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Saudi Aramco

Engineering Encyclopedia

Saudi Aramco DeskTop Standards

MATERIALS OF CONSTRUCTION FOR HEAT EXCHANGERS

Note: The source of the technical material in this volume is the Professional Engineering Development Program (PEDP) of Engineering Services.

For additional information on this subject, contact
PEDD Coordinator on 874-6556

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INTRODUCTION

This module prepares the participant to judge whether the materials that are specified by a contractor for heat exchanger components meet the requirements of applicable Saudi Aramco and industry engineering standards. The module discusses the criteria that engineers use to judge the acceptability of materials, and it explains how these criteria are applied. The participant is provided guidelines and procedures to use in the materials selection process. The concept of a Contractor Design Package is introduced as a means to document all of the design information about a particular heat exchanger. Exercises 1 and 2 provide practice in the application of these guidelines to materials that have been proposed for use in shell-and-tube and air-cooled heat exchangers.

DETERMINING WHETHER CONTRACTOR-SPECIFIED SHELL-AND-TUBE HEAT EXCHANGER MATERIALS MEET SAUDI ARAMCO MATERIAL SELECTION REQUIREMENTS

Materials that are used to construct shell-and-tube heat exchangers must comply with Saudi Aramco material specifications and the ASME Code requirements. For shell-and-tube heat exchangers, the applicable standards and specifications are SAES-E-004, *Design Criteria of Shell and Tube Heat Exchangers*, 32-SAMSS-007, *Heat Exchangers, Shell and Tube Type*, the TEMA Standard, and API-660.

Work Aid 1 provides a procedure that may be used to determine if contractor-specified materials meet Saudi Aramco requirements. The following sections provide additional information regarding shell-and-tube heat exchanger material selection.

The basic material selection factors and considerations that were discussed in MEX 202 and its prerequisite courses apply to shell-and-tube heat exchangers as well, and will not be discussed again. Instead, this section concentrates on additional material selection requirements that are specific to shell-and-tube heat exchangers.

Materials-Related Provisions of SAES-E-004

SAES-E-004 is the Saudi Aramco Engineering Standard that provides the general engineering requirements that are applicable to shell-and-tube heat exchangers. Several of the material selection requirements that are in SAES-E-004 are discussed in the following paragraphs.

Material Selection

The materials of construction for pressure-containing and nonpressure-containing components must be based on the design temperature, minimum design metal temperature, and service in accordance with 32-SAMSS-007 Table 1 and Table 2. These material requirements are generally acceptable for most Saudi Aramco applications and will be discussed in a later section. The Saudi Aramco engineer will specify the materials for exchanger services that require materials that differ from those that are specified in Table 1 and Table 2.

Para. 10.3 specifies that postweld heat treatment (PWHT) is required for exchangers that are fabricated from carbon or low-alloy steels and are in any of the following services:

- All caustic soda (NaOH) solutions at all temperatures.
- All mono-ethanol amine (MEA) solutions at all temperatures.
- All di-glycol amine (DGA) solutions above 140°C (280°F) design temperature.
- All rich amino di-isopropanol (ADIP) solutions above 90°C (195°F) design temperature.
- All lean ADIP solutions above 60°C (140°F) design temperature.
- Exchangers in hydrogen service at all temperatures that are manufactured from P-No. 3, 4, and 5A/B/C base materials.

When PWHT is required based on the exchanger service, ASME Code exemptions from PWHT are not permitted.

Gaskets

API-660, Para. 4.9.1 requires that gaskets for exchanger body flanges must be specified as either spiral-wound or double-jacketed types. The double-jacketed type gaskets will be used for most exchanger gaskets because spiral wound gaskets are more difficult to handle when their diameter is large.

Tubes

Para. 6.4.1 stipulates that unless otherwise approved by a Saudi Aramco engineer, the minimum tube outside diameter must be 19.05 mm (3/4 in.). Para. 6.4.3 requires that the tube wall thickness be specified in accordance with API-660. Para. 6.4.3 requires that the straight tube length not exceed 6.1 m (20 ft.) unless approved by a Saudi Aramco engineer. Tube lengths that are preferred are the commonly used lengths that are given in the TEMA standard.

The tube diameter and length are specified for material standardization purposes in order to minimize the number of different sized tubes that must be stocked as spare parts. Carbon steel and alloy tubes must be thicker than nonferrous tubes (based on API-660 requirements) in order to provide more corrosion allowance.

Materials-Related Provisions of 32-SAMSS-007

32-SAMSS-007 is the Saudi Aramco Materials System Specification that is applicable to the purchase of shell-and-tube heat exchangers. Several of the material selection requirements that are in 32-SAMSS-007 are discussed in the following paragraphs.

Design Requirements

Several of the design requirements for shell-and-tube heat exchangers are related to material selection, and specifically to the following topics:

- Cladding for Corrosion Allowance
- Baffles, Tube Supports, and Impingement Protection
- Nozzles and Other Connections
- Gaskets

Cladding for Corrosion Allowance - Addendum A augments the provisions of API-660 and the basic requirements that are in the body of 32-SAMSS-007 with regard to the use of cladding or weld-overlay lining as corrosion allowance.

Para. 4.2 requires that corrosion resistant linings be provided as specified on the data sheet by either of two acceptable methods as follows:

- Integral cladding (rolled or explosion bonded)
- Weld overlay

Either of these methods results in a tight bond between the corrosion resistant material and the base metal.

Unless otherwise specified on the exchanger data sheet, the minimum thickness of cladding must be 2.5 mm (0.1 in.). The weld overlay procedure must result in a minimum thickness of 2.5 mm (0.1 in.) that meets the specified chemical composition. The actual thickness of weld overlay will be greater than 2.5 mm (0.1 in.) because there will be some dilution of the weld metal chemistry in the region that is adjacent to the base material.

API-660 states that, when cladding (or weld overlay) is used, the full thickness of the cladding must be considered as corrosion allowance unless otherwise specified by the purchaser. This requirement does not permit the inclusion of any portion of the cladding thickness in calculation of the strength capabilities of the exchanger.

Baffles, Tube Supports, and Impingement Protection – Note 5 of Table 1 specifies that baffles, tube supports, and impingement protection shall be of the same basic material as the tubes. Matching the tube material ensures that these components will not corrode excessively. The materials for these components must be approved by a Saudi Aramco engineer when titanium tubes are used.

Nozzles and Other Connections – 32-SAMSS-007 paragraph 4.7.4 specifies that the permissible nozzle types for exchangers that are in hydrocarbon, hydrogen, caustic, amine, wet sour, and steam services as follows:

- Forged steel long welding neck.
- Forged steel welding neck flange with seamless pipe (or rolled plate with 100% radiography).
- Studded nozzles or proprietary designs that are in accordance with the design Codes and with prior approval of the Saudi Aramco engineer.

32-SAMSS-007 paragraph 4.7.4 specifies the permissible nozzle types for exchangers that are in utility services as follows:

- The same nozzle types as specified in Paragraph 9.1.4.
- Slip-on flange with seamless pipe nozzle neck (or rolled plate with 100% radiography) through a design temperature of 120°C (250°F) and a design pressure of 1.7 MPa (200 psig).

32-SAMSS-007 specifies additional nozzle design requirements for clad heat exchangers as follows:

- Where size permits, nozzle necks must be either rolled from clad plate and the longitudinal seam 100% radiographed, or must be weld overlayed.
- Loose sleeve liners are not permitted.
- Solid alloy nozzles are not permitted.

These nozzle material requirements ensure that the nozzle has the same corrosion resistance as the component to which the nozzle is attached.

Gaskets – 32-SAMSS-007 paragraph 5.2.4 specifies metallic material requirements for spiral wound gaskets as a function of temperature.

Table A 1 summarizes the gasket types that are typically used based on exchanger service.

Service	Typical Gasket Types
Hydrocarbon	• Double-jacketed metal, graphite-filled • Solid metal • Spiral-wound, graphite-filled
Sea Water	Double-jacketed Monel, non-asbestos filled
Steam	Spiral-wound, graphite-filled (for gaskets that are on the steam side of the exchanger)

Table A 1. Typical Gasket Types

API-660 requires that the metal used in gaskets have at least the same corrosion resistance as that of the gasket contact surface material. This requirement ensures that the gasket material will not corrode faster than the exchanger material that is exposed to the same fluid. Excessive gasket metal corrosion could lead to flange leakage.

32-SAMSS-007 - Table 1

Table 1, *Acceptable Exchanger Components Materials for Carbon and Alloy Steels* (reproduced in Work Aid 1), provides requirements for the selection of materials for the primary components of shell-and-tube heat exchangers. These components include:

- Shells, Channels, Heads, Tubesheets, Rolled Nozzle Necks, Covers, and Reinforcing Pads
- Pipe Nozzle Necks
- Tubes
- Forged Flanges and Forged Fittings
- Studs/Nuts for Pressure Connections
- Internal and External Attachment Clips
- Supports
- Anchor Bolts

The materials that are listed in Table 1 are considered suitable for services and design conditions that are normally encountered in Saudi Aramco operations. To verify material suitability, materials that are proposed by contractors for use in any Saudi Aramco shell-and-tube heat exchangers should first be compared to the materials that are listed in Table 1. The data that are contained in Table 1 include applicable ASTM specifications and grades, as necessary. Note that materials that are listed within a specific segment of Table 1 are not equivalent to each other, nor does the order in which materials appear imply the order of preference.

Shell-and-tube heat exchanger components should be resistant to corrosion or metallurgical attack that could be caused by the fluids that the components contact. Table 1 is subdivided into four service categories based on design temperature. Notes to Table 1 provide additional material selection requirements based on heat exchanger service. Component materials selections are then made based on the specific design temperature and heat exchanger service. The following highlights several of the material selection requirements.

- The category that covers the design temperature range from 1°C to 425°C (33°F to 800°F) includes most heat exchangers that are in typical process plant applications. The material specifications for all heat exchanger components, except the studs and nuts for pressure connections, are carbon steel. The stud and nut material specifications are alloys.
- The category that covers the design temperature range from 351°C to 645°C (651°F to 1200°F) overlaps the upper temperature portion of the prior category. The material specifications for most components are low-chrome alloys in order to provide high-temperature strength and corrosion resistance.
- Low-temperature service is divided into two temperature ranges: 0°C to -46°C (32°F to -50°F) and -47°C to -100°C (-51°F to -150°F). Brittle fracture is a major concern for this service. The materials are selected to ensure that they have adequate fracture toughness at these low temperatures.

Several of the materials that are suitable at temperatures to -46°C (-50°F) are not suitable for lower temperatures because they are unlikely to have adequate fracture toughness below -46°C (-50°F). Materials with greater fracture toughness are specified for the lower temperature range -47°C to -100°C (-51°F to -150°F).

- Tubes that are in hydrogen, wet sour, amine, or caustic services must be seamless. This requirement eliminates the possibility that cracks can initiate in a tube longitudinal weld.
- Saddle support wear plates must be the same material as that of the shell. Use of the same material ensures that the wear plate has the same strength, fracture toughness, and hydrogen resistance as the shell plate.

- If the exchanger is in hydrogen service with a design temperature of 260°C (500°F) and greater, all attachments must be the same material as the pressure component to which they are attached. Use of the same material ensures that the attachment has the same hydrogen attack resistance as the pressure component.
- 32-SAMSS-007 Note A requires that materials for exchangers that are in hydrogen service must be selected in accordance with API-941. API-941 and the Nelson Curves were discussed in MEX 202. In using API-941, the hydrogen partial pressure must be set at 10% above the design hydrogen partial pressure, and the temperature must be set at 30°C (50°F) above the design temperature.
- 32-SAMSS-007 Note B requires that materials for exchangers in amine service must be selected using Table 1 and
  API RP-945, *Avoiding Environmental Cracking in Amine Units*.
- 32-SAMSS-007 Note C specifies additional material requirements for exchangers that are in wet sour service with a design temperature up to 200°C (400°F). In this regard:
  - Specific material specifications must be used for forged flanges, forged fittings, studs and nuts.
  - The materials must satisfy the requirements of NACE MR-01-75 and NACE RP-04-72. The NACE requirements limit the hardness of welds in wet sour service in order to reduce the potential that they will crack during operation.
- 32-SAMSS-007 Note D specifies additional material requirements for exchangers that are in sea water service. In this service, carbon steel pressure components must be clad or weld overlayed with Monel, and the tube material must either be Cu/Ni or Titanium.

Impact Testing and 32-SAMSS-007 - Table 2

Fracture toughness, brittle fracture, and impact testing were discussed in MEX-202. Table 2 of 32-SAMSS-007 (reproduced in Work Aid 1) specifies the minimum acceptable design temperature ranges of carbon and low-chrome steels that are used for shell-and-tube heat exchanger components. For a specific material specification and minimum design metal temperature range, Table 2 specifies which of the following impact test requirements must be followed:

- Impact testing of the base material and the welding procedures are required.
- Impact testing of only the base material is required if the welding consumable classifications meet specified requirements.
- Impact testing is not required.

Impact test requirements for materials that are not listed in Table 2 must be obtained from the Saudi Aramco engineer.

Paragraph 5.4 contains specific impact test requirements. For example:

- Specified heat exchanger internal components (e.g., baffle plates, sealing strips, etc.) are exempt from impact testing.
- Minimum acceptable Charpy impact energy values are specified for carbon steels that are listed in Table 2.
- Impact testing must be done at the Minimum Design Metal Temperature (MDMT).

Refer to Paragraph 5.4 of 32-SAMSS-007 for the specific requirements.

Alternative Materials

Materials listed in Table 1 are the materials that are preferred by Saudi Aramco, but they may not necessarily be the optimum choices for all applications. Situations may arise in which the material that is proposed for a shell-and-tube heat exchanger component in a specific service is not listed for the intended service in 32-SAMSS-007, Table 1. When such a situation arises, the engineer should propose a material substitution and refer to the Consulting Services Department (CSD), which has jurisdiction over material selection issues, to verify that the choice is correct based on the reasons that he offers as explanation. For services that are not listed in Table 1, the engineer should verify the acceptability of the proposed materials with CSD. In general, as stated in Paragraph 5.1.2, alternative materials must comply with all the requirements of the applicable Code and 32-SAMSS-007.

Corrosion Allowance

MEX 202 covered the principles of corrosion and the methods normally used by designers to resist corrosion deterioration. MEX 202 described corrosion allowances as the method most often used to address corrosion in pressure vessels and heat exchangers. A corrosion allowance is the additional metal thickness that is added to a component in excess of the material that is required to resist the applied loads. The added thickness compensates for the reduction in metal thickness that results from corrosion that occurs while the exchanger is in service. Normally, the corrosion allowance for heat exchanger parts is specified by the materials engineer or the process licenser.

SAES-E-004, Para. 7.8, lists specific corrosion allowance requirements for heat exchanger components. Minimum corrosion allowances for pressure parts, and the minimum thickness of nonpressure parts, are provided in API-660 and the TEMA standard. These minimum thicknesses depend on whether the material is carbon steel or an alloy. For TEMA Class R exchangers, the minimum corrosion allowance for carbon steel pressure parts is 3.2 mm (1/8 in.).

Hydrogen Attack

MEX 202 discussed hydrogen embrittlement and hydrogen induced cracking (HIC), which occur in wet sour environments. These metal deteriorations are not strictly corrosion effects, and it is not practical to address either of these effects through corrosion allowances. API Publication 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*, specifies materials that resist hydrogen deterioration and are recommended for exposed heat exchanger components. There is no difference between pressure vessels and heat exchangers with respect to material selection based on hydrogen attack considerations.

Contractor Design Package

In most situations, the Saudi Aramco engineer will not take the lead role in the initial material specification and mechanical design of heat exchanger components. Lead roles are taken by the prime contractor that Saudi Aramco has employed for the particular project, and the specific heat exchanger manufacturer. The job of a Saudi Aramco engineer will normally be to review the work that is performed by the prime contractor and heat exchanger manufacturer for acceptability with respect to Saudi Aramco requirements. The term Contractor Design Package, as used in this course, describes the total of all the detailed design information for the heat exchanger that is prepared by both the prime contractor and the heat exchanger manufacturer. The Saudi Aramco engineer will use the information that is contained in a Contractor Design Package in order to perform his review function.

A complete Contractor Design Package for a shell-and-tube heat exchanger will include the following items:

- A completed Shell-and-Tube Heat Exchanger Data Sheet, Form 2714. This data sheet will normally be prepared by the prime contractor. The content and use of this form are discussed further in MEX 210.03, and blank copies are contained in Course Handout 3 for reference.
- Detailed fabrication drawings and welding requirements for all the heat exchanger components, such as the shell, channel, heads, nozzles, and flanges. These drawings and welding requirements will be prepared by the heat exchanger manufacturer.

- Heat exchanger inspection plan. This plan will be prepared by the heat exchanger manufacturer.
- Heat exchanger hydrotest procedure, in the form of a drawing or a written stepwise procedure. This procedure will be prepared by the heat exchanger manufacturer.
- Heat exchanger design calculations. Note that the prime contractor may have made preliminary thickness calculations for the major heat exchanger components and inserted these thicknesses in the appropriate locations on the data sheet. The final calculations and component thicknesses are determined by the heat exchanger manufacturer.
- Safety Instruction Sheet, Form 2713. Note that this form may actually be completed by either a Saudi Aramco engineer or the prime contractor, depending on the particular situation. Completion of the Safety Instruction Sheet will be discussed in MEX 210.03.

The information that participants will use to solve the Exercises and Evaluations in this and the next two modules is contained in Contractor Design Packages that are provided in Course Handout 4. Work Aid 1 may be used to help in the evaluation of the materials information that is in a Contractor Design Package.

Refer to the Shell-and-Tube Heat Exchanger Data Sheet, Form 2714, that is contained in Course Handout 3. Figure 1 shows the area on this form where information that is related to material selection is specified. Note that the material specifications for all the major components are specified in this area. This section of the form must be reviewed to help determine if the materials that are specified by the contractor meet Saudi Aramco requirements. Earlier sections of the form (not shown in Figure 1) define other items that are needed to evaluate the material selection (e.g., the heat exchanger service, design pressure, design temperature, and corrosion allowance).

B. CONSTRUCTION DATA (Continued)	MATERIAL AND SPECIFICATIONS	THICKNESS BASE METAL/ CLADDING	PWHT/XR
Tubes: O.D.....In. Wall Thk.....In./Bwg			
Number Length Feet			
Pitch Tube Pattern U-Bend			
Stationary Tube Sheet/Cladding	/	/	
Floating Tube Sheet/Cladding	/		
Channel Or Bonnet/Cladding	/	/	
Channel Cover/Cladding	/	/	
Shell/Cladding	/	/	
Shell Cover/Cladding	/	/	
Backing Ring			
Floating Head Cover/Cladding		/	
Baffles/Supports Type:			
% CUT PITCH (Spacing C/C)			
Longitudinal Baffle Yes/No			
Supports			
Bypass Seal Arrangement **Tube To Tubesheet Joint Rolled/Rolled & Welded**			
Bolting: Shell Cover To Shell			
Channel To Shell			
Channel Cover To Channel			
Floating Head Cover To Tubesheet			
Gaskets: Shell Cover To Shell			
Shell To Stat. Tubesheet			
Channel To Stat. Tubesheet			
Channel Cover To Channel			
Floating Head Cover To Tubesheet			

Figure 1. Form 2714 Excerpt

DETERMINING WHETHER CONTRACTOR-SPECIFIED AIR-COOLED HEAT EXCHANGER MATERIALS MEET SAUDI ARAMCO MATERIAL SELECTION REQUIREMENTS

For air-cooled heat exchangers, the applicable standards and specifications are 32-SAMSS-011, *Air-Cooled Heat Exchangers*, and API-661.

Work Aid 2 provides a procedure that may be used to determine if contractor-specified materials meet Saudi Aramco requirements. The following sections provide additional information regarding air-cooled heat exchanger material selection.

The basic material selection factors and considerations that were discussed in MEX 202 and its prerequisite courses apply to air-cooled heat exchangers as well, and will not be discussed again. Instead, this section concentrates on additional material selection requirements that are specific to air-cooled heat exchangers.

Materials-Related Provisions of 32-SAMSS-011

32-SAMSS-011 is the Saudi Aramco Materials System Specification that is applicable to the purchase of air-cooled heat exchangers. Several of the material selection requirements that are in 32-SAMSS-011 are discussed in the following paragraphs.

32-SAMSS-011 - Design

Section 6 address design requirements for air-cooled heat exchangers and section 7 addresses the material requirements. Several provisions in these sections are related to material selection, and specifically to the following topics:

- Gasket Material
- Nozzles
- Noncombustible Materials

Gasket Material – Provisions of API-661 specify that the use of compressed asbestos gaskets is not allowed. Compressed asbestos gaskets are not allowed because of Saudi Aramco's desire to eliminate the use of asbestos.

API-661 specifies other gasket material requirements. For example, gaskets for tube-access plugs must be either the solid-metal type or the double-metal-jacketed filled type. For either gasket type, the metal must be of the same general material as the plug in order to have the same corrosion resistance.

Nozzles – 32-SAMSS-011 Paragraph 6.1.9.10 stipulates that nozzles must be fabricated in one of the following ways for specified services (i.e., hydrocarbon, hydrogen, caustic, sour, wet sour, amine, steam):

- The nozzle neck and flange are integrally forged as a single component (i.e., long welding neck).
- The nozzle neck is made from seamless pipe, and a weld neck type flange is welded to the neck.

  Para. 6.1.9.10 also states that slip-on flanges may only be used for utility services. Slip-on flanges are not used in other services in order to use stronger flange designs (e.g., weld neck or integral forging) for more severe applications.

32-SAMSS-011 - Table 1 – Table 1, *Acceptable Materials for Carbon and Low-Chrome Steels* (reproduced in Work Aid 2), provides requirements for the selection of materials for the primary components of air-cooled heat exchangers. These components include:

- Plate for Headers, Pass Partitions, Stiffeners
- Nozzle Necks
- Tube (inner)
- Forged Flanges, Fittings and Plugs
- Wrought Fittings
- Studs and Nuts

For ordinary services, materials that are proposed by contractors for use in Saudi Aramco air-cooled heat exchangers should be compared to the materials that are listed in Table 1. The data contained in Table 1 include applicable ASTM specifications and grades, as necessary. Note that materials that are listed within a specific segment of Table 1 are not equivalent to each other, nor does the order in which materials appear imply the order of preference.

Air-cooled heat exchanger components should be resistant to corrosion or metallurgical attack that could be caused by the fluid that the components contact. Table 1 is subdivided into three temperature categories. Component material selections are then made based on the specific heat exchanger temperature category with additional considerations based on heat exchanger service. The use of Table 1 and the additional materials selection considerations are similar to the approach that was discussed for shell-and-tube heat exchangers.

Impact Testing and 32-SAMSS-011, Table 2

Fracture toughness, brittle fracture, and impact testing are also of concern with respect to air-cooled heat exchangers. Table 2 of 32-SAMSS-011 (reproduced in Work Aid 2) specifies the minimum acceptable design temperature ranges of carbon and low-chrome steels that are used for air-cooled heat exchanger components. This table is used in the same manner as the analogous table that is in 32-SAMSS-007. Additional impact test requirements are contained in Paragraph 7.4.

Alternative Materials

The materials listed in Table 1 are the materials that are preferred by Saudi Aramco, but they may not necessarily be the optimum choices for all applications. When the material proposed for an air-cooled heat exchanger component is not listed for that component in 32-SAMSS-011, Table 1, the engineer should propose a material substitution and refer to CSD to verify that the choice is correct, based on the reasons that he offers as explanation. For services that are not listed in Table 1, the engineer should verify the acceptability of the material with CSD. In general, as stated in Paragraph 7.1.11, alternative materials must comply with all the requirements of the applicable Code and of 32-SAMSS-011.

Contractor Design Package

The general use and contents of Contractor Design Packages, and the typical role of the Saudi Aramco engineer in reviewing these packages, were discussed earlier and apply to air-cooled heat exchangers also. A complete Contractor Design Package for an air-cooled exchanger will include the following items:

- A completed Air-Cooled Heat Exchanger Data Sheet, Form 2716. This data sheet will normally be prepared by the prime contractor. The content and use of this form are discussed further in MEX 210.03, and blank copies are contained in Course Handout 3 for reference.
- Detailed fabrication drawings and welding requirements for all the heat exchanger components, such as the header boxes and nozzles. These drawings and welding requirements will be prepared by the heat exchanger manufacturer.
- Heat exchanger inspection plan. This plan will be prepared by the heat exchanger manufacturer.
- Heat exchanger hydrotest procedure, in the form of a drawing or a written stepwise procedure. This procedure will be prepared by the heat exchanger manufacturer.
- Heat exchanger design calculations. The final calculations and component thicknesses are determined by the heat exchanger manufacturer.
- Safety Instruction Sheet, Form 6238. Note that this form may actually be completed by either a Saudi Aramco engineer or the prime contractor, depending on the particular situation. Completion of the Safety Instruction Sheet will be discussed in MEX 210.03.

The information that participants will use to solve the Exercises and Evaluations in this and the next two modules is contained in Contractor Design Packages that are contained in Course Handout 4. Work Aid 1 may be used to help in the evaluation of the materials information that is in a Contractor Design Package.

Refer to the Air-Cooled Heat Exchanger Data, Form 2716, that is contained in Course Handout 3. Figure 2 shows the area on this form where information that is related to material selection is specified. Note that this area includes items such as the design pressure and design temperature, corrosion allowance, and material specifications for the major components. This section of the form must be reviewed to help determine if the materials that are specified by the contractor meet Saudi Aramco requirements. An earlier section of the form (not shown in Figure 2) defines the heat exchanger service, which is also needed to evaluate the material selection.

41	**DESIGN - MATERIALS - CONSTRUCTION**			
42	Design Pressure psig	Test Pressure psig	Design Temperature ^{o}F	
43	TUBE BUNDLE	HEADER Type	TUBE Material	
44	Size	Material	(Seamless) (Welded)	
45	No./Bay No. Tube Rows	No. Passes* Slope in./ft.	OD in.	Min. Thick. in.
46	No. of Tubes/pass	Plug Material	No./Bundle Length ft.	
47	Arrangement	Gasket Material	Pitch in. ²	
48	Bundles in Parallel in Series	Corrosion Allowance in.	FIN, Type	
49	Bays in Parallel in Series	No., Size Inlet Nozzle in.	Material	
50	Bundle Frame	No., Size Outlet Nozzle in.	OD in.	Stock Thick. in.
51	MISCELLANEOUS	Special Nozzles	No./in. F	in Design Temp. ^{o}F
52	Struct. Mount.(grade)(piperack) c/c	Rating & Facing	Code-ASME VIII: Div. 1	Stamp (Yes)(No)
53	Surface Preparation	TI PI		
54	Weight-Empty/Full of water	lbs.		
55	Wind Load	PSI		
Give tube count of each pass when irregular.				

Figure 2. Form 2716 Excerpt

SUMMARY

This module provided instruction to prepare the participant to judge whether the materials that are specified by a contractor or heat exchanger manufacturer meet Saudi Aramco and industry requirements as specified in the applicable Saudi Aramco Materials System Specifications. The module discussed the criteria that engineers use to judge the acceptability of materials, and it explained how these criteria are applied. The module also discussed the content of typical Contractor Design packages for shell-and-tube and air-cooled heat exchangers.

After the heat exchanger construction materials have been selected, the detailed mechanical design can proceed. The mechanical design requirements for heat exchangers will be discussed in MEX 210.03.

WORK AIDS

WORK AID 1: PROCEDURE FOR DETERMINING WHETHER CONTRACTOR-SPECIFIED SHELL-AND-TUBE HEAT EXCHANGER MATERIALS MEET SAUDI ARAMCO MATERIAL SELECTION REQUIREMENTS

This Work Aid may be used in conjunction with the copies of SAES-E-004 and 32-SAMSS-007 that are contained in Course Handout 2, and the copies of the TEMA Standard and API-660 that are in Course Handout 1, to determine whether materials that are specified in a Contractor Design Package for shell-and-tube heat exchanger components meet Saudi Aramco requirements. For convenience, Table 1 of 32-SAMSS-007 is reproduced in this Work Aid as Table A2. Heat exchanger design information that is required to verify material selection is obtained from the Contractor Design Package.

Note: This Work Aid focuses only on material selection requirements that are specific to shell-and-tube heat exchangers. General pressure vessel material selection considerations that also apply to heat exchangers were discussed in MEX 202 (e.g., materials for hydrogen service and the Nelson Curves) and are not included in this procedure. Refer to MEX 202 for additional information.

1. Identify the heat exchanger service_____

2. Identify the heat exchanger design temperature. _____°C (_____°F)

   If the design temperature is below -100°C (-150°F) or above 645°C (1200°F), material selection requirements are beyond the scope of 32-SAMSS-007 requirements. Consult the Consulting Services Department.

3. Is the heat exchanger in a corrosive service that would require more than a 6.35 mm (0.25 in.) corrosion allowance for shell side or channel side components that are fabricated from carbon steel? Yes ___No___

   If yes, review material selection requirements with the Consulting Services Department.

4. Identify the heat exchanger corrosion allowance.
   _____mm (_____in.)

   Does the specified corrosion allowance conform to the requirements of SAES-E-004, Para. 7.8? Yes_____ No _____

5. Identify the material specifications that are specified by the contractor or vendor in the Contractor Design Package for the heat exchanger components that are summarized in Table A2.

Component	Material Specification
Shells, Heads, Tubesheets, Channels, Covers, Reinforcing Pads, Rolled Nozzle Necks	
Tubes	
Pipe for Nozzle Necks	
Forged Flanges and Forged Fittings	
Wrought Fittings	
Studs/Nuts	
Internal Attachment Clips	
External Attachment Clips	
Supports	
Anchor Bolts	

Table A2. Specified Heat Exchanger Materials

6. Refer to Table 1 in 32-SAMSS-007 and its associated notes (excerpted in **Error! Reference source not found.**/Table A 3). Confirm that the material specifications found in Step 5 are acceptable for the service and design temperature found in Step 1 and Step 2.
7. If the proposed materials are not contained in **Error! Reference source not found.**/Table A 3, further review is required. Consult the Consulting Services Department as needed.

Exchanger Component	Design Temperature (Note: The numbers in ( ) refer to the specific notes at the end of the table)			
	-100°C to -47°C (-150°F to -51°F)	-46°C to 0°C (-50°F to 32°F)	1°C to 425°C (33°F to 800°F)	351°C to 645°C (651°F to 1200°F)
Shells, Channels, Dished Heads, Tubesheets, Rolled Nozzle Necks, Covers, and Reinforcing Pads	SA-203 Grades D or E	SA-516 Grade 70N, or SA-537 Class 1	SA-516 Grade 70, or SA-537 Class 1 or SA-285 Grade C (1)	SA-387 Grade 11
Pipe, Nozzle Necks	SA-333 Grade 3	SA-333 Grade 6	SA-106 Grade B SA-53 Grade B (1)	SA-335 P11, 12 or 22
Tubes (2)	SA-249 Type 304	SA-334 or SA-249 Type 304	SA-179 or SA-214	SA-179 or SA-214 or SA-213 Type 304
Forged Flanges and Forged Fittings	SA-350 LF3	SA-350 WPL6	SA-105	SA-234 F11, 12, or 22
Wrought Fittings	SA-420 WPL3	SA-420 WPL6	SA-234 WPB	SA-234 F11, 12, or 22
Studs/Nuts for Pressure Connections	SA-320 L43 SA-194 Grades 4 or 7	SA-320 L7/ SA-194 Grade 2H	SA-193 B7/ SA-194 Grade 2H	SA-193 B5, or B16/ SA-194 Grade 3
Internal Attachment Clips (4)	SA-203 Grades D or E	SA-516 Grade 70N, or SA-537 Class 1	SA-516 Grade 70, or SA-537 Class 1 SA-285 Grade C(1)	SA-387 Grades 11, 12, or 22
External Attachment Clips (4)	SA-203 Grades D or E	SA-516 Grade 70N, or SA-537 Class 1	SA-516 Grade 70, or SA-537 Class 1 or SA-285 Grade C or SA-36(1)	SA-387 Grades 11, 12, or 22
Supports (3)	SA-203 Grades D or E	SA-516 Grade 70N, or SA-537 Class 1 or SA-285 Grade C	SA-516 Grade 70, or SA-285 Grade C, or SA-36 Grade (1)	SA-387 Grades 11, 12, or 22
Anchor Bolts	SA-307 Grade B	SA-307 Grade B	SA-307 Grade B	SA-307 Grade B

Table A 3. Acceptable Materials for Carbon and Alloy Steels, cont'd

8. Confirm that the following additional material selection requirements are met:

   a. Material for baffles, support plates, impingement protection, tie rods and spacers must be of the same basic material as the tubes. However, for titanium tubes the materials must be approved by the Saudi Aramco engineer.

   b. When the component to which a nozzle is attached is made of or lined with corrosion-resistant material, the

nozzle must also be of the same material, or likewise be clad or lined.

c. Gaskets in hydrocarbon service must be double-jacketed graphite-filled metal, solid metal, or spiral-wound graphite-filled metal.

d. Gaskets for sea water service must be double-jacketed Monel clad non-asbestos.

e. Gaskets for the steam side of exchangers in steam service must be spiral-wound type, graphite-filled.

f. If materials are specified that are not in Table 1 of 32-SAMSS-007, mechanical properties and chemical analysis must be furnished, and the use of these materials is subject to the buyer's approval. Rimmed steels must not be used. Semi-killed steels must not be used for components that require impact testing.

g. Materials for wet sour service must comply with 32-SAMSS-007 Table 2 Note C, NACE MR-01-75, and NACE RP-04-72.

h. Materials for hydrogen service must meet the requirements of 32-SAMSS-007 Table 2 Note A.

i. Materials for amine service must meet the requirements of 32-SAMSS-007 Table 2 Note B.

j. Materials for sea water service must meet the requirements of 32-SAMSS-007 Table 2 Note D.

9. Pressure-retaining components, including base metal, weld metal, and heat-affected zone (HAZ) must meet impact test requirements stipulated in Paragraph 5.4 of 32-SAMSS-007 and Table 2 (excerpted in Table A 4).

The following exchanger components are excluded from impact test requirements:

- Baffle plates
- Sealing strips
- Tie rods
- Sliding bars
- Tubes
- Spacers

- Support plates

Product Form	Minimum Design Metal Temperature (Note: The numbers in ( ) refer to the specific notes at the end of the table)				
	-100°C to -47°C (-150°F to -51°F)	**-46°C to -28°C (-50°F to -20°F)**	**-27°C to -18°C (-19°F to 0°F)**	**-17°C to -7°C (1°F to 20°F)**	**-6°C and above (20°F and above)**
Plate	SA-203 Grades D or E (Note 1)	SA-516 Grade 70N, or SA-537 Class 1 (Note 1)	SA-516 Grade 70N, or SA-537 Class 1 (Note 2)	SA-516 Grade 70N, or SA-537 Class 1	SA-516 Grade 70N, or SA-537 Class 1
Forged Fittings and Flanges	SA-350 LF3 (Note 1)	SA-350 LF2 (Note 1)	SA-350 LF2 (Note 2)	SA-350 LF2	SA-105
Piping	SA-333 Grade 3 (Note 1)	SA-333 Grade 6 (Note 1)	SA-333 Grade 6 (Note 2)	SA-333 Grade 6	SA-106 Grade B
Wrought Fittings	SA-420 WPL3 (Note 1)	SA-420 WPL6 (Note 1)	SA-420 WPL6 (Note 2)	SA-420 WPL6	SA-234 WPB

Table A 4. Minimum Design Metal Temperature Range of Carbon Steel and Low-Chrome Steels

10. Confirm that the specified corrosion allowances meet the following requirements for TEMA Class R exchangers:

    a. For carbon steel parts:

    - Pressure parts must have a corrosion allowance of 3.2 mm (0.125 in.), except as noted below.
    - Internal floating head covers must have the corrosion allowance on all wetted surfaces except gasket seating surfaces.
    - Tubesheets must have the corrosion allowance on each side with the provision that, on the grooved side of a grooved tubesheet, the depth of the gasketed groove may be considered as available for corrosion allowance.
    - Where flat external covers are grooved, the depth of the gasketed groove may be considered as available for corrosion allowance.

- Corrosion allowance must only be applied to the inside diameter of flanges where exposed to the fluids.
- Nonpressure parts do not require a corrosion allowance.
- Tubes, bolting, and floating head backing devices do not require a corrosion allowance.

b. No corrosion allowance is required for alloy parts.

11. Confirm that the following material selection requirements from API-660 are met:

a. In services where stress cracking is possible, internal bolting of ferritic material must be SA-193 Grade B7M.

b. Metal that is used for gaskets must have a corrosion resistance that is at least equal to that of the gasket contact surface material.

c. Integrally-finned tubes of copper alloy must be furnished in the annealed temper (ASME SB-359).

WORK AID 2: PROCEDURE FOR DETERMINING WHETHER CONTRACTOR-SPECIFIED AIR-COOLED HEAT EXCHANGER MATERIALS MEET SAUDI ARAMCO MATERIAL SELECTION REQUIREMENTS

This Work Aid may be used in conjunction with the copy of 32-SAMSS-011 that is contained in Course Handout 2 and the copy of API-661 that is in Course Handout 1 to determine whether materials that are specified in a Contractor Design Package for air-cooled heat exchanger components meet Saudi Aramco requirements. For convenience, Table 1 of 32-SAMSS-011 is reproduced in this Work Aid as Table A 5/Table A 6. Heat exchanger design information that is required to verify material selection is obtained from the Contractor Design Package.

Note: This Work Aid focuses only on material selection requirements that are specific to air-cooled heat exchangers. General pressure vessel material selection considerations that also apply to heat exchangers were discussed in MEX 202 (e.g., materials for hydrogen service and the Nelson Curves) and are not included in this procedure. Refer to MEX 202 for additional information.

1. Identify the heat exchanger service_____

2. Identify the heat exchanger design temperature. _____°C (_____°F)

   If the design temperature is below -46°C (-50°F) or above 645°C (1200°F), material selection requirements are beyond the scope of 32-SAMSS-011 requirements. Consult the Consulting Services Department.

3. Is the heat exchanger in a corrosive service that would require more than a 6.35 mm (0.25 in.) corrosion allowance for components that are fabricated from carbon steel? Yes _____ No _____

   If yes, review material selection requirements with the Consulting Services Department.

4. Identify the material specifications that are specified by the contractor or vendor in the Contractor Design Package for the heat exchanger components that are summarized in Table A 5.

Component	Material Specification
Plate for Headers, Pass Partitions, Stiffeners	
Nozzle Necks	
Tubes (Inner)	
Forged Flanges, Forged Fittings and Plugs	
Wrought Fittings	
Studs/Nuts	

Table A 5. Specified Heat Exchanger Materials

5. Refer to Table 1 in 32-SAMSS-011 and its associated notes (excerpted in Table A 6). Confirm that the material specifications found in Step 4 are acceptable for the service and design temperature found in Step 1 and Step 2.
6. If the proposed materials are not contained in Table A 6, further review is required. Consult the Consulting Services Department as needed.

Exchanger Component	**Design Metal Temperature (Note: The numbers in ( ) refer to the specific notes at the end of the table)**		
	-46°C to 0°C (-50°F to 32°F)	**1°C to 425°C (33°F to 800°F)**	**351°C to 645°C (651°F to 1200°F)**
Header Plates, Pass Partition Plates and Stiffener Plates	SA-516 Grade 70N, or SA-537 Class 1	SA-516 Grade 70, or SA-537 Class 1 or SA-285 Grade C (1)	SA-387 Grades 11, 12 or 22
Nozzle Necks	SA-333 Grade 6	SA-106 Grade B SA-53 Grade B (1)	SA-335 P11, 12 or 22
Tubes (inner) (2)	SA-334 or SA-249 Type 304	SA-179 or SA-214	SA-179 or SA-214 or SA-213 Type 304
Forged Flanges, Forged Fittings, and Plugs	SA-350 LF2	SA-105N	SA-182 F11, 12, or 22
Wrought Fittings	SA-420 WPL6	SA-234 WPB	SA-234 F11, 12, or 22
Studs/Nuts for Pressure Connections	SA-320 L7 w/ SA-194 Grade 2H	SA-193 B7/ SA-194 Grade 2H	SA-193 B5, or B16/ SA-194 2H, or 3

Table A 6. Acceptable Materials for Carbon and Low-Chrome Steels

7. Confirm that the following additional material selection requirements are met:

   a. Compressed asbestos gaskets are not allowed. Synthetic fiber gaskets with binder and parting agents on both sides may be used for water, lube, and seal oil service at design pressure of 2 100 kPa (ga) (300 psig) or less.

   b. For most services, nozzles must be fabricated either as a single integral forging of the nozzle and flange, or as a seamless pipe that is welded to a forged weld neck flange. See Paragraph 6.1.9.10 of 32-SAMSS-011.

   c. When the header is lined with corrosion-resistant material, the nozzle shall likewise be lined.

   d. If materials are specified that are not in Table 1 of 32-SAMSS-007, mechanical properties and chemical analysis must be furnished and the use of these materials is subject to the buyer's approval. Rimmed steels must not be used.

8. Confirm that the impact test requirements that are specified in Paragraph 7.4 and j.

	Minimum Design Metal Temperature			
Product Form	**-46°C to -28°C (-50°F to -20°F)**	**-27°C to -18°C (-19°F to 0°F)**	**-17°C to -7°C (1°F to 20°F)**	**-6°C and above (20°F and above)**
Plate	SA-516 Grade 70N, or SA-537 Class 1 (Note 1)	SA-516 Grade 70N, or SA-537 Class 1 (Note 2)	SA-516 Grade 70N, or SA-537 Class 1	SA-516 Grade 70N, or SA-537 Class 1
Forged Fittings and Flanges	SA-350 LF3 (Note 1)	SA-350 LF3 (Note 2)	SA-350 LF3	SA-105N
Piping	SA-333 Grade 6 (Note 1)	SA-333 Grade 6 (Note 2)	SA-333 Grade 6	SA-106 Grade B
Wrought Fittings	SA-420 WPL6 (Note 1)	SA-420 WPL6 (Note 2)	SA-420 WPL6	SA-234 WPB

Table A 7. Minimum Design Metal Temperature Range of Carbon Steel and Low-Chrome Steels

9. Confirm that the following material selection requirements from API-661 are met:

   a. Tube-access-plug gaskets must be either the solid-metal type or the double-metal-jacketed filled type. The gasket metal must be of the same general material classification as the plug.

b. The gasket that is used with a removable-cover-plate header or a removable-bonnet header must be the double-metal-jacketed, filled type. The filler material must be either asbestos or an equivalent material.

c. Additional general material requirements, plus material requirements for headers, louvers, and other components, are contained in Paragraphs 5.1 through 5.4.

GLOSSARY

austenitic	Either a chromium-nickel or a chromium-nickel-manganese alloy that has a minimum alloy content of 18% chrome plus 8% nickel and that is nonmagnetic.
cladding	A thin layer of corrosion-resistant metal that is bonded to a base metal to protect the base metal from corrosion.
fully killed steel	Steel from which most of the impurities and gas bubbles have been removed.
heat-affected zone (HAZ)	That portion of the base metal that is not melted during brazing, cutting, or welding, but whose micro-structure and properties are altered by the heat of those operations.
hydrogen embrittlement	A form of damage to carbon steel in hydrocarbon service that results from the build-up of gas pressure within the steel as a result of the combination of hydrogen (from the hydrocarbon fluid) and carbon (from the steel) to form methane gas.
hydrogen-induced cracking	Cracks that occur in carbon steel in hydrocarbon service because of the buildup of methane gas within the steel. (See "hydrogen-embrittlement.")
iron dilution	Solubility of iron in another metal. When Monel cladding is applied by weld overlay, some of the iron from the base metal becomes soluble in the cladding and can degrade the corrosion resistance of the cladding.
Monel	A nonferrous alloy that consists of approximately 70% nickel and 30% copper.
nonferrous	Metal that does not contain iron or iron derivatives.
rimmed steel	Steel that contains a significant amount of impurities and gas bubbles.
semi-killed steel	Steel from which a significant percentage of the impurities and gas bubbles has been removed.
sour gas	Hydrocarbon gas that contains Hydrogen Sulfide (H_2S) at a partial pressure greater than 345 Pa (abs) (0.05 psia) and a total maximum operating pressure of at least 450 kPa (abs) (65 psia).
sour wet gas	Hydrocarbon gas that has a minimum temperature below the water dew point and that contains H_2S at a partial pressure greater than 345 Pa (abs) (0.05 psia) and a total maximum operating pressure of at least 450 kPa (abs) (65 psia).