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MATERIAL SELECTION FOR SEAWATER COOLED HEAT EXCHANGERS

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Abstract

Seawater is employed as the cooling media for a variety of heat exchanger applications on ships, offshore platforms, and at coastal locations. Although seawater is used extensively as a coolant medium, it has two main disadvantages: Corrosion and fouling. Selection of material must be met to ensure economical design and reliable performance.

DENİZ SUYU SOĞUTMALI ISI DEĞİŞTİRİCİLERDE MALZEME SEÇİMİ

Özetçe

Deniz suyu; gemiler, offshore platformlar ve kıyı yerleşimlerindeki ısı değiştirici uygulamalarında soğutma ortamı olarak kullanılır. Deniz suyunun geniş bir şekilde soğutma ortamı olarak kullanılmasına rağmen iki ana dezavantajı vardır: Korozyon ve birikinti. Malzeme seçimi, ekonomik dizayn ve güvenli performansı sağlamalıdır.

Keywords: *Seawater, Heat exchanger, Material selection*
Anahtar kelimeler: *Deniz suyu, Isı değiştirici, Malzeme seçimi*

1. INTRODUCTION

Seawater is employed as the cooling media for a variety of heat exchanger applications on ships, offshore platforms, and at coastal locations. Heat exchangers are devices that provide the flow of thermal energy between two or more fluids at different temperatures [1]. Seawater cooled shell and tube heat exchangers are shown in Figure 1.

Figure 1. Seawater cooled shell and tube heat exchangers [2]

Although seawater is used extensively as a coolant medium, it has two main disadvantages: Corrosion and fouling. Corrosion is the gradual destruction of materials by chemical reaction with their environment. Fouling can be defined as the accumulation of undesirable substances on a surface. Selection of material must be met to ensure economical design and reliable performance. There are five groups material reported suitable for seawater cooled heat exchangers [3].

a. High-Performance Stainless Steels
b. Copper-Nickel Alloys
c. Nickel Alloys
d. Titanium
e. Zirconium

2. HIGH-PERFORMANCE STAINLESS STEELS

Stainless steels are ‘stainless’ because their chromium content – minimum 10.5%. Yet, martensitic, ferritic and austenitic stainless steels have no application in seawater-cooled heat exchangers. High performance stainless steels are iron-chromium alloys containing sufficient chromium to maintain passivity and corrosion resistance in a wide variety of corrosive media. High-performance stainless steels are the super-ferritic, the super-austenitic, and the duplex grades.

2.1 Super Ferritic Stainless Steels

The composition of important super ferritic grades of interest for seawater cooled heat exchangers is given in Table 1.

Table 1. Composition of Some Alloys

UNS	**%Cr**	**%Ni**	**%Mo**	**%C**	**%N**
S44635	24.5-26.0	3.5-4.5	3.5-4.5	0.025 (max.)	0.035(max.)
S44660	25.0-27.0	1.5-3.5	2.5-3.5	0.025 (max.)	0.035(max.)
S44735	28.0-30.0	1.0 (max.)	3.6-4.2	0.030 (max.)	0.045(max.)
S44800	28.0-30.0	2.0-2.5	3.5-4.2	0.010 (max.)	0.020(max.)

2.2 Super Austenitic Stainless Steels

The composition of the alloys in the super austenitic stainless steel category is given in Table 2.

Table 2 Composition of Some Alloys

UNS	**%Cr**	**%Ni**	**%Mo**	**%Cu**	**%C**
S31254	19.5-20.5	17.5-18.5	6.0-6.5	0.5-1.0	0.02 (max.)
N08020	19.0-21.0	32.0-38.0	2.0-3.0	3.0-4.0	0.07 (max.)
N08024	22.5-25.0	35.0-40.0	3.5-5.0	0.5-1.5	0.03 (max.)
N08026	22.0-26.0	33.0-37.2	5.0-6.7	2.0-4.0	0.03 (max.)

2.3 Duplex (Ferritic-Austenitic) Stainless Steels

The composition of duplex grades is given in Table 3.

Table 3. Composition of Some Alloys

UNS	**%Cr**	**%Ni**	**%Mo**	**%C**
S31200	24.0-26.0	5.5-6.5	1.2-2.0	0.03 (max.)
S31803	21.0-23.0	4.5-6.5	2.5-3.5	0.03 (max.)

3. COPPER-NICKEL ALLOYS

Cupronickel or copper-nickel is an alloy of copper that contains nickel and strengthening elements, such as iron and manganese. Cupronickel is highly resistant to corrosion in seawater, because its electrode potential is adjusted to be neutral with regard to seawater. Because of this, it is used for heat exchangers in seawater systems.

3.1 CuNi10Fe1Mn (UNS C70600)

Common names of alloy are 90/10 Copper-Nickel-lron, 90/10 Cupro-nickel, Cupro-nickel, 90/10. Composition and some physical properties are given Table 4 and 5, respectively.

Table 4. Composition (weight %)

Ni	9.0-11.0
Fe	1.0-2.0
Mn	0.3-1.0
Cu	Rem.

Table 5. Some Physical Properties

Density at 20 ^{o}C	8.90 g/cm^{3}
Specific heat (thermal capacity)	0.09 cal/g.^{o}C
Thermal conductivity at 20 ^{o}C	0.12 cal/cm.s.^{o}C
Modulus of elasticity	13800 kg/mm^{2}

Comparison of chemical composition between various specifications for cupronickel 90/10 used as tubing material is given in Table 6.

Table 6. Comparison of chemical composition between various specifications for cupronickel 90/10

Standard	DIN/EN	ASTM	ISO	EEMUA	KME
Designation	CuNi10Fe1Mn		CuNi10Fe1Mn		CuNi10 Fe1,6Mn
Ref. No.	2.0872/CW352H	UNS C70600		UNS 7060X	
Copper	Rem.	Rem.	Rem.	Rem.	Rem.
Nickel	9.0-11.0	9.0-11.0	9.0-11.0	10.0-11.0	10.0-11.0
Iron	1.0-2.0	1.0-1.8	1.0-2.0	1.5-2.00	1.50-1.8
Manganese	0.5-1.0	1.0	0.5-1.0	0.5-1.0	0.6-1.0
Tin	0.03	-	0.03	-	0.03
Carbon	0.05	0.05	0.05	0.05	0.02
Lead	0.02	0.02	0.02	0.01	0.01
Phosphorus	0.02	0.2	0.02	0.02	0.02
Sulphur	0.05	0.02	0.02	0.02	0.005
Zinc	0.05	0.5	0.5	0.2	0.05
Cobalt	0.1	-	0.05	-	0.1
Impurities	0.2	-	0.1	0.3	0.02
Single values represent the maximum content.					

3.2 CuNi30Mn1Fe (UNS C71500)

Common names of alloy are 70/10 Copper-Nickel-lron, 70/30 Cupro-nickel, Cupro-nickel, 70/30. Composition and some physical properties are given Table 7 and 8, respectively.

Table 7. Composition (weight %)

Ni	29.0-32.0
Fe	0.5-1.5
Mn	0.4-1.0
Cu	Rem.

Table 8. Some Physical Properties

Density at 20 ^{o}C	8.90 g/cm^3
Specific heat (thermal capacity)	0.09 cal/g.^{o}C
Thermal conductivity at 20 ^{o}C	0.12 cal/cm.s.^{o}C
Modulus of elasticity	13800 kg/mm^2

4. NICKEL ALLOYS

4.1 Chromium-Free Nickel-Base Alloys

The two types of chromium-free nickel-base alloys are 67 Ni-33 Cu (UNS NO4400) and 70 Ni-28 Mo (UNS N10001) type alloys. The alloy of nickel-copper is resistant to seawater corrosion. It has no tendency to stress corrosion cracking. Compositions are given Table 9 and 10, respectively.

Table 9. Composition Limits of 67 Ni-33 Cu, (weight %)

UNS	**%C**	**%Mn**	**%Fe**	**%Ni**	**%Si**	**%Cu**
NO4400	0.30	2	2.5	28-34	0.5	Bal.

Table 10. Composition Limits of 70 Ni-28 Mo, (weight %)

UNS	**%Cr**	**%Ni**	**%Mo**	**%Fe**	**%C**	**%Cr**
N10001	1.0 max	Bal.	26.0–30.0	4.0–6.0	0.05	1.0 max

4.2 Chromium-Bearing Nickel Alloys

4.2.1 UNS N06625

Nickel-chromium alloy 625 (UNS N06625/ W.Nr. 2.4856) is used for its high strength, excellent fabricability (including joining), and outstanding corrosion resistance. Service temperatures range from cryogenic to 982 °C. Composition is shown in Table 10. The properties of INCONEL alloy 625 that make it an excellent choice for seawater applications are freedom from local attack (pitting and crevice corrosion), high corrosion-fatigue strength, high tensile strength, and resistance to chloride-ion stress-corrosion cracking. Composition of alloy is given Table 11.

Table 11. Limiting Chemical Composition, %

Nickel	58.0 min.
Chromium	20.0-23.0
Iron	5.0 max.
Molybdenum	8.0-10.0
Niobium (plus Tantalum)	3.15-4.15
Carbon	0.10 max.
Manganese	0.50 max.
Silicon	0.50 max.
Phosphorus	0.015 max.
Sulfur	0.015 max.
Aluminum	0.40 max.
Titanium	0.40 max.

4.2.2 UNS N010276

Other common names of alloy are Alloy C276, Hastelloy C, Inconel C-276. It is a nickel-molybdenum-chromium superalloy with an addition of tungsten designed to have excellent corrosion resistance in a wide range of severe environments. Composition of alloy is shown in Table 12.

Table 12. Chemical Composition, % , of UNS NO10276

Ni	Mo	Cr	Fe	W	Co	Mn	C
Remainder	15.0-17.0	14.5-16.5	4.0-7.0	3.0-4.5	2.5 max	1.0 max	0.01 max
V	P	S	Si				
0.35 max	0.04 max	0.03 max	0.08 max				

5. TITANIUM

Titanium, a reactive metal, is the most common for use in seawater-cooled heat exchangers. Titanium has excellent corrosion resistance in oxidizing environments containing considerable amounts of chloride ion where various conventional heat exchanger materials may suffer corrosion damage. Composition of some alloys is given Table 13.

Table 13. Chemical compositions and tensile properties of Titanium

	Chemical compositions (%)					Tensile properties		
	N Max.	C max.	H max.	Fe max.	O max.	Tensile strength min. (MPa)	Yield strength 0.2% offset (MPa)	Elongation min. (%)
ASTM Grade 1	0.03	0.08	0.015	0.020	0.18	240	170-310	24
ASTM Grade 2	0.03	0.08	0.015	0.030	0.25	345	275-450	20
ASTM Grade 3	0.05	0.08	0.015	0.030	0.35	450	380-550	18
ASTM Grade 4	0.05	0.08	0.015	0.050	0.40	550	483-655	15

6. ZIRCONIUM

Zirconium, a reactive metal, has a high affinity for oxygen that results in the formation of a protective oxide layer in air at room temperature. This protective oxide gives Zirconium alloys their superior corrosion resistance and this oxide layer can be enhanced through a heat-treating process. A properly formed enhanced oxide layer serves as an excellent bearing surface against a variety of materials, imparts impressive erosion resistance in high velocity systems, and can improve the corrosion resistance in certain aggressive environments.

Zirconium is employed where severe process corrosion conditions its use. Zirconium is 2-3 times as expensive as titanium in tubular form. Composition of some alloys can be used in seawater cooled heat exchangers is given Table 14.

Table 14. Compositions of Some Alloys (%)

Alloy	Zirconium + Hafnium (min)	Hafnium (max)	Iron + Chromium (max)	Oxygen (max)
UNS R60702	99.2	4.5	0.20	0.16
UNS R60705	95.5	4.5	0.20	0.18

Table 15 lists the thermal properties for Zirconium alloys.

Table 15. Thermal Properties of Some Alloys

Grade	UNS R60702	UNS R60705
Melting Point	1852 °C	1840 °C
Specific Heat, KJ/kg-K (0-100°C)	0.2847	0.2805
Thermal Conductivity, W/mK (BTU/hr-ft-°F), 300-800 K	22 (13)	17.1 (10)
Coefficient of Thermal Expansion x 10-6/°C	5.8 (3.2)	3.6 (2.0)
149°C (300°F)	6.3 (3.5)	4.9 (2.7)
260°C (500°F)	7.0 (3.9)	5.6 (3.1)
371°C (700°F)	7.4 (4.1)	5.9 (3.3)

7. CONCLUSIONS AND RECOMMENDATIONS

Seawater cooled heat exchangers are susceptible to corrosive attack because of thin wall sections of the heat exchanger. Choice of material for seawater cooled heat exchangers will depend upon the particular environmental situation and the nature of the application. It will be affected by availability, price and political considerations, as well as the life expectancy; previous performance in similar situations will also influence the decision.

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