Commonly Associated with MIC is as follows

Organism	Action	Problem
Thiobacilus	Sulfate reducer	Produces H_2SO_4
Desulfovibrio	Sulfate reducer	Produces H_2S
Gallionella	Mn/fe Fixer	MnO_2, Fe_20_3
Crenothrix	Same	same
Spaerotilus	Same	Same
Nitrobacter	Nitrate Reducer	HNO_3

Stress corrosion cracking

Stress Corrosion Cracking (SCC) is another type of corrosion crack and that can cause rapid failure when the required specific combination of conditions coexists. Figure shows transgranular stress corrosion cracking in TP 304N feed water heater tubing. This failure mechanism is identified from other brittle-type failures, such as fatigue.

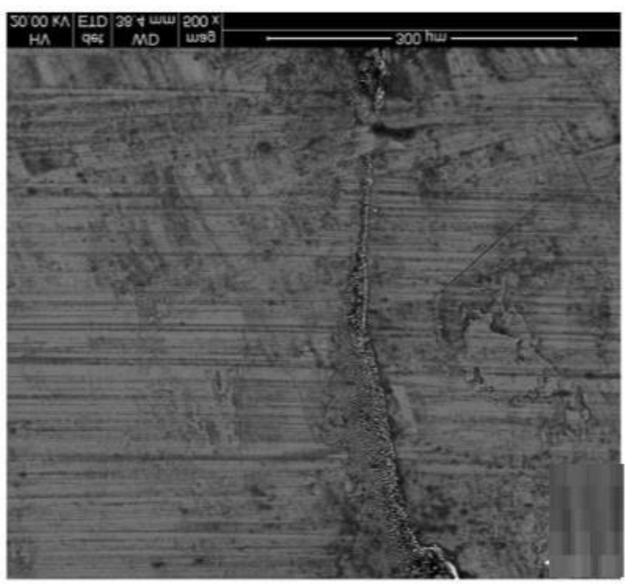

Fig-3

Erosion-related problems

Erosion resistance is also to be considered and this erosion is a function of the ability of the protective layer to remain attached to the substrate and the strength (hardness) of the substrate directly below the protective layer. There are two types of erosion commonly problems in the power industry:

- Flow assisted erosion/corrosion
- WATER droplet/steam impingement erosion.

Flow assisted erosion/corrosion

Flow assisted corrosion is created by the removal of the protective scale on the Inner Diameter of the tube because the fluid velocity is too high. Selected flow rates that are the maximum safe values for an alloy. Improved heat exchanger performance, higher velocities are having two advantages:

They allow higher heat transfer, and they keep surfaces clean,

Reducing the surface interface resistance.

Water droplet/steam impingement erosion

In some specialized conditions, it is possible to experience erosion of the tube OD surface due to localized impact of high velocity water droplets. This can occur near diverter plates that may focus steam velocity or during upset conditions. It often occurs in steam dump areas when the outlets are not properly designed. The resistance of this erosion is a direct function

Materials and Properties	Brass	Copper	Aluminum	Steel	Titanium
Melting point	900-940C and 1652 to1724 F	1357.77 K (1084.62 °C, 1984.32 °F)	933.47 K (660.32 °C, 1220.58 °F)	2550 K (1363°C)	1941 K (1668 °C, 3034 °F)
Boiling point	2700K (2480 °C, 4420 °F)	2835 K (2562 °C, 4643 °F)	2743 K (2470 °C, 4478 °F)	3560 K (1510 °C, 2750 °F)	3560 K (3287 °C, 5949 °F)
Density near r.t.	8.2 g/cm^3	8.96 g/cm^3	2.70 g/cm^3	8.05 g/cm^3	4.506 g/cm^3
Heat of fusion	12.22 kJ/mol	13.26 kJ/mol	10.71 kJ/mol	16.15 kJ/mol	14.15 kJ/mol
Thermal expansion	14.5 µm/(m·K) (at 25 °C)	16.5 µm/(m·K) (at 25 °C)	23.1 µm/(m·K) (at 25 °C)	13 µm/(m· K) (at 25 °C)	8.6 µm/(m·K) (at 25 °C)
Thermal conductivity	351 W/(m·K)	401 W/(m·K)	237 W/(m·K)	50.2 W/(m·K)	21.9 W/(m·K)
Young's modulus	110–118 GPa	110–128 GPa	70 GPa	180 GPa	116 GPa
Bulk modulus	130 GPa	140 GPa	76 GPa	139 GPa	110 GPa
Poisson ratio	0.33	0.34	0.35	0.27	0.32
Vickers hardness	333–359 MPa	343–369 MPa	160–350 MPa	293–321 MPa	830–3420 MPa
Brinell hardness	225–858 MPa	235–878 MPa	160–550 MPa	250–350 MPa	716–2770 MPa

Vibration resistance

Vibration is a major concern in condensers and other heat exchangers; especially during the conditions of the inlet water temperature is very low and having the pressure is normal. To avoid the vibration of the condenser lot of support system has been provided and during the time of the supporting design with consider of the OD of the surface. For this following formula are used. Coit, et al, developed this formula:-

L = 9.5 [(E I) / p v2 D)] ¼ (2)

I = Pi / 64 (D4 – ID4) (3)

Where:

E = Modulus of Elasticity (psi) I = Moment of Inertia (in4)

p = Turbine Exhaust Density (lb/ft3)

v = Average Exhaust Steam Velocity at Condenser Inlet D = Tube Outside Diameter

ID = Tube Inside Diameter

It is clearly stated from the above formula, considering the same OD and wall tube, the property that has the largest impact on vibration is the modulus of elasticity. Higher modulus alloys are stiffer and have more vibration resistance capacity.

Based upon a typical condenser tube with identical tube OD, support spacing, steam flow, and back pressure using Coit method for vibration.

Thermal conductivity

Although the pure material thermal conductivity of the various power-tubing materials has a very wide range, the actual range of tubing thermal performance is not as large a spread. Several factors impact the total thermal efficiency of an alloy:

1. Actual wall thickness of the tube material selected. Because of the low modulus and mechanical properties and a potential need for corrosion allowance, copper alloy tubes are normally much thicker than stainless steel tubes.
2. Boundary layers on both the OD and ID surfaces can act as additional thermal resistances.
3. Deposits can form creating additional resistances. To develop heat transfer parameters to be also noted during the selection of the condenser tube materials.

Economic considerations

As for as the economics of the system the price of the tube also to be considered during the selection of the condenser tube materials:-

Table Relative Prices of Heat Exchanger & Tube Materials 1"(25.4 mm) OD – 22 BWG, .028" Wall Thickness

Table 3 Cost of the tube Materials:-

3

Grade	Wall	Relative Price in Rupees / kg
TP 304		65
Al Brass	18 BWG	75
90/10 Cu/ Ni	20 BWG	100
SEA – CURE	25 BWG	130
Ti Grade 2	25 BWG	150

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Commonly Accepted Maximum Water Flow Rates for Erosion/Corrosion

Alloy	Maximum Velocity
Admirality	6 FPS
90/10 Cu/Ni	8 FPS
70/30 Cu/Ni	10 FPS
304/316 Stainless Steel	30+ FPS
Ti Grade 2	30+ FPS
Superferritic Stainless Steel	100+ FPS

CONCLUSIONS

To make a correct material selection have working knowledge of the system, heat exchanger type, corrosion Characteristics and plant maintenance must be incorporated .The materials for condenser tube to be selected for considering the maximum efficiency, long life and good performance of the system. Even though the Stainless steels can be the cost-effective heat exchanger tubing choice, based on the many factor consideration, the SEA – CURE and Titanium is the most suitable material because of its various mechanical & Physical properties like Elongation and Corrosion affects.

The two things is very important for the condenser efficiency concern and number of factors need to be considered including potential for corrosion and erosion, maximum temperatures, vibration potential, and mechanical property requirements.

When all factors are considered in the material selection decision, this Titanium grade 2 group of alloys can provide service for the long life of a plant and in this article it is clearly seen that SEA – CURE and Titanium is the best suitable Material for Heat Exchangers.

Condenser tube compare to Stainless steel. Even Nowadays Many of the Nuclear and Thermal Power Stations are using the Titanium based condenser tube (Titanium Grade 2). Further in near future the research study may be extended to detect the bio organism affect in sea water and the condenser tube and how to increase the life of the system.

New alloy may include these materials and get good strength, corrosion resistance and also vibration property etc., and get better performance of the system.

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