International Association of Oil & Gas Producers

SPECIFICATION S-614

DECEMBER 2018

Supplementary Specification to API Standard 660 Shell-and-Tube Heat Exchangers

Revision history

VERSION	DATE	AMENDMENTS
1.0	December 2018	Issued for Publication

Acknowledgements

This IOGP Specification was prepared by a Joint Industry Project 33 Standardization of Equipment Specifications for Procurement organized by IOGP with support by the World Economic Forum (WEF).

Foreword

This specification was prepared under a Joint Industry Project 33 (JIP33) “Standardization of Equipment Specifications for Procurement” organized by the International Oil & Gas Producers Association (IOGP) with the support from the World Economic Forum (WEF). Ten key oil and gas companies from the IOGP membership participated in developing this specification under JIP33 Phase 2 with the objective to leverage and improve industry level standardization for projects globally in the oil and gas sector. The work has developed a minimized set of supplementary requirements for procurement, with life cycle cost in mind, based on the ten participating members’ company specifications, resulting in a common and jointly approved specification, and building on recognized industry and international standards.

This specification has been developed in consultation with a broad user and supplier base to promote the opportunity to realize benefits from standardization and achieve significant cost reductions for upstream project costs. The JIP33 work groups performed their activities in accordance with IOGP’s Competition Law Guidelines (November 2014).

Recent trends in oil and gas projects have demonstrated substantial budget and schedule overruns. The Oil and Gas Community within the World Economic Forum (WEF) has implemented a Capital Project Complexity (CPC) initiative which seeks to drive a structural reduction in upstream project costs with a focus on industry-wide, non-competitive collaboration and standardization. The vision from the CPC industry is to standardize specifications for global procurement for equipment and packages, facilitating improved standardization of major projects across the globe. While individual oil and gas companies have been improving standardization within their own businesses, this has limited value potential and the industry lags behind other industries and has eroded value by creating bespoke components in projects.

This specification aims to significantly reduce this waste, decrease project costs and improve schedule through pre-competitive collaboration on standardization.

Following agreement of the relevant JIP33 work group and approval by the JIP33 Steering Committee, the IOGP Management Committee has agreed to the publication of this specification by IOGP. Where adopted by the individual operating companies, this specification and associated documentation aims to supersede existing company documentation for the purpose of industry-harmonized standardization.

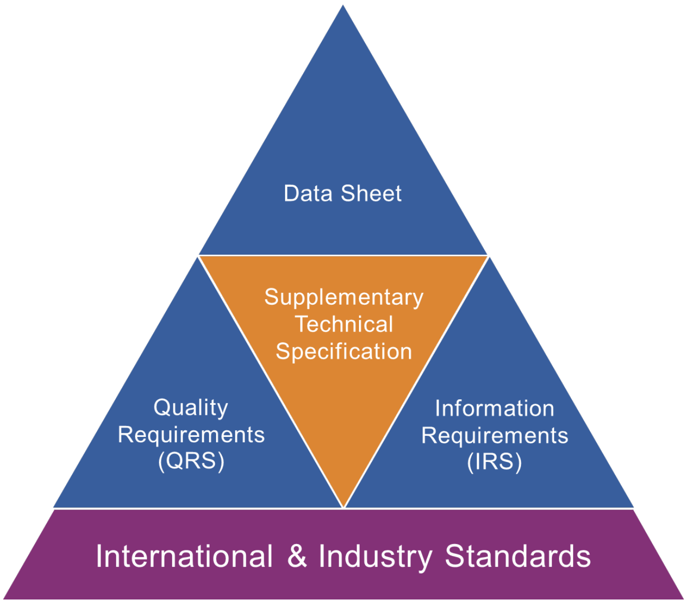
Table of Contents

Tables

Introduction

The purpose of this specification is to define a minimum common set of supplementary requirements for the specification for procurement of Shell-and-Tube Heat Exchangers in accordance with API Standard 660 9th Edition, March 2015 for application in the Petroleum and Natural Gas Industries.

This JIP33 standardized procurement specification follows a common document structure comprising the three documents as described below, which together with the purchase order documentation, define the overall technical specification for procurement. It should be noted however, that this specification package does not include a datasheet.



JIP33 Specification for Procurement Documents
Supplementary Technical Specification

It is required to use all of these documents in conjunction with each other when applying this specification, as follows:

S-614: Supplementary specification to API Standard 660 for Shell-and-Tube Heat Exchangers

This specification is written as an overlay to API Std 660, following the section structure of the parent standard, to assist in cross-referencing the requirements. Where sections from the parent standard (API Std 660) are not covered in this specification, there are no supplementary requirements or modifications to the respective section. The terminology used within this specification follows that of the parent standard and otherwise is in accordance with ISO/IEC Directives, Part 2.

Modifications to the parent standard defined in this specification are identified as *Add* (add to section or add new section), *Replace* (part of or entire section) or *Delete*.

S-614L: Information requirements for Shell-and-Tube Heat Exchangers

This document defines the information requirements, including format, timing and purpose, for information to be provided by the vendor. It also defines the specific conditions which must be met for conditional information requirements to become mandatory. The information requirements listed in the IRS have references to the source of the requirement.

S-614Q: Quality requirements for Shell-and-Tube Heat Exchangers

This document includes a conformity assessment system (CAS) which specifies standardized user interventions against quality management activities at four different levels. The applicable CAS level is specified by the purchaser in the datasheets.

The IRS is published as an editable document for the user to specify application specific requirements. The supplementary specification and QRS are fixed documents.

Unless defined otherwise in the purchase order, the order of precedence (highest authority listed first) of the documents shall be:

a) regulatory requirements;

b) contract documentation (e.g. purchase order);

c) purchaser defined requirements (equipment datasheets, IRS, QRS);

d) this specification;

e) the parent standard.

1 Scope

2 Normative References

Add to Section

The following normative references shall apply in addition to those listed in API Std 660 Shell-and-Tube Heat Exchangers.

API RP 578	Guidelines for a Material Verification Program (MVP) for New and Existing Assets
API RP 582	Welding Guidelines for the Chemical, Oil and Gas Industries
ASME BPVC Sec. VIII Div.1	Rules for construction of pressure vessels
ASME BPVC Sec. IX	Qualification standard for welding and brazing procedures, welders, brazers, and welding and brazing operators welding and brazing qualifications
ASTM A262	Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
ASTM A578	Specification for straight-beam ultrasonic examination of rolled steel plates for special applications
AWS A4.2	Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal
EN 10160	Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm ($^1/_4$ in.) (reflection method)
EN 10204	Metallic products. Types of inspection documents
ISO 3834	Quality requirements for fusion welding of metallic materials
ISO 8249	Welding – Determination of Ferrite Number (FN) in austenitic and duplex ferritic-austenitic Cr-Ni stainless steel weld metals
ISO 9712	Non-destructive testing – Qualification and certification of NDT personnel
ISO 14731	Welding Coordination – Tasks and Responsibilities
ISO 15156 (all parts)	Petroleum and natural gas industries – Materials for use in H2S-containing environments in oil and gas production
ISO 17945	Petroleum, petrochemical and natural gas industries – Materials resistant to sulphide stress cracking in corrosive petroleum refining environments
ISO 17781	Petroleum, petrochemical and natural gas industries – Test methods for quality control of microstructure of ferritic/austenitic (duplex) stainless steels
ISO 17782	Petroleum, petrochemical and natural gas industries – Scheme for conformity assessment of manufacturers of special materials
NACE TM 0284	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking
NORSOK M-650	Qualification of manufacturers of special materials
WRC-297	Local Stresses in Cylindrical Shells Due to External Loading on Nozzles
WRC-537	Precision Equations and Enhanced Diagrams for Local Stresses in Spherical and Cylindrical Shells Due to External Loading for Implementation of WRC Bulletin 107

3 Terms and definitions

Add new section

3.16 carbon equivalent (CE)

CE = (% C + % Mn / 6 + (% Cr + % Mo + % V) / 5 + (% Ni + % Cu) / 15)

4 General

4.5

Replace section with

Project or equipment specific requirements that are to be applied, as identified in Annex B, shall be specified by the purchaser on the heat exchanger datasheet.

4.10

Add to section before first sentence

For the purpose of this provision, ISO 15156 (all parts) is equivalent to NACE MR0175 (all parts). For the purpose of this provision, ISO 17945 is equivalent to NACE MR0103.

Add new section

4.13

For multiple pass heat exchangers, tube mean metal temperatures for each individual pass shall be specified on the datasheet whenever the tube side operating temperature range exceeds 110 °C (200 °F) per shell.

Add new section

4.14

When thermal and hydraulic design is in the scope of supply of the vendor, requirements including software and design methods to be applied shall be specified by the purchaser.

Annex D includes some general guidance for information and should be superseded by any specific guidance or requirements that may be provided by the purchaser. The vendor's design shall be subject to approval by the purchaser.

Add new section

4.15

The purchaser shall specify design loads to be used for the analysis of heat exchanger supports. Load combinations shall be as per Table 8 and Table 9, unless otherwise specified by the purchaser.

Table 8 – Design load combinations

Design load combination	Description
L2 + L10 + L12 + L14	Erected or (as installed) condition with full wind load and full snow load
L3 + L10 + L12 + L13 + L14 + L16	Operating condition (corroded), no pressure, with full wind load and full snow load
L3 + L11 + L12 + L13 + L14 + L16	Operating condition (corroded), no pressure, with full seismic load and full snow load
L3 + L6 + L10 + L12 + L13 + L14 + L16	Operating condition (corroded and uncorroded) with full pressure, full wind loads and full snow load (see note)
L3 + L6 + L11 + L12 + L13 + L14 + L16	Operating condition (corroded and un-corroded) with full pressure, full seismic loads and full snow load (see note)
L4 + L8 +(0.25)L10 (Note) + L12	Shop (or initial) hydrostatic test condition (uncorroded)
L4 + L9 +(0.25)L10 (Note) + L12	Field (or future) hydrostatic test condition (corroded)
L5 + L12 + L17	Transport condition
L3 + L7 + L12 + L13 + L14 + L15	Blast load Condition
NOTE 0.25 multiplied by wind load not wind speed	

Table 9 – Design load combination definitions

Design Load	Description
L1 – Fabricated Weight	Total weight of the vessel as fabricated in the shop
L2 -- Empty weight	Total weight of the vessel sitting on the foundation, fully dressed, waiting for operating liquid
L3 -- Operating weight	Empty weight plus any operating fluid weight
L4 -- Hydrotest weight	Empty weight of the vessel under hydrostatic test condition including the weight of the test fluid
L5 -- Shipping weight	Fabricated weight of the vessel plus any weight added for shipping purposes such as shipping saddle
L6	Internal (including static head) or external design pressure and internal or external design temperature
L7	Normal operating pressure and temperature
L8	Shop (or initial) hydro test pressure and temperature
L9	Field (or future) hydro test pressure and temperature
L10	Wind load
L11	Seismic load
L12	Snow load
L13	Static reactions from the load of attached equipment, such as motors, machinery, other vessels and piping
L14 -- Motion induced Load	Hull/floating unit movement effect, towing out motion, etc. whenever applicable.
L15	Blast load
L16 – Thermal Load	Steady state or transient effect of fluid flow such as icing, chilling, thermal shock, etc.
L17	Transportation load (transportation acceleration forces)

5 Proposal Information Required

5.1

Add to end of section

When a setting plan is furnished by the purchaser, the vendor shall adhere to the specified dimensions and shall provide a statement affirming compliance with this requirement.

5.2

Replace item b) with

b) preliminary dimensions for the annular distributor, including slot areas;

Add new section

5.6

When thermal and hydraulic design is in the scope of supply of the vendor, the proposal shall include calculations from the purchaser approved software package to support the design, including flow induced and acoustic vibration analysis.

Add new section

5.7

When the pressure design code does not include rules necessary for the design of all components the method of analysis to be applied shall be agreed with the purchaser.

Add new section

5.8

Use of any pressure vessel code cases shall be subject to approval by the purchaser.

6 Drawings and Other Required Data

6.1 Outline Drawings and Other Supporting Data

6.1.1

Replace item h) and i) with

h) tube bundle removal and component dismantling clearances;

i) mass of the heat exchanger, empty, operating and full of water, and of removable components with a mass greater than 25 kg (60 lb), (e.g. removable tube bundle, channel, channel cover, and shell cover);

Add to list

w) the minimum required tube wall thickness, and bend thinning allowance when applicable;

x) heat exchanger foundation loads, including bundle pulling loads;

y) tabulation of required bolt loadings (bolt torque with assumed nut factors or bolt elongations for bolts which are tensioned) along with any requirements for spring washers for girth flanges, channel covers, and floating head flanges.

6.1.2

Replace section with

When thermal and hydraulic design is in the scope of supply of the vendor or when a check-rating of exchanger designs provided by the purchaser is required, the vendor shall submit thermal and hydraulic design calculations including flow induced and acoustic vibration analysis. See A.3.2.

Add new section

6.1.5

The vendor shall submit material purchasing specifications, when specified by the purchaser.

6.2 Information Required After Outline Drawings Are Reviewed

6.2.2

Replace section with

The vendor shall furnish copies of applicable welding procedure specifications and welding procedure qualifications for review.

6.2.3

Add to list

l) total number of heat exchangers and their arrangement;

m) conditions for hydrogen, caustic or wet sour service (if applicable);

n) hydrostatic test pressures;

o) leak testing requirements;

p) lifting lugs;

q) test equipment which is shipped with the equipment, for example test covers and backing flanges;

r) nameplate and bracket details;

s) reference list of sub-vendor drawings such as bellows expansion joints, valves, separation equipment, spray nozzles, etc.

6.2.4

Replace first sentence with

The vendor shall submit for the purchaser's review the following documentation prior to the start of fabrication.

Add to list

f) pass partition plate and longitudinal baffle thickness calculations, if applicable;

g) inspection and test plan (ITP);

h) post weld heat treatment procedures, if applicable;

i) U-bend forming including post bend heat treatment procedures, if applicable;

j) non-destructive examination procedures;

k) pickling and passivation procedures, if applicable;

l) pressure and leak test procedures;

m) surface preparation and coating procedure;

n) packing and preservation procedure;

o) PMI procedure, if applicable;

p) tube expansion procedure, if applicable.

6.2.5

Replace section with

The vendor shall submit design calculations verifying design of supports, lifting and pulling devices and anchor bolt diameter.

6.3 Reports and Records

Replace item d) with

d) certified mill test reports type 3.1 (EN 10204) for all pressure parts, including tubes. Each material test report shall be identified by a part number. Welding consumable certificates shall be type 2.2 (EN 10204). Alternative certification shall be subject to agreement of purchaser;

Add to list

o) when thermal, hydraulic, and vibration calculations are included in the vendor's scope of supply, the calculations and the native electronic files, based on the "as built" heat exchanger for the specified cases. Electronic files shall be labelled with the equipment tag number;

p) results of the production test specimens.

7 Design

7.1 Design Temperature

Replace section heading with

7.1 Design Temperature and Design Pressure

7.1.1

Add to section after the first sentence

The coincident temperature and pressure for depressurization conditions, if any, shall be specified by the purchaser on the datasheet to enable the vendor to determine material impact test requirements.

Add new section

7.1.3

Unless otherwise specified by the purchaser, differential pressure design shall not be used.

7.2 Cladding for Corrosion Allowance

7.2.1

Delete from first sentence

unless otherwise specified or approved by the purchaser.

7.2.2

Replace section with

Weld overlays (including weld overlay restoration) shall have a minimum overall thickness of 3 mm ($^{1}/_{8}$ in.) including sufficient thickness to provide the specified chemical composition to a depth of at least 1.5 mm ($^{1}/_{16}$ in.) from the finished surface, unless otherwise specified by the purchaser. Pass partition grooves of tubesheets and gasket contact surfaces shall also comply with this requirement after final machining.

7.2.4

Replace section with

The cladding or weld overlay thickness on the shell side face of a tubesheet shall not be less than 12 mm ($^{1}/_{2}$ in.).

Add new section

7.2.6

The minimum cladding or weld overlay thickness at locations where the pass partition plates are welded shall be 5 mm ($^{3}/_{16}$ in.), whenever the base material requires post-weld heat treatment, unless the welding procedure specification utilized has been demonstrated to not affect the physical properties of the base metal.

Where clad components are used, the additional thickness at the pass partition plate junction may be achieved by weld deposit overlay prior to the heat treatment.

Add new section

7.2.7

The base metal nominal thickness shall not be less than 10 mm ($^{3}/_{8}$ in.).

Add new section

7.2.8

Minimum of two layers shall be applied for all weld overlay. Electroslag strip cladding may be performed with a single pass subject to the purchaser's approval.

Add new section

7.2.9

The minimum nozzle size for nozzles in cladded sections shall be DN 50 (NPS 2), unless otherwise specified by the purchaser.

Add new section

7.2.10

Nozzles shall be clad, either integrally or by weld overlay. Nozzles DN 100 (NPS 4) and smaller may be of solid alloy subject to approval of the purchaser.

Add new section

7.2.11

Radius or profiling at nozzle connections shall not reduce any clad thickness below specified minimum value.

Add new section

7.2.12

Other than pass partition plates, attachments may be welded directly to integrally clad plates if all of the following conditions are met:

a) the induced weld stress due to mechanical loads on the attachment do not exceed 25 % of the allowable stress for weld;

b) the temperature difference between the shell and the attachment is not expected to exceed 14 °C (25 °F).

All other attachments shall be welded directly to the base metal after stripping back the cladding locally. Cladding shall be restored by weld overlay.

Add new section

7.2.13

When clad restoration is required, the clad layer shall be stripped back for a minimum distance of 5 mm ($^{3}/_{16}$ in.) from the edge of the bevel. The edge of the cladding shall be rounded with a minimum radius of 1.5 mm ($^{1}/_{16}$ in.) or tapered at a minimum angle of 30°. The stripped-back area shall be etched with either a nitric acid or copper sulfate solution to ensure complete removal of the clad.

Add new section

7.2.14

Where there is change in geometry for highly stressed areas, the weld overlay shall have smooth contour finished surfaces with a minimum radius of 6 mm ($^{1}/_{4}$ in.).

Add new section

7.2.15

For transition areas at nozzles and flanges, the vendor shall provide a fabrication procedure which shall as a minimum include:

a) detailed arrangement drawing showing:

- functionality of the nozzle or flange;
- set in or set on;
- preparation of the nozzles or flanges;
- tapering;
- line up and measurement prior to overlay welding.

b) details of overlay welding, including:

- reference to the applicable welding procedure;
- number of layers.

c) method of preparation after overlay welding;

d) examination after overlay welding, including:

- thickness;
- liquid penetrant.

7.3 Shell Supports

7.3.3

Add to section after first sentence

No more than two heat exchangers shall be stacked, unless otherwise agreed by the purchaser.

7.3.6

Replace section with

Localized stresses caused by concentrated loads on nozzles or any external structural attachment due to piping reactions, supported equipment, lifting of exchanger etc. shall be evaluated. Evaluation shall be performed in accordance with WRC 297, WRC 537 or finite element analysis. Any other standard or numerical methods may be used subject to approval by the purchaser. All geometrical limits specified in methods (such as WRC etc.) used for local load analysis shall be followed. Extrapolation beyond stated limits is not allowed.

7.3.7

Replace with

All heat exchangers shall be provided with two grounding lugs located on different supports.

7.4 Stationary and Floating Heads

7.4.2

Replace section with

The pressure differential used to calculate the pass-partition plate thickness in accordance with TEMA, Section 5, RCB-9.132 shall be at least twice the allowable pressure drop per shell and shall be applied across each pass-partition plate.

The plate thickness shall not be less than two times the tube side corrosion allowance, plus 3 mm ($^1/_8$ in.), or the minimum thickness required by TEMA, whichever is greater.

7.4.3

Add to section after second sentence

Floating heads shall be through bolted; studded-in bolts shall not be used.

7.4.11

Replace section with

External custom-designed girth flanges, channel covers and floating-head flanges shall be provided with 3 mm ($^1/_8$ in.) future machining allowance on the gasket contact seating surfaces (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure.

This requirement does not apply to clad or weld overlay construction.

Add new section

7.4.12

The minimum thickness of the shear dimension for split rings (the *t* dimension per TEMA RCB-5.141) shall not be less than the nominal stud diameter.

Add new section

7.4.13

Washers shall not be provided on floating head cover joints.

7.5 Tube Bundle

7.5.1 Tubes

7.5.1.3

Add to section after first sentence

For low-fin tubing in other materials, the wall thickness under the fin shall be specified by the purchaser.

7.5.1.4

Replace second sentence with

For martensitic stainless steels, super austenitic stainless steels (> 6 wt % Mo), super duplex stainless steels, titanium, and high nickel alloys (> 30 wt % Ni), the mean radius of U-bends shall not be less than 2.0 times the nominal outside diameter of the tube.

Add to section after second sentence

Where duplex stainless steel (e.g., S31803 or S32205) tubes are specified, the mean radius of U-bends shall not be less than 2.0 times the nominal outside diameter of the tube when heat treatment is performed after bending, and 3.3 times the nominal outside diameter of the tube when no heat treatment is applied.

7.5.2 Tubesheets

7.5.2.1

Replace section with

For a vertical heat exchanger where the stationary tubesheet is at the bottom, a suitable means of holding the tube bundle in place shall be provided for when the bonnet or channel is removed. If collar bolts are used, at least four integral (one piece) bolts shall be provided with their location identified on the drawings and by stamped markings on the outside diameter of the tubesheet. The use of drilled and tapped holes is prohibited.

7.5.2.4

Replace section with

A full diameter stationary tubesheet shall be provided for removable tube bundle exchangers with bonnets (see TEMA, Figure N-1.2, Type B stationary head). The tubesheet shall be provided with integral (one piece) collar bolts for a minimum of 25 % of the bolts (four minimum). The tubesheet design shall allow for hydrostatic testing of the shell side with the bonnet removed and all bolting installed. The use of drilled and tapped holes is prohibited.

7.5.2.5

Replace section with

Tubesheets shall be provided with 3 mm ($^{1}/_{8}$ in.) future machining allowance on all the gasket contact seating surfaces (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure.

This requirement does not apply to clad or weld overlay construction.

7.5.2.6

Replace section with

For vertical fixed tubesheet exchangers, a means shall be provided to completely vent and drain the shell, through the tubesheets.

Add new section

7.5.2.7

The welded connections between a tubesheet and the adjacent cylinder shall be in accordance with ASME Section VIII, Div. 1 Figure UW-13.3, Type (a), (b) or (c), or equivalent configurations from the applied design code, for any of the following conditions:

a) cyclic service;

b) welded joint thickness equal to or greater than 38 mm ($1^1/_2$ in.);

c) design temperature greater than 400 °C (750 °F);

d) other services when specified by purchaser.

For other cases, tubesheet connection details indicated in ASME Section VIII, Div. 1 Figure UW-13.2 Type (a), (b), (c), (e-2), (f), (i), (j), or (k), or equivalent configurations from the applied design code, may be used. A configuration equivalent to UW-13.2 Type (d) may be used provided the cylinder overlap does not exceed 2 mm ($^3/_{32}$ in.). Use of alternative configurations shall be subject to approval of the purchaser.

Add new section

7.5.2.8

When the tubesheet design is outside of the scope of design code (e.g. thin flexible tubesheets, large un-tubed areas, etc.), the method of design analysis shall be subject to the approval of the purchaser.

Add new section

7.5.2.9

The tube and tube-to-tubesheet joint stresses shall be analysed for multi-pass fixed tubesheet or floating head heat exchangers whenever the tube mean metal temperature difference between adjacent passes exceeds 60 °C (108 °F).

7.5.3 Baffles and Support Plates

7.5.3.1

Replace section with

The thickness of carbon steel or low-alloy steel (maximum 9 % chromium) transverse baffles and support plates shall be TEMA (Table R-4.41) minimum plus a single shell side corrosion allowance. See A.4.2 for additional guidance.

7.5.3.2

Replace section with

To facilitate drainage and venting of the shell, transverse baffles and support plates shall have notches that are 6 mm ($^1/_4$ in.) in height for shell diameters up to and including 406 mm (16 in.), and 10 mm ($^3/_8$ in.) in height for larger shell diameters.

Add new section

7.5.3.4

Floating head support plate thickness shall be minimum 19 mm (3/4 in.) for all shell diameters. Corrosion allowance need not to be added.

Add new section

7.5.3.5

The standard tube hole diameter in the baffle and support plates shall be +0.4 mm (1/64 in.) over the outside diameter of the tubes. Tube hole tolerance shall be in accordance with TEMA RCB-4.2.

Add new section

7.5.3.6

Tie rods and spacers shall not obstruct the cleaning lane between tube rows for bundles with square or rotated square tube layouts.

Add new section

7.5.3.7

When the shell inlet or outlet nozzle is located before the U-bend, a full support plate shall be provided, located approximately 50 mm (2 in.) from the U-bend tangent.

Add new section

7.5.3.8

Welded longitudinal baffle thickness shall be calculated as per TEMA R-4.422 using 1.5 times the shellside allowable pressure drop or the TEMA minimum thickness plus a single shell side corrosion allowance; whichever is greater.

7.5.4 Impingement Protection

7.5.4.5

Replace section with

The impingement plate baffle shall be supported (e.g. by welding to at least two spacers) with a minimum clearance of 3 mm (1/8 in.) to the nearest row of tubes.

7.5.6 Tube Bundle Skid Bars

Add new section

7.5.6.6

For No-Tube-in-the-Window (NTIW) bundles, when the distance between transverse baffles exceed 1000 mm (39 in.), two skid bars shall be located in each un-tubed area (i.e. a total of 4).

Add new section

7.5.6.7

Skid bars dimensions shall be in accordance with Table 10. The skid bars shall be radially orientated and located between 15° to 20° from the vertical centerline. Skid design for bundles over 18150 kg (40000 lb) shall be subject to approval by purchaser. See A.4.3 for additional guidance.

Table 10 – Skid bar dimensions

Shell inside diameter	**Skid bar dimensions (minimum)** Dimensions in millimetres (inches)	
	Thickness	Height
< 760 (30)	13 (0.5)	38 (1.5)
761 to 1067 (30 to 42)	19 (0.75)	38 (1.5)
> 1068 (42)	25 (1)	50 (2)

7.6 Nozzles and Other Connections

7.6.1

Replace section with

All nozzle connections shall be flanged except as permitted in 7.6.2.

7.6.3

Replace section with

The minimum nozzle size, including auxiliary connections such as vents, drains and instrument connections, shall be DN 40 (NPS 1$^1/_2$). In cases where tubesheet thickness limits this size, smaller tubesheet vents and drains may be used subject to the agreement of the purchaser.

7.6.4

Replace item c) with

c) rolled plate welded to forged welding-neck flange subject to approval of the purchaser.

7.6.5

Replace section with

Slip-on flanges shall not be used.

7.6.9

Replace last sentence with

Evaluation shall be performed in accordance with WRC 297, WRC 537 or finite element analysis. Any other standard or numerical methods may be used subject to approval by the purchaser. All geometrical limits specified in methods (such as WRC etc.) used for local load analysis shall be followed. Extrapolation beyond stated limits is not allowed. When the application of these nozzle loads would require an increase in the local cylinder or head thickness, acceptable loads shall be agreed mutually with the purchaser.

7.6.11

Replace section with

Reinforcement pads shall not be used for nozzles in following services:

a) cyclic service;

b) hydrogen service;

c) sour or wet hydrogen sulfide service;

d) services with operating temperatures above 400 °C (750 °F).

Add new section

7.6.13

Set-in type nozzles shall be used. Except for sour or wet hydrogen sulfide service, set-on type nozzles may be used subject to the agreement of the purchaser.

Add new section

7.6.14

For carbon and low alloy steel material, nozzles DN 50 (NPS 2) and smaller shall be long weld neck type.

Add new section

7.6.15

The thickness of reinforcing pads shall be no thinner than the nominal wall thickness minus the total corrosion allowance and shall not exceed 50 mm (2 in.).

Add new section

7.6.16

Fittings shall not be directly welded to the exchanger shell or channel wall.

7.7 Flanged External Girth Joints

7.7.1

Replace second sentence with

Studded-in bolting shall not be used.

7.7.7

Replace section with

Stud lengths shall be such that they extend beyond the nut by at least three threads on each end.

When bolt tensioning is used, the bolting shall have additional thread length equivalent to one bolt diameter, extending from the nut at one end, to allow attachment of the bolt-tightening device. The exposed length shall be protected with an additional nut.

7.7.15

Replace section with

External custom-designed girth flanges shall be provided with 3 mm ($^1/_8$ in.) future machining allowance on the gasket contact seating surface (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure.

This requirement does not apply to clad or weld overlay construction.

Add new section

7.7.17

Maximum spacing between bolt centres shall be as calculated by TEMA RCB-11.22.

7.8 Girth Flange Joint Supplementary Design Requirements

7.8.1

Replace first sentence with

The joint component approach, as defined in ASME PCC-1, Appendix O, and the requirements contained within this section, shall be applied to both sides of the heat exchanger for girth flange and floating head flange joints.

Add new section

7.8.10

For floating head covers, in Step 6 of ASME PCC-1, the following additional check, as calculated by Equation (3), shall be undertaken to verify that the selected assembly bolt stress include the effects of pressure acting from the opposing side of the floating head cover.

$$Sb_{sel} \geq \frac{Sg_{min-o} \times A_{g,FH} + \left[\left[\frac{\pi}{4} \times \left(G_{ID,FH}\right)^2 \times P_T\right] - \left[\frac{\pi}{4} \times \left(FH_{OD}\right)^2 \times P_S\right]\right]}{\varphi_g \times n_b \times A_b} \quad (3)$$

where

A_b	is the bolt root area, expressed in mm^2 (in.^{2});
$A_{g,FH}$	is the floating head gasket area, expressed in mm^2 (in.^{2});
FH_{OD}	is the outside diameter of the floating head flange, expressed in mm (in.);
$G_{ID,FH}$	is the floating head gasket inner diameter, expressed in mm (in.).

7.9 Expansion Joints

7.9.1

Replace first sentence with

Expansion joints in shells shall be thick walled flanged and flued unless otherwise approved by the purchaser.

7.9.2

Replace item c) with

c) be designed to meet the requirements of the pressure design code. In no case shall the cycle life as calculated by EJMA be less than 1500 normal operating cycles;

Replace item g) with

g) be single ply construction for internal floating-head tailpipe expansion joints and shall be fitted with permanent stays. The stays shall be designed to prevent damage due to over extension or lack of weight bearing support during maintenance and hydrostatic testing with the shell cover removed. The stays shall permit the expansion joint's full design movements.

7.10 Gaskets

7.10.1

Replace first sentence with

Flanged external girth joint gaskets and floating-head gaskets in hydrocarbon or steam service shall be spiral-wound, grooved metal with soft gasket-seal facing or corrugated metal with soft gasket-seal facing.

7.10.2

Replace section with

Double-jacketed gaskets shall not be used.

7.10.6

Replace section with

If the gasket OD is less than or equal to 610 mm (24 in.), the peripheral portion shall be of one piece (non-welded) construction. If the gasket OD exceeds 610 mm (24 in.), the maximum quantity of welds in the peripheral portion shall not exceed the greater of either two, or the ratio of gasket OD/610 mm (gasket OD/24 in.).

7.10.9

Replace section with

Double jacketed gaskets shall not be used.

Add new section

7.10.14

Where serrated, corrugated metal or grooved metal gaskets with graphite, polytetrafluoroethylene (PTFE), or other similar facing are used, the values of *m* and *y* used in the flange design and analysis shall be greater than or equal to 3.75 and 52.4 MPa (7600 psi) respectively.

Add new section

7.10.15

When welded lip seal or welded diaphragm joints are specified, they shall be designed to accommodate differential thermal growth. The design and method of analysis shall be subject to approval of the purchaser.

7.11 Handling Devices

Add to section

7.11.3

Where the outer face is clad (including weld overlay) the tapped holes shall be of the same nominal chemistry as the face. Weld overlay shall be deposited in an over-sized hole. A minimum of 3 mm ($^1/_8$ in.) of weld overlay shall remain after drilling and tapping the hole. Alternative configurations may be used if approved by the purchaser.

7.11.4

Replace second sentence with

The lifting devices shall be provided on the shell section above the center of gravity.

Add new section

7.11.5

Localized stresses caused by concentrated loads due lifting of the exchanger shall be evaluated. Evaluation shall be performed in accordance with WRC 537 or finite element analysis. Any other standard or numerical methods may be used subject to approval by the purchaser. All geometrical limits specified in methods (such as WRC, etc.) used for local load analysis shall be followed. Extrapolation beyond stated limits is not allowed.

7.12 Requirements for Hydrogen Service

7.12.1

Replace with

All external attachment welds to the pressure boundary shall be full penetration. If it is not possible to avoid enclosed spaces between welds, then the space shall be vented with a 6 mm ($^1/_4$ in.) diameter hole.

8 Materials

8.1 General

8.1.2

Add to section

These attachments, if permanent, shall be suitable for the minimum design metal temperature of the exchanger.

8.1.5

Replace section with

Tubesheets that are welded to the adjacent shell or channel cylinder shall be provided as forged material.

Add new section

8.1.6

Shell side components (baffles, tie rods, etc.) shall be manufactured from material with equivalent chemical composition and corrosion resistance to those for the tubes unless otherwise specified on the datasheets.

Add new section

8.1.7

The minimum design metal temperature specified shall be used to evaluate the impact test requirements and exemptions as per the design code.

Further reduction in the minimum design metal temperature (e.g. reduction for thickness ratio) for impact test exemption shall be approved by the purchaser.

When impact tested carbon steel materials are used, the minimum acceptable Charpy impact energy values, at minimum design metal temperature or impact testing temperature specified in design code whichever is lower, shall be average 27 J (20 ft-lb) and single 20 J (15 ft-lb) or as specified in the design code, whichever is higher. Testing shall include base metal, weld metal and heat affected zone.

Add new section

8.1.8

The maximum allowable CE shall be in accordance with Table 11.

Table 11 – Maximum allowable CE

Plate thickness	Maximum allowable CE
≤ 50 mm (2 in.)	0.43
> 50 mm (2 in.) ≤ 100 mm (4 in.)	0.45
> 100 mm (4 in.)	0.48

Add new section

8.1.9

The maximum carbon content of carbon steel material shall not exceed 0.23 %.

Add new section

8.1.10

The maximum iron content for alloy 276 and alloy 625 overlay shall be 10 %.

8.2 Requirements for Carbon Steel in Sour or Wet Hydrogen Sulfide Service

Add new section

8.2.4

When HIC testing requirement is specified by the purchaser, one plate per lot shall be HIC tested in accordance with NACE TM0284, using test solution A and the following acceptance criteria shall apply:

a) crack length ratio (CLR) ≤ 15 % per specimen;

b) crack thickness ratio (CTR) ≤ 5 % per specimen;

c) crack sensitivity ratio (CSR) ≤ 2 % per specimen;

d) 5 mm (0.2 in.) maximum individual crack length;

e) ultrasonically tested as per ASTM A578 S1; S2.1 or EN 10160 quality classes S2 (plate) E3 (edge).

Add new section

8.2.5

HIC resistant base metal is not required for fully cladded exchangers.

8.3 Gaskets

8.3.2

Replace section with

Materials for the metallic core of grooved metal or corrugated metal gaskets shall have a corrosion resistance at least equal to that of the gasket contact surface material.

8.3.3

Replace section with

Unless otherwise specified by the purchaser, spiral wound gaskets shall comply with the following:

a) inner rings, outer centering rings (when provided), and metal windings shall be of 316 grade stainless steel;

b) when gaskets are made with welds they shall be low carbon grade 316L stainless steel;

c) where the gasket contact seating surface is of a higher alloy than 316 stainless steel, the gasket material shall match the composition of that alloy.

8.3.4

Replace section with

The metallic core material of corrugated and grooved metal gaskets shall be softer than the gasket contact surface.

8.4 Tubes

8.4.2

Replace section with

All tubes shall be eddy-current tested in the finished condition over their full length.

Add new section

8.5 Requirements for Austenitic Stainless Steel, 22Cr Duplex and 25Cr Super Duplex

Add new section

8.5.1

Material shall be supplied in solution annealed condition. Stainless steel grades 321 and 347 shall be stabilized after solution annealing heat treatment.

Add new section

8.5.2

Cold formed heads and toriconical transition sections shall be solution annealed after forming and before welding to the shell.

Add new section

8.5.3

Hot formed heads shall be solution annealed followed by rapid cooling.

Add new section

8.5.4

Arc-air or Oxy-gas methods of cutting and bevelling are not permitted.

Add new section

8.5.5

Vendor shall have in place measures to ensure no cross-contamination between ferritic and austenitic and duplex materials.

Add new section

8.5.6

Only stainless steel brushes and clean, iron-free sand, ceramic, or stainless steel grit shall be used for cleaning surfaces.

Add new section

8.5.7

Cleaning tools or materials shall not have been previously used on carbon steel.

Add new section

8.5.8

Exterior surfaces shall be protected from chloride exposure at all times.

Add new section

8.5.9

Materials for marking, painting, or inspection containing halides and heavy metals shall not be used. Aluminium and zinc based paints shall not be used for material identification.

Add new section

8.5.10

Ferrite control shall be required for austenitic stainless steel weld metal if any of the following conditions are met.

a) the material is operating in high temperature service;

b) the weld will be post weld heat treated;

c) the welding procedure is qualified with impact testing.

Add new section

8.5.11

The ferrite number (FN) shall be measured during procedure qualification and production welding prior to any post weld heat treatment using a ferritescope calibrated in accordance with ISO 8249 or AWS A4.2.

Add new section

8.5.12

Ferrite number measurements of production welds shall as a minimum include all longitudinal and circumferential pressure retaining welds, and a minimum of three separate measurements shall be performed per weld.

Add new section

8.5.13

The ferrite number for procedures qualification and production welds of austenitic stainless steel material requiring impact testing or in high temperature service shall not exceed 8FN.

Add new section

8.5.14

When post weld heat treatment is specified, the acceptable ferrite number range shall be 3FN to 10FN, except for type 347 weld deposit which shall have a minimum 5FN.

Add new section

8.5.15

The internal surfaces of exchangers with a wall thickness of less than 10 mm ($^3/_8$ in.), shall be pickled and passivated after completion of all welding activities.

Add new section

8.5.16

Surfaces including cladding, contaminated with iron during fabrication shall be pickled and passivated.

Add new section

8.5.17

All internal and external surfaces of welds shall be pickled and passivated.

Add new section

8.6 Additional Requirements for 22Cr Duplex and 25Cr Duplex

Add new section

8.6.1

All pressure retaining components shall be supplied by manufacturers qualified in accordance with the requirements of ISO 17782 or NORSOK M-650.

Add new section

8.6.2

22Cr duplex and 25Cr duplex shall not be post weld heat treated.

9 Fabrication

9.1 Shells

9.1.1

Add to section after first paragraph

The main cylinder (shell and channel) seams, connections and external attachments (except circumferential stiffening and insulation support rings) shall be laid out so that connections or reinforcement pads do not intersect seams and the distance between weld toes should be a minimum of 50 mm (2 in.) unless otherwise approved by the purchaser.

Add new section

9.1.4

Longitudinal weld seams on horizontal exchangers shall be located above the horizontal centerline. When this is not possible, longitudinal seams shall not be located more than 30° below the horizontal centerline, unless accepted by the purchaser. Weld seams shall not be located under saddle bearing plates.

Add new section

9.1.5

Where attachments will cover main seam welds, the length of the main seam weld covered by the attachment and projecting at least 50 mm (2 in.) beyond each side of the attachment shall be ground flush and inspected with 100 % volumetric examination and magnetic particle or liquid penetrant examination.

9.2 Pass-partition Plates

Replace section with

Longitudinal baffles which are welded to the shell and pass-partition plates for channels and floating-heads shall be welded full length, either from both sides or with full-penetration welds, except for special designs approved by the purchaser. If welded from both sides, the first 50 mm (2 in.) from the gasket face shall be a full-penetration weld.

Add new section

9.2.1

A 6 mm ($^{1}/_{4}$ in.) diameter drain hole shall be provided in all pass partition plates.

Add new section

9.2.2

For hydrogen service on the tube side, pass partition plates shall be full penetration welded over their entire length.

Add new section

9.2.3

For hydrogen service on the shell side, welded longitudinal baffles shall be full penetration welded over their entire length.

9.3 Connection Junctions

Add new section

9.3.1

Except as required by 9.3.2, all inside edges of nozzles and connections shall be rounded off to a radius of at least 3 mm ($^{1}/_{8}$ in.).

Add new section

9.3.2

Heat exchangers designed for cyclic service shall comply with the following:

a) round the inside edge of nozzles to 25 % of the thickness of the penetrated shell/head but not less than 6 mm ($^1/_4$ in.) or more than 19 mm ($^3/_4$ in.);

b) contour the inside corners in finished openings and in nozzle necks before overlay welding, where required;

c) the inside edge of the nozzle shall be rounded after the application of any weld overlay.

9.5 Welding

9.5.1

Add to section after first sentence

Welding and welder qualification shall be performed as per the requirements specified in the design code, datasheet and requirements in this specification.

9.5.4

Replace section with

Backing strips shall not be used, unless otherwise approved by the purchaser.

9.5.7

Replace section with

The qualification of the weld procedure for a strength-welded tube-to-tubesheet joint shall be in accordance with ASME BPVC Section IX QW-193.1 or equivalent, and the following additional requirements:

a) the minimum leak path (i.e. the distance from the root of the weld to the outer surface nearest to the root) shall not be less than two thirds of the nominal tube wall thickness;

b) a minimum of three tensile pull-tests shall be performed on the qualification test coupon whenever it cannot be proven by calculation that the strength of the weld is greater than the axial strength of the tube or if requested by the purchaser.

9.5.9

Replace section with

Repair-associated welding procedures, including heat treatment and non-destructive examination procedures, shall be submitted to the purchaser for review prior to the start of the repair.

9.5.11

Add to section

The hardness testing for welding procedure qualifications shall take place after the minimum anticipated heat treatment cycle (normally, the first heat treatment cycle).

Add new section

9.5.13

The performance qualification of the weld operators for a strength-welded tube-to-tubesheet joint shall be in accordance with ASME BPVC Section IX QW-193.2 or equivalent.

Add new section

9.5.14

Temporary attachment welds shall be removed and the affected area examined by either liquid-penetrant or magnetic particle examination. If necessary, the locations may be repaired by fill-welding and ground smooth prior to the examination.

Add new section

9.5.15

Dissimilar metal welds are prohibited for pressure-retaining joints unless approved by the purchaser.

Add new section

9.5.16

For material in sour or wet hydrogen sulfide service, the following dissimilar welds if in contact with process fluid (wetted surface) are not permitted unless approved by the purchaser:

a) ferritic steels and austenitic stainless steel;

b) ferritic steels and 22Cr duplex or 25Cr duplex;

c) ferritic steels and nickel base alloy steels.

Add new section

9.5.17

Production test plates, if required as per design code or as indicated on datasheet, shall be fabricated using the same base material of same heat and thickness and shall be subjected to the same welding procedures used for the longitudinal and circumferential weld joints in shell and head.

For low alloy steels, the requirements for production test plates shall be specified by the purchaser.

Add new section

9.5.18

When post weld heat treatment is required, simulated post weld heat treatment of production test plates and weld procedure qualification shall be subjected to a minimum one additional post weld heat treatment cycle.

For low alloy steels, the requirements for production test plates shall be specified by the purchaser.

Add new section

9.5.19

Complete weld procedure qualification mechanical testing shall be performed both after the initial heat treatment and a second simulated post weld heat treatment.

For low alloy steels, the requirements for production test plates shall be specified by the purchaser.

Add new section

9.5.20

Arc strikes outside the welds shall be removed by light grinding and inspected with magnetic particle or liquid penetrant examination.

Add new section

9.5.21

All welding and related activities shall comply with the requirements of ISO 3834 and ISO 14731 or ASME Section IX, if applicable.

Add new section

9.5.22

FCAW self-shielded is not permitted. FCAW gas-shielded is acceptable for weld passes other than the root pass in single sided weld joints.

Add new section

9.5.23

GTAW-P and GMAW-P shall be performed with the same make and model of equipment, and using the same program settings as those used in the qualification procedure.

Add new section

9.5.24

Active flux shall not be used for submerged arc welding.

Add new section

9.5.25

Any change in the following essential variables shall require requalification of the applicable welding procedure.

a) base materials:

1. carbon steel material, an increase in CE of more than 0.03 than the value qualified in the procedure qualification record, when any of the following conditions apply:

    i. subject to sour service regardless of their wall thickness;

    ii. the wall thickness greater than 38 mm (1.5 in.), regardless of the service;

    iii. subject to PWHT due to service, regardless of their wall thickness;

    iv. subject to impact toughness requirements.

2. carbon steel material other than covered in a)1, an increase in CE of more than 0.03 when the relevant value of the material tested during procedure qualification is greater than 0.43;

3. from type 22Cr duplex to type 25Cr duplex.

b. welding consumables:

1. consumable brand name when impact testing is required. This does not apply to solid wire provided with documentation confirming there is no change in origin, chemical composition and mechanical properties;

2. for SMAW, any increase of size in consumable in the root run of single sided welds;

3. for FCAW-gas shielded, any increase of size in consumable other than in the root run of single sided welds;

4. for SAW, whenever the welding flux is changed from one consumable brand name to another.

c. welding position:

1. from vertical uphill to vertical downhill welding;

2. from vertical downhill to vertical uphill welding.

d. technique:

1. from multi pass to single pass when impact testing is required.

e. joints:

1. from double sided welding to single sided welding;

    NOTE Single sided welding with backing strip is equivalent to double sided welding.

2. decrease in the included angle of more than 10° for included angles less than 60°;

3. deviation from qualified angle or more than ± 2.5° if the qualified angle is less than 30° (except for portions of compound bevels).

Add new section

9.5.26

Tack welds incorporated into the main weld shall have their ends ground and feathered, and shall be free of visible defects.

Add new section

9.5.27

All welding consumables shall be individually marked as per consumable specification.

Add new section

9.5.28

Preheating, if required, shall satisfy following requirements.

a) the required preheat temperature shall be reached before commencement of welding and maintained until the welding has been completed;

b) the preheat temperature shall be measured at a distance of not less than 75 mm (3 in.) on either side of the weld groove;

c) the interpass temperature measurements shall be taken from deposited weld metal. The minimum interpass temperature shall not be less than the specified preheat temperature.

Add new section

9.5.29

For carbon steel material in sour or wet hydrogen sulfide service, the preheat temperature reported during procedure qualification is an essential variable and shall be the minimum specified preheat temperature for production welding.

Add new section

9.5.30

For materials in sour or wet hydrogen sulfide service, heat input values (per welding process) used for production welding shall not be less than the minimum heat input (per welding process) reported during procedure qualification.

Add new section

9.5.31

For carbon steel materials, the maximum interpass temperature shall be 315 °C (600 °F)

Add new section

9.5.32

For austenitic stainless steel, 22Cr and 25Cr duplex material, the chemical composition of welding consumables and as-welded deposits during procedure qualification shall meet the requirements of API RP 582.

Add new section

9.5.33

For 25Cr duplex with thickness ≤ 7mm (0.276 in.), the minimum thickness qualified shall be the thickness of the test piece.

Add new section

9.5.34

For austenitic stainless steel, 22Cr and 25Cr duplex material, the minimum preheat temperature shall be 10 °C (50 °F).

Add new section

9.5.35

Unless otherwise qualified, the maximum interpass temperature shall not exceed the values listed in Table 12.

Table 12 – Interpass Temperature Limits

Material	Maximum interpass temperature
austenitic stainless steel	175 °C (350 °F)
22Cr Duplex	150 °C (300 °F)
25Cr Duplex	120 °C (250 °F)

Add new section

9.5.36

For austenitic stainless steel, 22Cr and 25Cr duplex material, the maximum variation in heat input shall be ± 15 %.

Add new section

9.5.37

The maximum number of repairs of the same defective area shall not exceed the values list in Table 13.

Table 13 – Repair Limits

Material	Repairs allowed
22Cr Duplex	2
25Cr Duplex	1

9.6 Heat Treatment

9.6.11

Add to section after first sentence

For single pass floating head heat exchangers, post-weld heat treatment on the circumferential weld joining the stub-ends of the expansion joint and the floating head cover shall only be performed when required by pressure design code or for process reasons.

Add new section

9.6.14

Thin walled bellows type expansion joints shall not be subjected to any heat treatment other than that performed by the expansion joint manufacturer. When post-weld heat treatment of the stub end attachment weld is required, the bellows shall be protected from overheating.

Add new section

9.6.15

Cold formed carbon steel heads shall be normalized after forming. Hot formed carbon steel heads not formed in the normalizing range shall be normalized.

Add new section

9.6.16

For quenched and tempered or normalized and tempered carbon steel materials, the post weld heat treatment holding temperature shall be at least 15 °C (25 °F) below the original tempering temperature of the base metal, unless the vendor demonstrates and the purchaser approves that mechanical properties can be achieved at a different post weld heat treatment temperature and holding time.

9.7 Dimensional Tolerances

9.7.4

Replace with

Dimensional tolerances on U-bend forming:

a) flattening at the bend shall not exceed 10 % of the nominal tube outside diameter;

b) wall thinning shall be in accordance with TEMA RCB-2.31;

c) bend diameter shall be ± 1.5 mm ($^{1}/_{16}$ in.);

d) bend deviation from the plane shall be ± 1.5 mm ($^{1}/_{16}$ in.).

Compliance shall be demonstrated by a test bend of the same material grade, same wall thickness, same tube diameter and the smallest bend radius of the bundle.

9.8 Gasket Contact Surfaces Other Than Nozzle Flange Facings

9.8.1

Add to Table 4

Table 4 – Gasket Contact Surface Finishes

Type	Surface Roughness R_a Dimensions in micrometres (micro-inches)
Non-metallic soft cut sheet gaskets, ≤ 1.5 mm ($^1/_{16}$ in) thickness	3.2 to 6.3 (125 to 250)
Non-metallic soft cut sheet gaskets, > 1.5 mm ($^1/_{16}$ in) thickness	3.2 to 12.7 (125 to 500)

9.8.2

Replace section with

The flatness tolerance (maximum deviation from a plane) on peripheral gasket contact surfaces shall be as specified in Table 5.

9.8.3

Replace section with

The flatness tolerances on peripheral gasket contact surfaces shall be as specified in Table 5.

9.10 Tube-to-Tubesheet Joints

9.10.3

Replace section with

When tubes are to be expanded into the tubesheet, they shall be expanded through the full thickness of the tubesheet. However, in no case shall the expansion extend within 3 mm ($^1/_8$ in.) of the shell side face of the tubesheet.

9.10.4

Replace with

For shell side clad (or weld overlay) tubesheets, the tube shall be expanded to seal against the cladding material for a minimum distance of 9 mm ($^3/_8$ in.). No groove shall be provided in the shell side cladding.

Add new section

9.10.8

When specified by the purchaser, tube-to-tubesheet expanded joint procedures shall be qualified in accordance with ASME BPVC Section VIII Div 1 Appendix HH, or equivalent requirements.

10 Inspection and Testing

10.1 Quality Control

10.1.1

Add to list

g) all butt welds for sour or wet hydrogen sulfide service shall be subject to 100 % volumetric examination. Nozzle to shell and nozzle to channel wall joints shall be 100 % ultrasonic tested;

h) if nozzles are rolled from plate, longitudinal and circumferential welds in the nozzle section shall be subject to 100 % volumetric examination;

i) where 100 % volumetric examination is specified by the purchaser, the complete length of all butt welds, nozzle to exchanger wall joints, nozzle neck weld seams, and nozzle to flange joint welds shall be examined.

10.1.3

Add to section

Unless otherwise specified by the purchaser, the minimum extent shall be as per ASME BPVC.VIII.2:2017, Table 7.2.

10.1.5

Add to section

Unless otherwise specified by the purchaser, the minimum extent shall be as per ASME BPVC.VIII.2:2017, Table 7.2, except tube-to-tubesheet welds shall be 100 % liquid-penetrant examined after completion of tube expansion.

10.1.6

Replace Table 7 with

Table 7 – Hardness Limits

Material	Maximum Weld Hardness
Carbon Steel	225 HBW
Chromium Steel (up to 3 % Cr)	225 HBW
Chromium Steel (5 % Cr to 17 % Cr)	241 HBW
Duplex Stainless Steel (22 % Cr)	320 HV10 or 28 HRC
Super Duplex Stainless Steel (25 % Cr)	350 HV10 or 32 HRC
NOTE These hardness values are for general services. More stringent hardness testing and acceptance criteria can be required for special services (e.g. sulfide stress cracking or other types of environmental cracking services as specified in NACE standards).	

Add new section

10.1.19

When specified by the purchaser, U-bends shall be metallurgically examined and corrosion tested prior to the start of production bending. One tube of each heat shall be bent to the smallest radius, and heat treated (if applicable) prior to the test. Test procedures and acceptance criteria shall be specified by the purchaser.

Add new section

10.1.20

Positive material identification shall be carried out at the exchanger manufacturer's shop in accordance with API RP 578 or other equivalent standard to verify all pressure part components of alloy steel material including cladding and overlay welding.

Add new section

10.1.21

Extent of PMI shall be specified by the purchaser.

Add new section

10.1.22

All cold formed heads shall have the inside and outside surfaces of the knuckle region examined by magnetic particle or liquid penetrant examination after completion of all forming and material heat treatment.

Add new section

10.1.23

The responsible person for the non-destructive examination shall be qualified to ISO 9712 level III, American Society for Nondestructive Testing (ASNT) Central Certification Program (ACCP) level III or equivalent. All non-destructive examination operators shall be qualified to ISO 9712 level II, ACCP level II or equivalent as specified by the purchaser.

Add new section

10.1.24

Integrally clad formed heads or sections shall be ultrasonically tested after forming.

Add new section

10.1.25

Cut areas of integrally clad material shall be ultrasonically examined within 50 mm (2 in.) from the edge of the opening.

Add new section

10.1.26

The acceptance criteria for liquid penetrant examination of weld overlay shall be zero linear indications. All linear indications shall be repaired.

Add new section

10.1.27

If overlay welding is to be machined, such as nozzles and flange facings, machined surfaces shall be subject to liquid penetrant examination. If the overlay is examined 100 % prior to any final post weld heat treatment, the overlay shall be re-examined after heat treatment.

Add new section

10.1.28

When post weld heat treatment of integrally clad and weld overlay material is required, weld procedure qualifications shall include corrosion testing according to ASTM A262 practice E for austenitic stainless steel. Test coupons shall be heat treated prior to testing with at least twice the fabrication heat treatment soak time as specified for the equipment.

Add new section

10.1.29

For 22Cr duplex and 25Cr super duplex stainless steels, corrosion testing, impact testing, ferrite measurement and microstructure examination shall be carried out according to ISO 17781.

Add new section

10.1.30

For 22Cr duplex and 25Cr super duplex stainless steels, ferrite measurement shall also include the heat affected zone and shall comply with ferrite content requirement for weld metal.

10.2 Pressure Testing

10.2.6

Replace first sentence with

The chloride content of the test water used for equipment with austenitic stainless steel, 22Cr duplex steel and 25Cr super duplex steel materials that would be exposed to the test fluid shall not exceed 50 mg/kg (50 parts per million by mass) and 250 mg/kg (250 parts per million by mass) for all other materials.

10.2.9

Replace section with

Nozzle reinforcing pads and other welded pads provided with vent holes shall be pneumatically tested between 100 kPa (ga) (15 psig) and 170 kPa (ga) (25 psig) after completion of any post weld heat treatment and prior to the final pressure test.

10.2.11

Replace first sentence with

Flanged joints that have been taken apart after the final pressure test, shall be reassembled with new gaskets and re-pressure tested, unless otherwise approved by the purchaser.

10.2.13

Replace with

Heat exchangers that are to be stacked in service with directly interconnecting nozzles and interconnecting pipe spool pieces (when supplied) shall be pressure tested in the stacked position.

Add new section

10.2.14

During the hydrotest, the primary membrane stress in any pressure containing component shall not exceed 95 % of the material minimum yield strength, unless otherwise specified by the design code.

Add new section

10.2.15

Hydrostatic pressure testing shall be performed with the same gaskets and bolting as those required in service for all body flanges, custom designed flanges and permanently blinded connections.

10.3 Nameplates and Stampings

10.3.1

Add to section after first sentence

A warning nameplate shall be provided to identify any restrictions such as differential pressure design and testing, or any limitations on the operation and testing of expansion joints, when applicable.

11 Preparation for Shipment

11.1 Protection

11.1.1

Add to section after first sentence

The purchaser shall specify if any additional requirements for drying are required.

11.1.4

Replace section with

All flange-gasket surfaces shall be coated with an easily removable rust preventative and shall be protected with:

a) permanent blind flanges or covers shall be fully bolted with service gaskets, stud bolts and nuts;

b) flange faces not supplied with a permanent blind flange shall be protected with a 6 mm ($^1/_4$ in.) minimum thickness metallic cover. Metal shipping covers shall be clearly marked that they are “for shipping only”;

c) connections without permanent blind flanges shall be provided with 1.5 mm ($^1/_{16}$ in.) thick composition or neoprene gaskets secured to the flange with a minimum of four bolts for shipping.

11.1.5

Replace section with

All threaded connections shall be protected with threaded plugs or caps of compatible materials and with the use of an appropriate rust preventive compound. Polytetrafluoroethylene (PTFE) tape shall not be used.

11.1.8

Replace section with

Exposed threads of bolts and nuts which are not to be coated during painting or provided with an integral protective coating shall be protected from sandblasting and painting and be provided with an easily removable rust preventative. Tapped holes, including tell-tale holes on reinforcing pads, shall be plugged with grease.

11.1.11

Replace section with

Any equipment protected by an inert gas fill shall have the following warning displayed on a tag on all openings:

"DANGER - NON-LIFE SUPPORTING ATMOSPHERE Contents are under <Inert gas> pressure and must be depressurized before opening."

11.2 Identification

Replace section with

11.2.1

The item number, shipping mass, centre of gravity and purchaser’s order number shall be clearly marked on the heat exchanger.

Add new section

11.2.4

Heat exchangers that have titanium components shall have the words "TITANIUM EQUIPMENT - DO NOT PERFORM HOT WORK" stencilled on the exchanger.

12 Supplemental Requirements

12.2 Design

12.2.1

Add to section after third sentence

Set-on type nozzles may be used subject to the agreement of the purchaser.

12.3 Examination

12.3.6

Add to section after first sentence

Liquid penetrant examination shall be substituted for non-magnetic materials.

12.3.8

Add to section after first sentence

Liquid penetrant examination shall be substituted for non-magnetic materials.

12.3.9

Add to section

Nozzle to shell attachment welds shall be examined by full volumetric examination method. Method and procedures used shall be subject to the agreement of the purchaser.

Annex B
(informative)
Shell-and-Tube Heat Exchanger Checklist

Add to section after first paragraph

Where this supplement has changed the meaning of a section, so that a decision is not required by the purchaser, the section is still included below for consistency, but the requirement column has been amended as follows: "Yes/~~No~~" means no purchaser decision is required as vendor shall comply with the section.

Replace Table B.1 with

Table B.1 – Checklist for Shell-and-Tube Heat Exchangers

Section	Item	Requirement
4.1	Pressure design code.	State required code
4.3	Applicable local regulations.	State local regulations
4.7	Do the shell side fluid characteristics require special considerations? If yes, provide detailed information.	Yes / No
	Do the tube side fluid characteristics require special considerations? If yes, provide detailed information.	Yes / No
4.8	Is cyclic service design required? If yes provide detailed information.	Yes / No
4.10	Is the unit subject to sour or wet hydrogen sulfide service on the shell side?	Yes / No
	Is the unit subject to sour or wet hydrogen sulfide service on the tube side?	Yes / No
4.11	Is the shell side in hydrogen service?	Yes / No
	Is the tube side in hydrogen service?	Yes / No
4.12	Is input data required to determine the need for an expansion joint?	Yes / No
4.13	For multiple pass fixed tubesheet and floating head heat exchangers with a tube side operating temperature range exceeding 110 °C (200 °F) per shell, the tube mean metal temperatures for each individual pass shall be specified on the datasheet.	
4.14	When thermal and hydraulic design is in the scope of supply of the vendor, requirements including software and design methods to be applied shall be specified by the purchaser.	
4.15	The purchaser shall specify design loads and load combinations to be used for the analysis of heat exchanger supports.	
6.1.2	When thermal and hydraulic design is in the scope of supply of the vendor, or when a check-rating of exchanger designs provided by the purchaser is required, the vendor shall submit thermal and hydraulic design calculations including flow induced and acoustic vibration analysis. See A.3.2.	Yes / ~~No~~
6.2.2	The vendor shall furnish copies of applicable welding procedure specifications and welding procedure qualifications for review.	Yes / ~~No~~
6.2.5	The vendor shall submit design calculations for supports, lifting and pulling devices and verification of anchor bolt diameter.	Yes / ~~No~~
6.3	After the heat exchanger is completed the vendor shall furnish the purchaser with the following documents in the format and quantities specified by the purchaser:	

Section	Item	Requirement
7.1.1	Specify the maximum design temperature and a minimum design metal temperature (MDMT) for shell and tube side. Specify the coincident temperature and pressure for depressurization conditions, if any.	
7.3.6	Specify if supports on the shell shall be analysed for local stresses. If yes, provide detailed information.	Yes / ~~No~~
7.4.11	External custom-designed girth flanges, channel covers, and floating-head flanges shall be provided with 3 mm (⅛ in.) future machining allowance on the gasket contact seating surfaces (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure. This requirement does not apply to clad or weld overlay construction.	Yes / ~~No~~
7.5.2.5	Tubesheets shall be provided with 3 mm (⅛ in.) future machining allowance on all the gasket contact seating surfaces (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure. This requirement does not apply to clad or weld overlay construction.	Yes / ~~No~~
7.5.7.3	When strength welds are applied, the degree of expansion and use of grooves shall be specified or agreed.	
7.6.1	All nozzle connections shall be flanged except as permitted in 7.6.2.	Yes / No
7.6.2	Are nozzles to be welded to the connecting piping (by others)? If so, specify which connections.	Yes / No
7.6.6	Specify insulation thickness: Shell.	
	Specify insulation thickness: Channel.	
7.6.8	Are chemical cleaning connections required?	Yes / No
7.6.9	Are specific nozzle loads and moments specified?	Yes / No
7.6.10	If nozzle sizes are larger than those listed in Table 2, specify the moments and forces.	
7.7.1	Channel and shell external girth joints shall be of through-bolted construction. Studded-in bolting shall not be used.	Yes / ~~No~~
7.7.6	Specify if hydraulic bolt tensioning is required.	Yes / No
7.7.8	If a bolt-tightening device is used, specify any special requirements required for adequate clearance.	
7.7.15	External custom-designed girth flanges shall be provided with 3 mm (1/8 in.) future machining allowance on the gasket contact seating surface (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure. This requirement does not apply to clad or weld overlay construction.	Yes / ~~No~~
7.8.1	The joint component approach, as defined in ASME PCC-1, Appendix O, and the requirements contained within this section, shall be applied to both sides of the heat exchanger for girth flange and floating head flange joints. Definition of terms and symbology contained within this section are consistent with ASME PCC-1. See A.4.5 for additional guidance.	Yes / ~~No~~
7.11.5	Handling devices on the shell shall be analysed for local stresses.	Yes / ~~No~~
7.12.2	Specify if any supplemental requirements are required for low chrome steels in high temperature or high pressure hydrogen service. If yes, provide detailed information.	Yes / No
8.1.4	Specify required materials of construction, including bolting and gaskets.	
8.1.7	Specify the minimum design metal temperature on the datasheet	

Section	Item	Requirement
8.2.3	Specify maximum allowable carbon equivalent and/or restrictions on other residual elements and micro-alloying elements for carbon steel components in sour or wet hydrogen sulfide service.	
8.2.4	Specify when HIC testing is required on the datasheet	Yes / No
9.5.11	Specify if weld procedure qualifications for carbon steel in sour or wet hydrogen sulfide service shall include a micro-hardness survey. If yes, specify any additional restrictions on residual elements or micro-alloying elements for the qualification coupon materials.	Yes / No
9.5.12	Specify if weld procedure qualifications for duplex stainless steel shall include a micro-hardness survey. If yes, establish the acceptance criteria.	Yes / No
9.5.17	Specify if Production Test Plates are required on the datasheet	Yes / No
9.5.18	Specify Production Test Plate PWHT requirements for low alloy steels on the datasheet	Yes / No
9.5.19	Specify Production Test Plate mechanical testing requirements for low alloy steels on the datasheet	Yes / No
9.6.2	Is heat treatment required after bending for U-tubes for process reasons?	Yes / No
9.6.5	Is heat treatment of ferritic and martensitic stainless steels, stabilized austenitic stainless steels, duplex stainless steels, copper, copper nickel, or high nickel alloys (Ni > 30 %) U-tubes required after cold working?	Yes / No
9.6.8	Specify if heat treated portion of U-tubes shall be de-scaled.	Yes / No
9.6.10	Specify if post weld heat treatment of weld-overlaid channels and bonnets is required.	Yes / No
9.6.12	Is post weld heat treatment required for process reasons on the shell side?	Yes / No
	Is post weld heat treatment required for process reasons on the tube side?	Yes / No
9.10.3	When specified by the purchaser tubes shall be expanded through the full thickness of the tubesheet. However, in no case shall the expansion extend within 3 mm (⅛ in.) of the shell side face of the tubesheet.	Yes / No
9.10.4	For shell side clad (or weld overlay) tubesheets, the tube shall be expanded to seal against the cladding material for a minimum distance of 9 mm (⅜ in.). No groove shall be provided in the shell side cladding.	Yes / ~~No~~
9.10.8	When specified by the purchaser, tube-to-tubesheet expanded joint procedures shall be qualified in accordance with ASME BPVC Section VIII Div.1 Appendix HH, or equivalent requirements.	Yes / No
10.1.16	Specify if carbon steel plate in sour or wet hydrogen sulfide service shall be subjected to an ultrasonic lamination check.	Yes / No
10.1.19	When specified by the purchaser, U-bends shall be metallurgically examined and corrosion tested prior to the start of production bending. One tube of each heat shall be bent to the smallest radius, and heat treated (if applicable), prior to the test. Test procedures and acceptance criteria shall be specified by the purchaser	Yes / No
10.1.21	Specify extent of PMI on the datasheet	Yes / No
10.2.2	Specify if tube-to-tubesheet joint integrity shall be tested after final expansion of the tubes by a helium leak test.	Yes / No
10.2.7	Are there additional requirements for drying or preservation? If yes, provide detailed information.	Yes / No

Section	Item	Requirement
11.1.1	All liquids used for cleaning or testing shall be drained from heat exchangers before shipment. The purchaser shall specify if any additional requirements for drying are required. See A.8.1 for additional information.	Yes / No
11.1.7	Are there requirements for surface preparation and protection? If yes, provide detailed information.	Yes / No
11.1.10	Is inert gas purge and fill required?	Yes / No
12.1	Are the additional requirements specified in Section 12 required for the shell side?	Yes / No
	Are the additional requirements specified in Section 12 required for the tube side?	Yes / No

Annex C
(informative)
Shell-and-Tube Heat Exchanger Datasheets

Add to section after third paragraph

Table C.1 defines supplemental data items that may be required in order to fully specify a shell-and-tube heat exchanger in accordance with this specification and to API Std 660 Shell-and-Tube Heat Exchangers.

Table C.1 – Supplementary data items

	Description	Requirement
1	**Equipment Data**	
1.1	Conformity Assessment Level (CAS)	A / B / C / D (Refer to S-614Q, Annex A)
1.2	Orientation	Horizontal / Vertical / Sloped (If sloped include angle and direction)
1.3	Thermal & Hydraulic Design by Vendor	No / Design / Check Rate
1.4	Fluid Allocation changeable	Yes / No
1.5	Type of Cleaning Maintenance	Chemical / Mechanical
2	**Shell Side and Tube Side / Inlet and Outlet**	
2.1	**Performance of one unit**	
2.1.1	Design Margin	
2.1.2	Dew Point	
2.1.3	Bubble Point	
2.1.4	Surface Tension	
2.1.5	Maximum Size of Solids	
2.1.6	Maximum Concentration of Solids	
2.1.7	Molecular Weight Vapors	
2.1.8	Molecular Weight Non-condensables	
3	**Shell Side and Tube Side**	
3.1	**Service Requirements**	
3.1.1	Fluid with special considerations	
3.1.2	Lethal Service	
3.1.3	Maximum H2 Partial Pressure	
3.1.4	Maximum H2S Partial Pressure	
3.2	**Construction per shell**	
3.2.1	Finned Tube Wall Thickness - Nominal	
3.2.2	Finned Tube Wall Thickness - under Fin	
3.2.3	Finned Tube Fin Height	
3.2.4	Finned Tube Fin Density	

	Description	Requirement
3.2.5	Finned Tube Fin Thickness	
3.2.6	Tube Internal Grooves	
3.2.7	Tube Internal Flutes	
3.2.8	Tube to Tubesheet joint – Mock up demonstration required for Strength weld joint	Yes / No
3.2.9	Production Test Coupons	Yes / No
3.2.10	Outer Tube Limit	
3.2.11	Baffle Spacing (Inlet)	
3.2.12	Baffle Spacing (Outlet)	
3.2.13	Impingement protection type	
3.2.14	Expansion Joint Required	Yes / No - Expansion joint data mandatory if expansion joint specified (see page 5 of Figure C.1 and Figure C.2)
3.2.15	PWHT - Shell Side	
3.2.16	PWHT - Channel Side	
3.2.17	PWHT - Floating Head	
3.2.18	PWHT - Weld Overlaid Channels and Bonnets	
3.2.19	Tube Mean Metal Temperature Pass	
3.2.20	Heat Treatment of U-bends	Yes / No
3.2.21	Radiography – Shell Side	
3.2.22	Radiography – Channel Side	
3.2.23	Insulation Type – Shell Side	None / Personnel Protection / Other
3.2.24	Insulation Type – Channel Side	None / Personnel Protection / Other
3.2.25	Operating Weight	
3.3	**Design Data**	
3.3.1	Coincident Depressurization Conditions	
3.3.2	Test Pressure	
3.3.3	Purchaser Specifications	
3.3.4	Hydraulic Bolt Tensioning	Yes / No
3.3.5	Hydraulic Bolt Tensioning – Clearances	
3.4	**Additional Loads**	
3.4.1	Nozzle Loadings and Moments	Nozzle allowable forces and moments if different from API 660 Table 2.
3.4.2	Wind	
3.4.3	Earthquake	
3.4.4	Blast	
3.4.5	Motion	
3.4.6	Snow and Ice	
3.4.7	Transport Accelerations	

	Description	Requirement
4	**Other**	
4.1	Cyclic Service Data	Mandatory if Exchanger in Cyclic Service (see page 6 of Figure C.1 and Figure C.2)
4.2	Materials of Construction	Include any special components not listed in page 2 of Figure C.1 and Figure C.2

Annex D (new)
(informative)
Thermal and Hydraulic Design Guidelines

D.1 Introduction

This annex has been prepared to give general guidance when the thermal and hydraulic design is in the scope of supply of the vendor and should be superseded by any specific guidance or requirements that may be provided by the purchaser.

D.2 Process design

D.2.1 Maximum wetted skin and bulk fluid temperatures

D.2.1.1

The maximum bulk and wetted skin temperature of utility water streams should be in accordance with Table D.1:

Note The wetted skin temperature is the wetted surface temperature for the design (fouled) condition at the interface between the fouling layer (when fouling resistances are applied) and the fluid, or the tube wall temperature (metal surface temperature) on the fluid side of the tube in clean condition or when an area design margin is applied in lieu of fouling resistances.

a) in determining the maximum bulk water and wetted skin temperature for the heat exchanger, all known operating conditions should be examined, including a clean operating condition with consideration of the form of active heat duty process control, if any, along with the design or maximum cooling water supply temperature;

b) for exchangers which have no active process duty control, a maximum duty case with clean exchanger operation should be used to determine the maximum bulk and wetted skin temperatures.

Table D.1 – Cooling Water Maximum Skin and Bulk Temperatures

Location	Open Recirculated Cooling Tower Water		Closed Loop Cooling Water		Brackish Water		Raw Surface Water		Seawater		Produced Water	
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Skin Temperature	60	140	No Limit	No Limit[(2)]	54	130	49	120	54	130	60	140
Bulk [(1)]	49	120	No Limit	No Limit	43	110	43	110	43	110	49	120
NOTE 1	Lower outlet bulk temperatures might be required by regulations on maximum water temperature increase.											
NOTE 2	Maximum local skin temperature should be maintained a minimum of 6 °C (10 °F) below the saturation temperature at the lowest anticipated operating pressure.											

D.2.1.2

To prevent thermal decomposition of glycol streams, the maximum local glycol solution skin temperatures in glycol heaters and reboilers should be limited as follows:

a) monoethylene and diethylene glycol: 165 °C (330 °F);

b) triethylene glycol: 204 °C (400 °F).

D.2.1.3

To prevent thermal decomposition of amine streams:

a) the bulk amine solution temperature and heating medium temperature should not exceed 127 °C (260 °F) and 177 °C (350 °F), respectively.

b) maximum local skin temperature should not exceed 150 °C (300 °F).

D.2.1.4

For fluids which are specified by the purchaser to have critical skin temperature limitations (e.g. hydrate, wax, scale, decomposition, freezing or solidification, coking, etc.), the wetted skin temperature should be calculated with consideration of all anticipated conditions including turndown, clean exchanger operation, operation with cold (winter) cooling water temperatures, etc. to prevent operating problems.

D.2.2

The heat flux for vaporizing streams should not exceed 80 % of the maximum allowable heat flux to avoid film boiling/departure from nucleate boiling.

D.2.3

For utility stream heated reboilers, operation in the clean condition should be modelled to ensure that nucleate boiling will be maintained in the clean condition, and that appropriate process control can be applied.

D.2.4

For steam heated exchangers, after completion of the exchanger thermal design, the lowest expected steam pressure (minimum condensing pressure) that will result under clean operation under turndown operation should be determined in order to ensure that an appropriate control scheme and condensate handling hardware can be applied.

NOTE The minimum condensing pressure should not fall below the condensate discharge header-pressure to prevent condensate from backing up into the heat exchanger.

D.3 General Thermal Design

D.3.1

Heat exchangers should be provided with effective surface areas between 100 % and 105 % of the required surface area for the design condition.

NOTE It is not expected that the exchanger's tube length be shortened from conventionally supplied tube lengths in order to limit the over-design to no more than 105 %.

The above surface area requirement is in the fouled condition and is in addition to any process design or fouling margin that may have been specified for the design condition, for example on flow rates and heat duty.

The purchaser might specify an additional margin to be applied when necessary to account for uncertainties in the design methods applied.

D.3.2

Heat exchangers should be of the horizontal configuration unless otherwise specified by the purchaser (e.g. vertical tube side thermosiphon reboilers).

A vertical arrangement may be considered, subject to purchaser agreement, for certain process requirements or if there is limited space available. Space limitations, when applicable, are to be specified by the purchaser.

D.3.3

Where a tube is specified to a minimum tube wall thickness, the tube wall thickness used for thermal and hydraulic calculation purposes should be 1.1 times the minimum tube wall thickness.

D.3.4 Fluid Velocity

D.3.4.1

The target minimum velocities for single phase non-erosive liquid streams, excluding cooling water, should be as specified in Table D.2.

Table D.2 – Target minimum velocities for single phase non-erosive liquid streams, excluding water

Fouling Characterization	Fouling Factor		Tube Side Velocity		Shell Side Crossflow Velocity	
	m^2K/W	hrft² °F/Btu	m/s	ft/s	m/s	ft/s
Low	≤ 0.00026	≤ 0.0015	1.0	3.0	0.3	1.0
Medium	≤ 0.00052	≤ 0.003	1.8	6.0	0.6	2.0
High	≤ 0.0012	≤ 0.0068	2.0	6.5	0.6	2.0
Severe	> 0.0012	> 0.0068	2.2	7.2	0.7	2.3

D.3.4.2

The velocity should be maximized for the available pressure drop to provide the highest heat transfer coefficient and to reduce fouling tendency.

D.3.4.3

Cooling water velocity requirements should be as specified in Table D.3 and Table D.4.

Table D.3 – Cooling water velocities (Tube side) – Minimum In-tube Velocity

Tube Material	Open Recirculated Cooling Tower Water		Closed Loop Cooling Water[1]		Brackish Water		Raw Surface Water		Seawater		Produced Water	
	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s
Ferrous	1.5	5.0	1.0	3.3	---	---	---	---	---	---	1.5	5.0
Non-Ferrous	1.5	5.0	1.0	3.3	1.2	4.0	1.5	5.0	1.5	5.0	1.5	5.0
NOTE 1	De-ionized or boiler feedwater/condensate quality.											

Table D.4 – Maximum In-tube Velocity

Tube Material	Open Recirculated Cooling Tower Water		Closed Loop Cooling Water		Brackish Water		Raw Surface Water		Seawater		Produced Water	
	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s
Ferrous	3.0	10.0	4.9	16.0	---	---	---	---	---	---	2.4	8.0
Admiralty	2.4	8.0	---	---	---	---	---	---	---	---	2.1	7.0
Al-Brass	2.4	8.0	---	---	2.1	7.0	2.1	7.0	2.1	7.0	2.1	7.0
Cupro-Nickel (90-10)	2.4	8.0	---	---	2.1	7.0	2.1	7.0	2.1	7.0	2.1	7.0
Cupro-Nickel (70-30)	3.0	10.0	---	---	2.1	7.0	2.1	7.0	2.1	7.0	2.1	7.0
Austenitic Stainless	3.7	12.0	4.9	16.0	---	---	---	---	---	---	3.7	12.0
Duplex Stainless	3.7	12.0	4.9	16.0	---	---	---	---	---	---	3.7	12.0
Monel	3.7	12.0	4.9	16.0	4.3	14.0	4.3	14.0	4.3	14.0	3.7	12.0
Titanium	4.9	16.0	4.9	16.0	4.9	16.0	4.9	16.0	4.9	16.0	4.9	16.0

D.3.4.4

The maximum in-tube velocity for lean amine streams should be 2.4 m/s (8 ft/s).

D.3.4.5

The maximum in-tube velocity for rich amine streams should be 1.5 m/s (5 ft/s) for carbon steel materials and 2.4 m/s (8 ft/s) for 316L stainless steel materials.

NOTE Where amine heating services include vapor breakthrough (vaporization), the maximum tube velocity is to be applied to the all-liquid portion of the exchanger.

D.3.4.6

The maximum in-tube velocity for saturated vapors, and two-phase fluids, should be such that the velocity head (ρV^2) in the tubes does not exceed 8930 kg/ms^2 (6000 lb/ft s^2), where V is the linear velocity in m/s (ft/s) and ρ is the fluid density in kg/m^3 (lb/ft^3).

a) For two-phase fluids, the homogeneous velocity should be used.

NOTE These velocity limits are intended to prevent erosion of the tube inlets. Higher velocities might be accepted on a case by case basis or when tube ferrules, sleeves or similar devices are applied.

For non-erosive liquids, excluding cooling water and amine streams, the maximum allowable velocity head should be calculated using the equivalent maximum cooling water velocities as specified in Table D.4 for the different tube materials

For dry non-erosive gasses, no specific tube velocity limits apply.

D.3.4.7

For erosive liquid streams, minimum and maximum allowable velocities are to be agreed with the purchaser.

D.3.4.8

Irrespective of the velocity criteria (e.g. erosion limits, vibrations, pressure drop versus velocity, minimum deposition), the stream should be in fully turbulent flow, i.e. Reynolds Number Re > 3000 for shell side fluids and Re > 10000 for tube side fluids.

D.3.5 Pressure Drop

D.3.5.1

The allowable pressure drop specified on the heat exchanger's process datasheet should be applied as the maximum pressure drop in the exchanger's fouled condition. When the allowed pressure drops are insufficient to achieve the target velocities the purchaser should be consulted.

D.3.5.2

For distributed systems, such cooling water, the actual pressure difference between the supply and return headers should be provided by the purchaser as the allowable pressure drop. The calculated pressure drop should be as close as practicable to the allowable pressure drop.

NOTE This is to ensure that the distribution system will be hydraulically balanced to avoid having low pressure drop consumers "stealing" flow from high pressure drop exchangers. The practice of designing exchangers for equal outlet temperatures can be unrealistic.

D.3.5.3

Opportunities to appreciably reduce the size or cost of the heat exchanger design by increasing the allowable pressure drop should be investigated to determine if the allowable pressure drop can be increased.

D.3.5.4

Pressure drop in the fouled condition should be estimated for use in hydraulic system calculations.

Since the thickness and surface roughness of fouling deposits are not usually known, it is necessary to estimate the increase in pressure drop above a clean condition due to fouling, as it cannot be accurately calculated by simulation.

Except for cooling water, the pressure drop for the fouled condition should be estimated by multiplying the calculated pressure drop for the clean condition by the appropriate factor from Table D.5. When specific fouling factors are not provided, the purchaser should indicate the pressure drop multiplier.

Table D.5 – Hydraulic multipliers for fouling

Fouling Characterization	Fouling Factor		Pressure Drop Multiplier
	m^2K/W	hrft² °F/Btu	
Low	≤ 0.00026	≤ 0.0015	1.1
Medium	≤ 0.00052	≤ 0.003	1.2
High	≤ 0.0012	≤ 0.0068	1.3
Severe	> 0.0012	> 0.0068	1.4

D.3.5.5

For cooling water the following hydraulic multipliers should be used:

a) 1.5 for cooling waters other than closed loop systems which utilize carbon steel tubes;

b) 1.25 for cooling waters other than closed loop systems which utilize other tube materials;

c) 1.1 for closed loop cooling water systems regardless of tube materials.

D.3.6 Fouling

D.3.6.1

Area design margins (ADM), fouling resistances or resistance factors should be as specified by the purchaser on the datasheets.

With agreement of the purchaser, when no values have been specified on the datasheet, fouling resistances should be chosen in accordance with TEMA Section 10, RGP T-2, or an ADM of 25 % should be used.

D.3.6.2

When the thermal resistance due to fouling exceeds 30 % of the overall thermal resistance for the heat exchanger, the purchaser should be consulted.

NOTE A reduction in the applied fouling resistances may be considered on a case-by-case basis. Large amounts of excess area for fouling margins are discouraged as this can lead to poor exchanger design, control problems and an increase in fouling tendency.

D.3.7

The log mean temperature difference (LMTD) correction factor should not be less than 0.8.

D.3.8

For each single shell, the temperature approach should not be less than 5 °C (9 °F). The temperature approach is the temperature difference between the hot fluid inlet and the cold fluid outlet for a counter-flow configuration (or between the hot fluid outlet and the cold fluid inlet for a co-current or mixed flow configuration).

NOTE Closer temperature approaches could be technically possible; however experience shows that the required surface to achieve these criteria would be excessive and would increase the costs significantly.

D.4 Fluid Allocation

D.4.1

The preferred fluid allocation may be specified by the purchaser on the datasheet.

When a preferred allocation has been specified, an exchanger design with a reversed fluid allocation may be presented as an alternate to the base design for consideration by the purchaser.

When no preferred allocation has been provided, the tube and shell side stream allocation selection should be guided by Table D.6. Where the use of this table results in conflicting guidance based on the nature of the two streams, the fluid allocation should be agreed with the purchaser.

Table D.6 – Stream placement

Service	Shell	Tube
Sea or brackish water		X
Cooling tower water		X
Lower allowable pressure drop	X	
Larger flow w/similar properties	X	
High pressure		X
Corrosive service, OR alloy construction required		X
Fluids with large temperature ranges; > 110 °C (200 °F)	X	
Fluids with difficult to clean deposits		X
Slurry service		X
High viscosity (>5 cP)	X	
Suspended solids		X
Streams requiring water wash		X
Oxygen service		X

NOTE Traditionally, high fouling fluids are placed on the tube side, particularly where mechanical cleaning or highly effective hydro-blasting is required. However, where the high fouling stream or stream with suspended solids also has a high viscosity, that stream might be placed on the shell side to reduce the surface area or number of shells required. A higher wall shear stress and U value can be achieved with the higher viscosity stream on the shell side, potentially reducing fouling tendency with a proper design. Attention to baffle design and maintaining low leakage stream flow fractions is critical in these situations.

The fluid with the lower allowable pressure drop should be placed on the shell side. An appropriate combination of baffle cut, spacing and type (segmental, double segmental, rod-baffle, etc.) can accommodate nearly any pressure-drop requirement. Services under vacuum almost always are on the shell side because of pressure drop sensitivity.

Higher pressure fluid/stream should be placed on the tube side. Lower pressure fluid on the shell side might enable reduction in shell thickness and will result in a significantly lower tube wall thickness.

Corrosive fluids should be placed on the tube side. This might enable selection of expensive corrosion resistant alloys to only tubes, tubesheets, heads and channels.

Sensible cooling gas streams should be placed on the shell side. Gas normally has a higher volume and lower heat-transfer coefficient than a liquid. Shell side allocation typically reduces pressure drop for a given volume and provides a higher heat-transfer coefficient.

If the variation in the temperature of a fluid is greater than 110 °C (200 °F) this fluid should be placed on the shell side whenever more than one pass through the tube side is used. If this arrangement is not practicable, refer to D.5.2.12.

D.4.2

Multiple component condensing and all boiling streams (both single and multiple component) require the careful evaluation of both fluid allocation and resulting two-phase flow regimes in order to achieve the design performance.

a) For condensing services, exchanger designs and geometries that allow the gross separation of liquid and vapor phases should not be used for multi-component condensing mixtures that have a large condensing range, typically greater than 50 °C (90 °F). If unable to achieve a shear dominated flow regime over the majority of the heat transfer surface area for such cases, the purchaser should be consulted.

NOTE Gross separation of liquid and vapor phases in multi-component condensers can invalidate the assumptions of phase equilibrium and uniform flow distribution inherent in the thermal hydraulic performance modelling methods. When the liquid separates from the vapor to the extent that it is no longer in equilibrium, the remaining vapor composition becomes progressively leaner, reducing the temperature required to achieve further condensation. If unable to achieve vapor/liquid equilibrium, it may be necessary to use a differential rather than integral condensation model.

b) For flow boiling services, geometries that allow the gross separation of liquid and vapor phases should not be used. If unable to achieve a shear dominated and wet wall flow regime over the majority of the heat transfer surface area the purchaser should be consulted.

NOTE For flow boiling services, most of the heat duty is achieved by the latent heat of vaporization of the liquid phase. In order for the surface area of the heat exchanger to be effective, it must remain wetted by the liquid. Designs, particularly with shellside boiling, can result in dry conditions to occur over part of the heat transfer surface and a failure to meet the design performance. Current thermal hydraulic performance modelling methods are unable to consider this rigorously.

c) For tube side multi-component condensing and all boiling streams (both single and multiple component) which are two-phase at the inlet of the heat exchanger, designs which allow for the gross separation of liquid and vapor phases in the exchanger's inlet channel should not be used.

d) For tube side multi-component condensing and all boiling streams (both single and multiple component) which are more than one pass using straight tubes or more than two passes in U-tubes, designs which allow for the gross separation of the liquid and vapor phases in the pass turnaround areas of the channels should not be used.

D.4.3

For services which may be susceptible to solidification or freezing, the purchaser should be consulted on fluid allocation.

D.5 TEMA Type Selection

D.5.1 Shell Type Selection

D.5.1.1

The shell type for most applications should be TEMA type E with segmental baffles. Other shell types may be selected as follows:

a) where the shell side pressure drop is a constraint, the divided flow shell TEMA type J, X, or H shells should be selected;

b) TEMA type G shells may be selected for slight amounts of temperature cross between the hot and cold fluids that could not otherwise be achieved using a TEMA type E shell, subject to approval by the purchaser;

c) TEMA type J, X or H shells should be used for horizontal thermosiphons. TEMA type E or G shell thermosiphons may be considered when approved by the purchaser.

d) TEMA type K type shells should be selected for pool boiling applications (typically with 0 % to 5 % liquid entrainment) is required;

e) where design option TEMA type F type shell with 2 shell side passes can reduce the number of exchanger in series. However, TEMA type F requires purchaser approval.

D.5.1.2

Multiple shell pass designs should be applied only when agreed by the purchaser or in services with non-removable bundles or removable bundles that will not require frequent disassembly for mechanical cleaning; i.e., shell side fluid has a very low, or low fouling tendency with fouling resistances ≤ 0.000176 m^2K/W (0.001 $hrft^2$ °F/Btu).

a) The maximum allowable shellside pressure drop should be less than 100 kPa (15 psi) for baffles which are continuously welded to the shell, or 70 kPa (10 psi) for baffles using flexible seals.

The difference between the shell side inlet and outlet temperature should not exceed 110 °C (200 °F).

D.5.1.3

The thermal leakage across the longitudinal baffle should be included in the thermal design calculations.

D.5.1.4

An insulated longitudinal baffle (baffle composed of two plates, separated by spacers with a dead fluid zone between them or a single baffle with an insulation layer properly attached) should be considered when the thermal leakage correction factor to the mean temperature difference is less than 0.9 as calculated by the approved thermal design software.

The selected type of insulated longitudinal baffle requires the purchaser’s approval.

D.5.1.5

When used in two-phase flow shell side services the longitudinal baffle should be the insulated type unless otherwise agreed by the purchaser.

Note Thermal and hydraulic performance modelling software typically does not calculate thermal leakage across the longitudinal baffle for two-phase streams.

D.5.2 Front and Rear Head Type Selection

D.5.2.1

The use of removable tube bundles is generally preferred.

D.5.2.1.1

Consideration should be made for maintenance requirements. Recommended maximum limits for removable bundles are as follows:

a) bundle weight: 18145 kg (40,000 lb);

b) bundle diameter: 1525 mm (60 in.);

c) straight tube length: 7315 mm (24 ft).

Larger bundles may be used if agreed by the purchaser.

D.5.2.2

Fixed tubesheet heat exchangers may be used only in services where all of the following conditions are satisfied:

a) the shell side fluid has a low fouling tendency with fouling resistances ≤ 0.00018 m^2K/W (0.001 $hrft^2$ °F/Btu) and not requiring mechanical cleaning;

b) shell side entry is not required for shell/nozzle inspection or maintenance, as specified by the purchaser.

D.5.2.3

The use of expansion joints in fixed tubesheet exchangers to accommodate the differential expansion stresses is subject to the limitations indicated in 7.9.

a) a floating-head type or U-tube type heat exchanger should be selected if the differential temperature induced stress limits cannot be satisfied with the use of fixed tubesheet.

D.5.2.4

Fixed tubesheet exchangers should not be used when the expected tube bundle life is less than twice the anticipated process unit run lengths between turnarounds.

D.5.2.5

U-tube bundle heat exchangers may be used only in services where the following conditions are satisfied.

a) tube side fluids with very low or low fouling tendencies, with a fouling resistance not exceeding 0.00026 m^2K/W (0.0015 $hrft^2$ °F/Btu);

b) for tube side fluids with higher fouling tendencies, U-tubes may be used subject to the approval of the purchaser, a should have a minimum nominal tube diameter of 25.4 mm (1 in.) with a centre-to-centre distance between the parallel legs of the U-tube of at least 4 times the tube outside diameter.

D.5.2.6

U-tube bundles should be considered for all high pressure applications, typically greater than 6.2 MPa (ga) (900 psig), regardless of tube side fouling tendency when it is economically attractive to do so and approved by the purchaser.

D.5.2.7

Floating head heat exchangers should be used in all services for which fixed tubesheet or U-tube bundles are not allowed.

D.5.2.8

Removable channel covers should be specified on the stationary head of all heat exchangers having a tube side fluid with a medium or higher fouling tendency with a fouling resistance exceeding 0.00026 m^2K/W (0.0015 $hrft^2$ °F/Btu) and for all exchangers in cooling water service.

a) exchangers with a nominal shell size not exceeding 450 mm (18 in.) may be specified with bonnet covers on the stationary head regardless of fouling tendency when approved by the purchaser.

D.5.2.9

For fixed tubesheet heat exchangers with an odd number of tube passes and a removable channel cover on the stationary head, the rear head should also be specified with a removable channel cover.

a) for fixed tubesheet heat exchangers with an even number of tube passes, the rear head should be specified with a bonnet cover.

D.5.2.10

TEMA type C heads may be used on designs with a large number of tube side passes (typically 8 or more) to improve the reliability of the gasketed joint at the tubesheet.

D.5.2.11

TEMA type C heads for removable bundle units, or type N heads for fixed tubesheet designs, should be used for tube side design pressures greater than 10.3 MPa (ga) (1500 psig).

D.5.2.12

TEMA type C heads should be used when the difference in design pressures between the high (tube) side and low (shell) side exceeds 5.2 MPa (ga) (750 psig).

D.5.2.13

TEMA type C heads should be used when the temperature gradient across the tube side face of the tubesheet exceeds 110 °C (200 °F).

a) in such cases, an internally gasketed pass partition box shall be supplied so that the channel cover and bolting operate at a uniform temperature, typically at the lower tube side operating temperature.

b) a TEMA type N head may be used for non-removable tube bundles.

D.5.2.14

If the temperature gradient across the thickness of a tubesheet at any location exceeds 140 °C (250 °F), TEMA type C heads or other designs which eliminate a dual-gasketed seal between the tubesheet to the channel and shell should be used.

a) when high temperature differences can exist, the location of the shell inlet and outlet nozzles along the shell should be selected to minimize the temperature gradient across the tubesheet.

D.5.2.15

When a floating head exchanger is used, the choice between split ring and pull through types should be in accordance with the following:

a) split ring TEMA type S for nominal shell diameters less than or equal to 1200 mm (48 in.);

b) pull-through TEMA type T for nominal shell diameters greater than 1200 mm (48 in.) and for all vertical heat exchangers and kettle type exchangers regardless of diameter.

D.5.2.16

TEMA type S floating heads should be limited to services below both the following design pressures:

a) 4.1 MPa (ga) (600 psig) on the tube side;

b) 6.2 MPa (ga (900 psig) on the shell side.

D.5.2.17

TEMA type T floating heads should be limited to a design pressure on either side of 6.2 MPa (ga) (900 psig).

D.5.2.18

TEMA type D or other closures may be considered in high-pressure tube side services, where they may be more economical than TEMA type A, B, C or N heads and subject to approval by the purchaser.

D.5.2.19

Where single pass floating head style exchangers are to be used, the tailpipe-to-shell cover seal shall be of the flanged type.

D.5.3 Tubes, Tube Bundle, Tube Layout and Baffles

The use of enhanced tube geometries (e.g. low finned tubes, internally finned or ribbed tubes) or other novel heat transfer solutions such as non-conventional baffle types may be considered with the approval of the Purchaser.

D.5.3.1

The surface area in the 'U' bends should be excluded from the heat transfer calculations except for services which are iso-thermal boiling or condensing on the shell side with the shell side nozzle located over or beyond the U-bend, and for all kettle style reboilers, stab-in bundles and chillers.

D.5.3.2

Triangular pitch may be considered for shell side services when fouling resistance of the stream is not greater than 0.000176 m^2K/W (0.001 $hrft^2$ °F/Btu) where shell side does not require cleaning (e.g. clean utility streams such as steam or refrigerants) and for all fixed tubesheet exchangers.

The layout angle should be 30° except that 60° layouts may be considered to minimize pressure drop or to avoid tube vibration concerns.

D.5.3.3

Square pitch should be specified for reboilers and removable tube bundle exchangers with shell side services when fouling resistance of the stream is greater than 0.000176 m²K/W (0.001 hr ft² °F/Btu).

The layout angle should be 90° except that 45° should be considered for shell side laminar flow regimes.

The 45° layout angle may be considered for other services but should not be used for shell side vapor streams.

D.5.3.4

For square and rotated square pitches, a minimum of 6.4 mm (0.25 in.) shall be provided between adjacent tubes.

D.5.3.5

Baffle cuts orientation should generally be as follows:

a) vertical cut baffles are preferred for most services;

b) horizontal cut baffles may be used for shellside single phase services with two-pass U-tube arrangements;

c) baffle cut should be perpendicular to nozzles for no-tube-in-window (NTIW) exchangers;

d) vertically cut baffles should be used for shellside condensing and vaporizing services and for fluids containing suspended solids.

D.5.3.6

Impingement rods are preferred over the use of impingement plates, and should be used for the following cases:

a) when the diameter of an impingement plate would exceed 50 % of the inlet baffle spacing;

b) for all NTIW baffle designs;

c) when the inlet baffle spacing is greater than or equal to 10 % of the effective tube length.

Registered Office
City Tower
40 Basinghall Street
14th Floor
London EC2V 5DE
United Kingdom

T +44 (0)20 3763 9700
F +44 (0)20 3763 9701
reception@iogp.org

Brussels Office
Bd du Souverain,165
4th Floor
B-1160 Brussels
Belgium

T +32 (0)2 566 9150
F +32 (0)2 566 9159
reception@iogp.org

Houston Office
10777 Westheimer Road
Suite 1100
Houston, Texas 77042
United States

T +1 (713) 470 0315
reception@iogp.org

www.iogp.org