

Shell-and-Tube Heat Exchangers

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Introduction

It is necessary that users of this standard be aware that further or differing requirements can be needed for individual applications. This standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this standard and provide details.

This standard requires the purchaser to specify certain details and features.

A bullet (●) at the beginning of a section indicates a requirement for the purchaser to make a decision or provide information (for information, a checklist is provided in Annex B).

In this standard, where practical, U.S. Customary (USC) or other units are included in parentheses for information.

Shell-and-Tube Heat Exchangers

1 Scope

This standard specifies requirements and gives recommendations for the mechanical design, material selection, fabrication, inspection, testing, and preparation for shipment of shell-and-tube heat exchangers for the petroleum, petrochemical, and natural gas industries.

This standard is applicable to the following types of shell-and-tube heat exchangers: heaters, condensers, coolers, and reboilers.

This standard is not applicable to vacuum-operated steam surface condensers and feed-water heaters.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API RP 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*

ASME B16.5¹, *Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard*

ASME PCC-1-2013, *Guidelines for Pressure Boundary Bolted Flange Joint Assembly*

EJMA², *Standards of the Expansion Joint Manufacturers Association*

NACE MR0103³, *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE MR0175, *Petroleum and natural gas industries—Materials for use in H₂S containing environments in oil and gas production—Parts 1, 2 and 3*

NACE SP0472, *Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

TEMA⁴, Ninth Edition, *Standards of the Tubular Exchanger Manufacturers Association*

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1

annular distributor

An additional chamber incorporated into a shell side nozzle to evenly distribute shell side fluids entering or exiting the tube bundle.

¹ ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.

² Expansion Joint Manufacturers Association, 25 North Broadway, Tarrytown, New York 10591, www.ejma.org.

³ NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77084-4906, www.nace.org.

⁴ Tubular Exchanger Manufacturers Association, 25 North Broadway, Tarrytown, New York 10591, www.tema.org.

3.2**category A welded joint**

Longitudinal welded joint within the main shell, communicating chambers, nozzles, or transitions in diameter; or any welded joint within a sphere or within a formed or flat head; or circumferential welded joint connecting hemispherical heads to main shells, to transitions in diameters, or to communicating chambers.

3.3**category B welded joint**

Circumferential welded joint within the main shell, communicating chambers, nozzles, or transitions in diameter including joints between the transitions and a cylinder at either the large or small end; or circumferential welded joint connecting formed heads, other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

3.4**communicating chamber**

Heat exchanger appurtenance that intersects the shell or heads of the heat exchanger and forms an integral part of the pressure-containing envelope.

EXAMPLE Sump, Annular Distributor.

3.5**cyclic service**

Process operation with periodic variation in temperature, pressure, and/or flow rate.

3.6**effective heat transfer area**

Outside surface area of the tubes that contributes to heat transfer including finned surface (if any).

3.7**full-penetration weld**

Welded joint which results in weld metal through the entire thickness of the components being joined.

3.8**heat exchanger unit**

One or more heat exchangers arranged in series or parallel for a specified service that operate together to perform the intended duty.

3.9**high temperature hydrogen attack****HHTA**

Damage mechanism affecting carbon and low-alloy steels due to the exposure to hydrogen at elevated temperatures and pressures, resulting in the loss of carbides and strength of the materials and cracking.

3.10**high temperature hydrogen service**

Services with operating hydrogen partial pressure above 350 kPa (50 psi) absolute and operating temperatures above 200 °C (400 °F).

3.11**hydrogen service**

Services that contain hydrogen at a partial pressure exceeding 700 kPa (100 psi) absolute.

3.12**item number**

Purchaser's identification number for a heat exchanger unit.

3.13**minimum design metal temperature****MDMT**

Lowest metal temperature at which pressure-containing elements can be subjected to design pressure.

EXAMPLE Ambient temperature or process fluid temperature.

3.14**nubbin**

Projection on the flange gasket surface, positioned at the center of the gasket, used to concentrate the bolt load on the gasket.

3.15**pressure design code**

Recognized pressure vessel standard specified or agreed by the purchaser.

EXAMPLE ASME *BPVC, Section VIII*, EN 13445 (all parts).

3.16**seal-welded**

Tube-to-tubesheet joint weld of unspecified strength applied between the tubes and tubesheets for the sole purpose of reducing the potential for leakage.

3.17**strength-welded**

Tube-to-tubesheet joint welded so that the design strength is equal to, or greater than, the axial tube strength specified by the pressure design code.

4 General

- **4.1** The pressure design code shall be specified or agreed by the purchaser. Pressure components shall comply with the pressure design code and the supplemental requirements given in this standard.
- **4.2** Heat exchanger construction shall conform to TEMA, Class R, unless another TEMA class is specified.
- **4.3** The vendor shall comply with the applicable local regulations specified by the purchaser.
- **4.4** Annex A includes some recommended mechanical and design details for information.
- **4.5** Annex B provides a checklist that can be used by the purchaser to ensure that bulleted items in this standard are addressed.
- **4.6** Annex C provides examples of data sheets.
- **4.7** The purchaser shall specify if either stream has fluid characteristics requiring special considerations (e.g. slurry, entrained particulates, or other certain types of fouling mechanisms).
- **4.8** The purchaser shall specify if cyclic service design is required.

4.9 If cyclic service is specified, the purchaser shall specify the type and magnitude of variation in pressure, temperature and flow rate, the time for the variation (hours, weeks, months, etc.) and the number of cycles or frequency for this variation expected during the life of the equipment. The extent and acceptance criteria of any required analysis shall be subject to the agreement of the purchaser. See A.2.1 for guidance on cyclic service.

- **4.10** The purchaser shall specify if the service is designated as sour in accordance with NACE MR0175 (all parts) for oil and gas production facilities and natural gas processing plants or is designated as wet hydrogen sulfide service in accordance with NACE MR0103 for other applications (e.g. petroleum refineries, LNG plants, and chemical plants), in which case all materials in contact with the process fluid shall meet the requirements of the applicable standard to mitigate potential for sulfide stress cracking (SSC). Identification of the complete set of materials, qualification, fabrication, and testing specifications to prevent in-service environmental cracking is the responsibility of the user (purchaser). See A.2.2 for guidance on sour or wet hydrogen sulfide service.
- **4.11** The purchaser shall specify if the shell or tube side is in hydrogen service.
- **4.12** For single tube pass floating-head and all fixed tubesheet heat exchangers, the purchaser shall specify the data required to determine the need for an expansion joint. This shall include all intended operating conditions defined on the expansion joint datasheet shown in Annex C.

5 Proposal Information Required

5.1 For each heat exchanger unit, the vendor's proposal shall include completed datasheets, such as those given in Annex C, or if a datasheet is included in the inquiry, a statement indicating complete compliance with that datasheet.

5.2 The vendor's proposal shall include sketches that are sufficient to describe the construction for the following, if provided:

- a) design features that are not fully defined by the nomenclature in TEMA, Section 1;
- b) an annular distributor;
- c) floating-head designs which include a tail-pipe and expansion joint;
- d) expansion joints for fixed tubesheet exchangers. Including the location, material and type;
- e) high pressure closure including channel to tubesheet attachment, shell to tubesheet attachment, and welded diaphragm or welded lip-seal construction.

5.3 The proposal shall include a detailed description of all exceptions to the requirements of the purchaser's inquiry.

5.4 For stacked heat exchangers, the vendor shall supply the following components, unless otherwise specified by the purchaser:

- a) bolts, nuts, and gaskets for interconnecting nozzles;
- b) shims or spacers and bolting for interconnecting supports.

5.5 The vendor shall provide a separate quotation for the following items, unless otherwise specified by the purchaser.

- a) A test component consisting of a test ring and gland, in accordance with TEMA, Figure E-4.13-2 or equivalent, for each heat exchanger or group of similar heat exchangers with floating heads.

- b) One spare gasket for each external girth flange, floating-head flange (if applicable), and internal pass-partition flange (if applicable) per heat exchanger.

6 Drawings and Other Required Data

6.1 Outline Drawings and Other Supporting Data

6.1.1 The vendor shall submit, for review by the purchaser, outline drawings for each heat exchanger unit. The drawings shall include at least the following information:

- a) service, item number, project name and location, purchaser's order number, vendor's shop order number, and other special identification numbers;
- b) design pressure, test pressure, design temperature, minimum design metal temperature, and any restriction on testing or operation of the heat exchanger;
- c) maximum allowable working pressure (MAWP) in the corroded condition and at the design temperature for the shell side and tube side;
- d) connection sizes, location, orientation, projection, direction of flow and, if flanged, the rating and facing or, if welded to the connecting piping, the weld bevel preparation;
- e) coupling sizes, rating, and orientation;
- f) dimensions, orientation and location of supports, including bolt holes and slots, and the stacking arrangement;
- g) overall dimensions of the heat exchanger;
- h) tube bundle removal clearance;
- i) mass of the heat exchanger, empty 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);
- j) specified corrosion allowance for each side of the heat exchanger (see A.3.1);
- k) references to the applicable code and the purchaser's specification;
- l) requirements for postweld heat treatment;
- m) requirements for non-destructive examination (NDE);
- n) requirements for material impact testing;
- o) requirements for surface preparation and painting;
- p) gasket materials;
- q) insulation thickness;
- r) location of expansion joints, annular distributors, and any other special components or closures;
- s) location and orientation of nameplates, lifting lugs, grounding clips or other attachments;
- t) location of the center of gravity of the heat exchanger (empty and full of water);

u) forces and moments on connections as specified by the purchaser (see 7.6.9);

v) material specifications and grades for all components.

- **6.1.2** The vendor shall submit flow-induced vibration analysis, if specified by the purchaser. See A.3.2.

6.1.3 The vendor shall recommend the tools required for the assembly and maintenance of the heat exchanger. If torquing or tensioning of bolts is required, the vendor shall provide applicable procedures.

6.1.4 The review of engineering documents by the purchaser shall not relieve the vendor of the responsibility of meeting the requirements of the purchase order.

6.2 Information Required After Outline Drawings Are Reviewed

6.2.1 The vendor shall submit gasket details, including type and material, on a separate drawing. This drawing shall not be marked with any restrictions for use.

- **6.2.2** If specified by the purchaser, the vendor shall furnish copies of applicable welding procedure specifications and welding procedure qualifications for review or record.

6.2.3 Upon receipt of the purchaser's review comments on the outline drawings, the vendor shall submit copies of all detailed drawings for the purchaser's review. These shall fully describe the heat exchanger and shall include at least the following information:

a) full views and cross-sectional views with all dimensions and materials sufficient for stress calculations for each part;

b) tube bundle details, including the following:

- tube layout,
- tube description and number in each pass,
- number of baffles, type and description (for segmental baffles include cross-baffle cut, layout, and orientation in a view that shows the cuts),
- details and locations of all sealing and sliding strips,
- details and locations of tie-rods and spacers,
- details and locations of support plates,
- details of tubesheet and tube holes, including cladding or weld overlay if required,
- details of pass-partition plates,
- impingement protection device details, if applicable,
- U-tube bend schedule, if applicable;

c) details of each pressure-retaining weld, including weld material, weld nominal thickness, weld location, and applicable non-destructive examination method;

- d) details of each weld and weld nominal thickness for nonpressure attachments welded to pressure parts and for all load bearing attachments;
- e) complete bills of materials, including the material specification;
- f) expansion joint details;
- g) details of cladding and weld overlay;
- h) weld map for each heat exchanger showing the weld joints, including welding procedure number(s);
- i) details of tube-to-tubesheet joints, including procedures for installation, welding, expansion, inspection, and testing;
- j) flange-face finish;
- k) special installation and maintenance instructions including lifting and handling.

6.2.4 The vendor shall submit for the purchaser's review the following documentation.

- a) Mechanical design calculations for all the heat exchanger pressure-retaining components. If calculations are made using computer software, all input and output data shall be detailed so as to facilitate an understanding of the calculation procedures. The formulas in the applicable sections of the pressure design code and TEMA shall be referenced.
 - b) Design calculations based on seismic, wind, transportation, and piping loads, if these loads are provided by the purchaser.
 - c) Proposed procedures for assembly of flanged joints, if controlled bolt-tightening procedures (such as hydraulic torque wrenches or hydraulic tensioning devices) are used. Any required lubricants shall be stated.
 - d) Design calculations for thermal loads imposed on nozzles of stacked heat exchangers, when the shell mean metal temperature differential between the stacked shells exceeds 110 °C (200 °F) for ferritic steels and 75 °C (135 °F) for non-ferritic steels.
 - e) Design calculations for expansion joints, if applicable.
- **6.2.5** The vendor shall submit design calculations for supports, lifting, and pulling devices, if specified by the purchaser.

6.2.6 After final review the vendor shall revise all the required drawings and welding procedures, and submit each with the following text marked on every sheet separately and dated: "CERTIFIED FOR CONSTRUCTION."

6.3 Reports and Records

- 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:
 - a) "as-built" datasheet;
 - b) all outline and detail drawings, marked "CERTIFIED AS-BUILT";
 - c) certified record of all impact tests performed;

- d) certified mill test reports for all pressure parts, including tubes (each material test report shall be identified by a part number);
- e) complete certified bill of materials suitable for obtaining all replacement parts, including quantity, description, material specification, and identification of each part;
- f) temperature charts of all postweld heat treatments;
- g) completed manufacturer's data report in accordance with the pressure design code;
- h) nameplate rubbing or a facsimile;
- i) all mechanical design calculations, marked "CERTIFIED AS-BUILT";
- j) non-destructive examination (NDE) map;
- k) all associated NDE reports, including radiographic, magnetic-particle, liquid-penetrant, ultrasonic, hardness, impact, positive material identification (PMI), and any other reports as applicable;
- l) tube-to-tubesheet leak-test results;
- m) hydrostatic test records in the form of a chart or certification;
- n) tube wall reduction records.

7 Design

7.1 Design Temperature

- **7.1.1** All heat exchangers shall have two design temperatures for each side, a maximum design temperature and a minimum design metal temperature (MDMT), as specified by the purchaser.

7.1.2 The design temperature of a component (including external bolting) influenced by both the shell side and tube side fluids shall be the more severe of either the shell side or tube side design temperature.

7.2 Cladding for Corrosion Allowance

7.2.1 If cladding (including weld overlay) is used, the cladding thickness including weld overlay restoration shall be used only as corrosion allowance and not as the pressure retaining envelope, unless otherwise specified or approved by the purchaser.

7.2.2 Weld overlays (including weld overlay restoration) shall have 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.

7.2.3 The cladding (including weld overlay) thickness at the tube side face of a tubesheet shall not be less than 10 mm ($3/8$ in.) when tubes are expanded only, and 5 mm ($3/16$ in.) when tubes are welded to the tubesheet.

7.2.4 The cladding or weld overlay thickness on the shell side face of a tubesheet shall not be less than 10 mm ($3/8$ in.).

7.2.5 Where seal-welded diaphragm or lip-seal gaskets are used, the weld overlay shall have a minimum thickness of 6 mm ($1/4$ in.) applied to the gasket seating surface.

7.3 Shell Supports

7.3.1 When the support of a removable-bundle heat exchanger is fixed to the shell, it shall be designed to withstand a longitudinal force equal to 150 % of the bundle mass applied at the heat exchanger bundle centerline. The shear stress for supports shall not exceed 40 % of the yield strength of the material.

7.3.2 Horizontal heat exchangers shall be provided with two or more saddles designed to support the heat exchanger under all specified conditions. Design of the saddles shall be as follows:

- a) saddles shall be attached to saddle bearing-plates;
- b) the bearing surface of the saddles shall be at least one-third of the circumference of the shell;
- c) saddle-bearing plates shall have the same nominal chemical composition as the shell and shall be continuously welded directly to the heat exchanger shells;
- d) saddle-bearing plates shall be provided with vent holes 6 mm ($1/4$ in.) in diameter, located at the vertical centerline;
- e) saddle-bearing plates shall be at least 6 mm ($1/4$ in.) thick and shall have all corners rounded to a radius of at least 25 mm (1 in.).

7.3.3 The lower shells of stacked removable-bundle heat exchangers shall be designed to carry the superimposed loads without suffering distortion that could cause binding of the tube bundles.

7.3.4 The vendor's design shall provide for a shim allowance of approximately 6 mm ($1/4$ in.) between the faces of stacked heat exchanger intermediate supports.

7.3.5 For horizontal heat exchangers, slotted holes shall be provided in the baseplate of all but one of the saddles to allow for longitudinal movement due to thermal expansion or contraction. The width of the slot shall be equal to the anchor bolt diameter plus 8 mm ($5/16$ in.). The length of the slot shall be equal to the anchor bolt diameter, plus the allowance for longitudinal movement, plus 8 mm ($5/16$ in.).

- **7.3.6** For all supports the local stresses in the shell shall be analyzed using a method which is specified or agreed with the purchaser.

EXAMPLE WRC BUL 537.

7.3.7 A grounding lug shall be attached to at least one of the exchanger supports.

7.4 Stationary and Floating Heads

7.4.1 Stiffeners shall not be used for channel cover design as a means of retaining pressure or to prevent deflection.

7.4.2 The pressure differential used to calculate the pass-partition plate thickness in accordance with TEMA, Section 5, Paragraph RCB-9.132 shall be at least twice the calculated pressure drop 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.).

7.4.3 Floating-head cover bolting shall comply with TEMA, Section 5, Paragraph RCB-11. Bolt spacing and clearances shall not be less than the minimum recommended by TEMA.

7.4.4 Floating-head cover bolting shall be readily accessible and shall have adequate spanner (wrench) clearance between the floating-head bolts and the shell flange at the cover end when the shell cover is removed.

7.4.5 Packed floating-head tailpipe and packed floating tubesheet designs (e.g. TEMA types P and W) shall not be used.

7.4.6 Unless otherwise specified by the purchaser, floating-heads shall be designed for design pressure on either side, with atmospheric pressure or, if specified, vacuum on the other side. Examples of acceptable floating-head designs are shown in Figure 1.

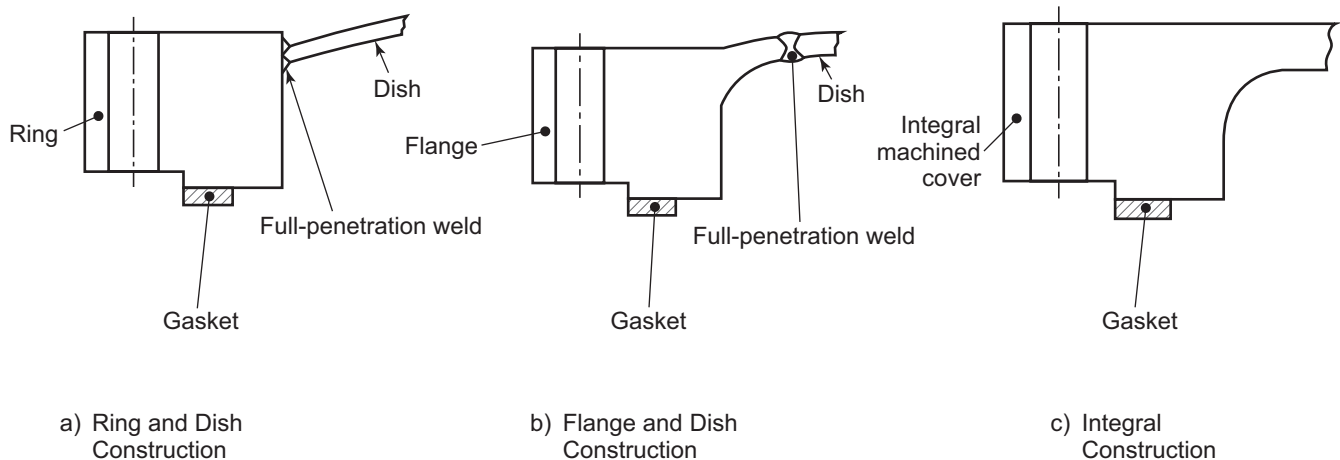


Figure 1—Typical Designs for Floating-head Covers

7.4.7 Internal floating-head covers shall have the specified corrosion allowance on all wetted surfaces, except gasket seating surfaces. The specified corrosion allowance shall be included on the back side of the floating-head backing device.

7.4.8 Nubbins shall not be used on floating-head flanges.

7.4.9 The shell cover on horizontal S-type floating-head exchangers shall be equipped with a vent and drain.

7.4.10 S-type floating-heads shall utilize style A (dove-tail) split rings per TEMA, Figure RCB-5.141. The dove-tail mating surfaces shall have rounded corners.

- **7.4.11** When specified by the purchaser, all 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.

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

7.5 Tube Bundle

7.5.1 Tubes

7.5.1.1 The minimum outside diameter of the tubes shall be 19.05 mm ($3/4$ in.), unless otherwise specified or approved by the purchaser. See A.4.1 for additional guidance on selection of tube diameter.

7.5.1.2 The tube wall thickness shall be as listed in Table 1, or thicker if required by the design conditions, including any tube corrosion allowance specified by the purchaser.

Table 1—Minimum Thickness of Tubes

Dimensions in millimeters (inches)

Tube Material	Minimum Thickness^a
Carbon steel, low-alloy steel (max. 9 % chromium), aluminum, and aluminum alloy	2.11 (0.083)
Copper and copper alloys	1.47 (0.058)
High-alloy [austenitic, ferritic, and austenitic/ferritic (duplex)] steel and other nonferrous materials	1.47 (0.058)
Titanium	1.07 (0.042)
^a Tubes shall be furnished on either a minimum wall basis or an average wall basis, provided the tube thickness is not less than that specified above.	

7.5.1.3 For carbon and low alloy steel low-fin tubing, the wall thickness under the root of the fin shall be in accordance with Table 1.

7.5.1.4 The mean radius of U-bends shall not be less than 1.5 times the nominal outside diameter of the tube. For martensitic stainless steels, super austenitic stainless steels (>6 wt % Mo) 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.

7.5.1.5 For U-tubes, design calculations shall be based on the reduction in wall thickness associated with bending. The thickness of the tubes need not be increased to meet the requirements in Table 1 provided the wall thickness in the U-bends meet the minimum requirements of the pressure design code and any specified tube corrosion allowance.

7.5.1.6 For U-tube and floating head type exchangers, the minimum clearance between any part of the U-bend or floating head cover, and the shell rear head, shall be 38 mm (1¹/₂ in.), to accommodate thermal expansion of the tube bundle. Both the crown and knuckle of the head shall be considered.

7.5.1.7 The number of tubes in any pass shall not be greater than 10 % above or below the average number of tubes per pass, unless otherwise approved by the purchaser.

7.5.2 Tubesheets

7.5.2.1 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 or drilled-and-tapped holes are used, at least four shall be provided and their location shall be identified on the drawings and by stamped markings on the OD of the tubesheet.

7.5.2.2 The distance between the edge of the tube holes and the edge of all gasket grooves (including pass-partition grooves) shall not be less than 1.5 mm (1/16 in.) for tubesheets with expanded tube-to-tubesheet joints and not less than 3 mm (1/8 in.) for tubesheets with welded tube-to-tubesheet joints.

7.5.2.3 Unless otherwise specified or approved by the purchaser, tubesheets shall be designed for design pressure on either side, with atmospheric pressure or, if specified, vacuum on the other side.

7.5.2.4 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 collar studs or tapped tubesheet holes for a minimum of 25 % of the bolts (4 minimum). The tubesheet design shall allow for hydrostatic testing of the shell side with the bonnet removed and all bolting installed.

- 7.5.2.5 When specified by the purchaser, tubesheets shall be provided with 3 mm ($1/8$ in.) future machining allowance on the gasket contact seating surface (including pass-partition surfaces). The purchaser shall state if this 3 mm ($1/8$ in.) allowance shall be provided on one or both of the shell side and tube side surfaces of the tubesheet. The additional thickness shall not be used in the calculation of maximum allowable working pressure.

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

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

7.5.3 Baffles and Support Plates

7.5.3.1 The thickness of carbon steel or low-alloy steel (maximum 9 % chromium) transverse baffles and support plates shall not be less than twice the specified shell side corrosion allowance. See A.4.2 for additional guidance.

7.5.3.2 To facilitate drainage 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.

7.5.3.3 If shell side longitudinal baffles are used, the minimum clearance (ligament) between the transverse baffle edge and the tube holes in the baffles shall be 3 mm ($1/8$ in.) as shown in Figure 2.

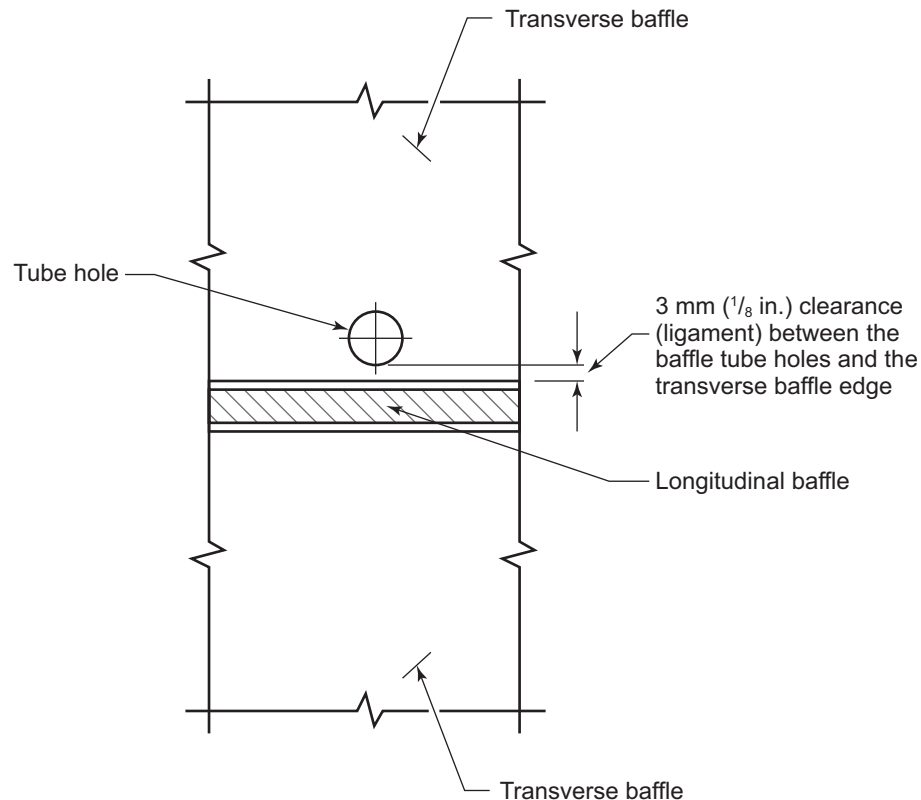


Figure 2—Clearance Between Tube Holes and Transverse Baffle Edge with Longitudinal Baffle

7.5.4 Impingement Protection

7.5.4.1 If required by TEMA, Section 5, Paragraph RCB-4.61, impingement protection shall be provided by a plate baffle or rods on the tube bundle, an annular distributor, or another means agreed by the purchaser and vendor.

7.5.4.2 If an impingement plate baffle is used, it shall extend at least 25 mm (1 in.) beyond the projection of the nozzle bore (e.g. for a round impingement plate, the plate diameter shall be at least 50 mm (2 in.) larger than the nozzle bore) or 20 % greater than the inlet nozzle inside diameter, whichever is larger.

7.5.4.3 If impingement protection is used, the shell entrance and tube bundle entrance areas (as defined by TEMA, Section 5, Paragraph RCB 4.62) shall not be less than the flow area of the inlet nozzle.

7.5.4.4 The nominal thickness of impingement plate baffles shall not be less than 6 mm ($1/4$ in.).

7.5.4.5 The impingement plate baffle shall be adequately supported (e.g. by welding to at least two spacers) to avoid mechanical damage due to vibration.

7.5.4.6 Perforated impingement plate baffles shall not be used.

7.5.4.7 If impingement rods are utilized, the following shall be applied.

- a) A minimum of two rows of staggered rods shall be used.
- b) The rods shall not have a diameter less than 19 mm ($3/4$ in.).
- c) Tube center-to-center spacing shall be 1.25 to 1.33 times the rod diameter.
- d) The length and width of the rod array shall extend at least 50 mm (2 in.) beyond the projection of the nozzle bore or 20 % greater than the inlet nozzle inside diameter, whichever is larger.
- e) For carbon, low alloy, and austenitic stainless steel materials the rods shall be supplied as solid bars; for other materials tubing can be used if approved by the purchaser.
- f) Impingement rods shall be supported at both ends. When attached to the tubesheet, impingement rods shall not be attached by welding alone.

7.5.5 Bypass Sealing Devices

7.5.5.1 Bypass sealing devices (such as seal bars, dummy tubes or tie-rods) as shown in Figure 3 shall be used for non-isothermal shell side services if bypass clearances exceed 16 mm ($5/8$ in.) and shall be located as follows.

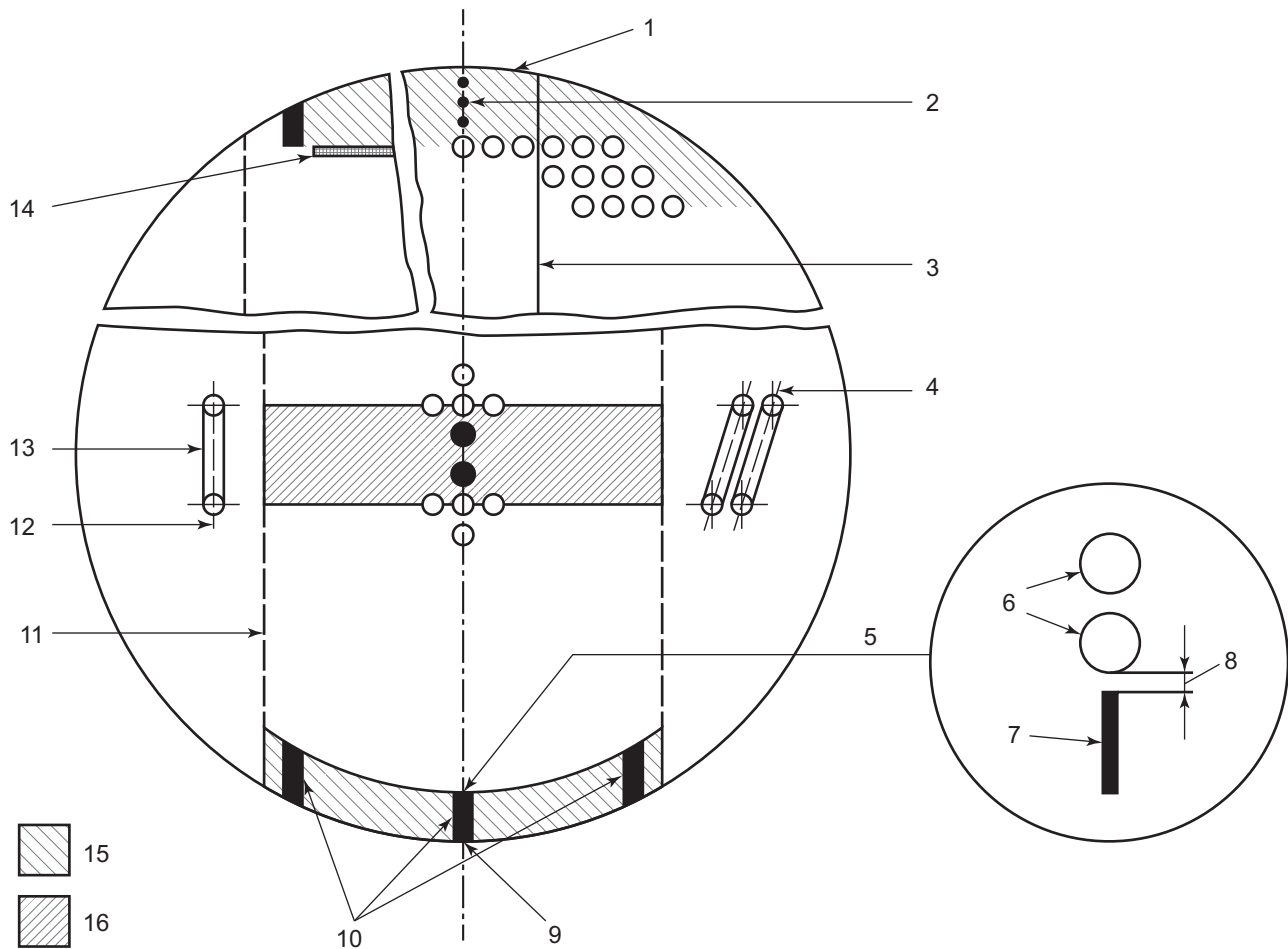
- a) If the distance between baffle-cut edges is six tube pitches or less, a single seal located approximately halfway between the baffle cut shall be provided.
- b) If the distance between baffle-cut edges exceeds six tube pitches, multiple seals shall be provided. A seal shall be located every five to seven tube pitches between the baffle cuts, with the outermost seals not more than 75 mm (3 in.) from each baffle-cut edge.

7.5.5.2 Peripheral bypass seals shall extend from the peripheral edge of the transverse baffle into the tube bundle so that the clearance to the nearest tube does not exceed the nominal clearance between tubes.

7.5.5.3 Internal bypass seals shall be installed so that the clearance to the nearest tube does not exceed the nominal clearance between tubes.

7.5.5.4 Bypass sealing devices shall either be located to minimize obstruction of mechanical cleaning lanes or shall be readily removable. Continuous cleaning lanes shall be maintained for square (90°) and rotated-square (45°) pitch.

7.5.5.5 The nominal thickness of seal strips shall be the nominal thickness of the transverse baffles or 6 mm ($1/4$ in.), whichever is less.



Key

- | | |
|--|----------------------------------|
| 1 peripheral edge of baffle | 9 single seal on centerline |
| 2 tie-rods, dummy tubes, or flat bar | 10 multiple seals, evenly spaced |
| 3 edge of baffle cut | 11 edge of baffle cut |
| 4 plane of U-tube bend | 12 plane of U-tube bend |
| 5 detail of seals and tube clearance | 13 U-tube bend |
| 6 tubes | 14 impingement plate |
| 7 seal | 15 peripheral bundle bypass lane |
| 8 clearance: not to exceed nominal clearance between tubes | 16 internal bundle bypass lane |

Figure 3—Typical Cross-sections of Tube Bundle Showing Locations of Bypass Sealing Devices

7.5.5.6 Bypass seal strips shall be attached to the transverse baffles by continuous welds on one side of each baffle.

7.5.5.7 The leading and trailing edges of seal strips shall be provided with a radius or a bevel to prevent damage to the shell when inserting or removing the tube bundle.

7.5.5.8 Peripheral bypass seal strips shall not restrict the tube bundle inlet or outlet flows.

7.5.6 Tube Bundle Skid Bars

7.5.6.1 For all removable tube bundles with a mass of more than 5500 kg (12,000 lb), continuous sliding surfaces shall be provided to facilitate bundle removal. If skid bars are used, they shall be welded to the transverse baffles and support plates to form a continuous sliding surface. See A.4.3 for additional guidance.

7.5.6.2 If skid bars are used, a minimum of two shall be provided.

7.5.6.3 Skid bars shall not restrict the tube bundle inlet or outlet flows.

7.5.6.4 Skid bars shall protrude 1 mm ($1/32$ in.) beyond the outside diameter of baffle and support plates.

7.5.6.5 The leading and trailing edges of skid bars shall be provided with a radius or a bevel to prevent damage to the shell when inserting or removing the tube bundle.

7.5.7 Tube-to-Tubesheet Joint

7.5.7.1 Tube-to-tubesheet joints shall be expanded with a minimum of two grooves, unless a strength-welded tube-to-tubesheet joint is specified by the purchaser on the datasheet.

7.5.7.2 If welded tube-to-tubesheet joints are specified, the joint shall be welded by one of the following methods:

a) strength-welded only;

b) strength-welded and expanded;

c) seal-welded and expanded.

- **7.5.7.3** When strength welds are applied, the degree of expansion and the use of grooves shall be specified or agreed to by the purchaser. See Annex A.4.4 for additional guidance on the selection of tube-to-tubesheet joints.

7.6 Nozzles and Other Connections

- **7.6.1** Connections DN 40 (NPS $1\frac{1}{2}$) and larger shall be flanged. The purchaser shall specify the required flange design code (e.g. ASME B16.5).
- **7.6.2** The purchaser shall specify if nozzles are to be welded to the connecting piping (by others). They shall be beveled and details shall be specified or agreed with the purchaser.

7.6.3 Non-flanged connections smaller than DN 40 (NPS $1\frac{1}{2}$) shall be forged couplings with a rating that meets or is equivalent to ASME B16.11 class 6000, or shall be integrally reinforced welding fittings with tapered threads that meet or are equivalent to ASME B1.20.1, and shall comply with the pressure design code. Threaded connections shall not be used in hydrogen, sour, or wet hydrogen sulfide service. This includes auxiliary connections, such as vents, drains, instrument connections, and chemical cleaning connections.

7.6.4 Flanged connections shall be of one of the following types:

a) forged integrally flanged;

b) pipe or forged cylinder welded to forged welding-neck flange;

c) pipe welded to a forged slip-on flange, except as noted in 7.6.5.

7.6.5 Slip-on flanges shall not be used in any of the following conditions:

- a) design pressure greater than 2100 kPa (ga) (300 psig);
- b) design temperature greater than 400 °C (750 °F);
- c) corrosion allowance greater than 3 mm ($1/8$ in.);
- d) hydrogen, sour, or wet hydrogen sulfide service;
- e) cyclic service.

- **7.6.6** The projection of flanged connections shall allow through-bolting to be removed from either side of the flange without removing the insulation. For stacked units, this requirement need only be applied to one side of directly coupled connections. The insulation thickness shall be specified by the purchaser.

7.6.7 Integrally reinforced nozzles shall be designed so that standard spanners (wrenches) fit the nuts without interference from nozzle neck reinforcement.

- **7.6.8** The purchaser shall specify if chemical cleaning connections are required. Their nominal size shall be not less than DN 50 (NPS 2).
- **7.6.9** Nozzles shall be designed to withstand the simultaneous application of forces and moments in the corroded condition, as defined in Figure 4 and listed in Table 2, unless otherwise specified by the purchaser. Non-piped auxiliary connections, such as vents, drains, and cleaning connections, are excluded from this requirement. The type of analysis applied shall be specified or agreed with the purchaser.
- **7.6.10** For nozzle sizes larger than those listed in Table 2, the purchaser shall specify the moments and forces.

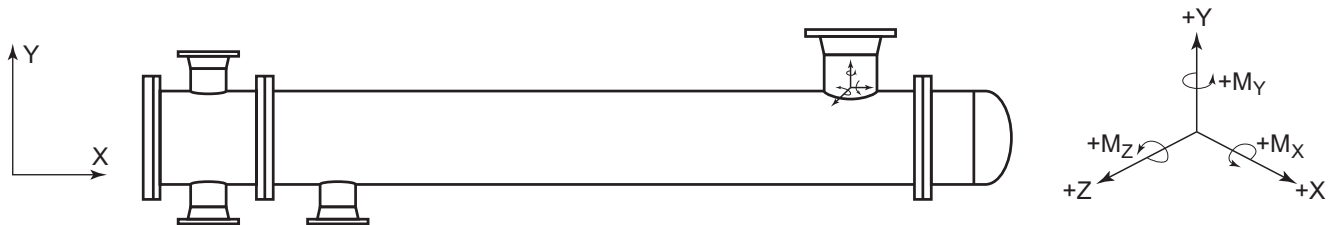


Figure 4—Directions of Moments and Forces on Nozzles

7.6.11 Reinforcement pads shall not be used for nozzles in cyclic service, hydrogen service with operating temperatures above 230 °C (450 °F), or other services with operating temperatures above 400 °C (750 °F).

7.6.12 The maximum allowable working pressure shall not be limited by nozzle reinforcement.

7.7 Flanged External Girth Joints

- **7.7.1** Channel and shell external girth joints shall be of through-bolted construction. Studded-in bolts may be used when specified or approved by the Purchaser.

Table 2—Nozzle Allowable Forces and Moments at the Nozzle Neck to Shell/Channel Interface

Nominal Diameter		Flange Rating	M_x		M_y		M_z		F_x		F_y		F_z	
DN	(NPS)		N·m	(lbf·ft)	N·m	(lbf·ft)	N·m	(lbf·ft)	N	(lbf)	N	(lbf)	N	(lbf)
50	2	150	270	200	430	320	340	250	1590	370	1270	290	1590	370
		300	340	250	540	400	430	320	1990	450	1590	360	1990	450
		600	470	350	750	560	590	440	2780	630	2220	500	2780	630
		900	600	440	970	720	760	560	3580	820	2860	650	3580	820
		1500	600	440	970	720	760	560	3580	820	2860	650	3580	820
		2500	670	490	1080	790	850	630	3970	900	3170	720	3970	900
80	3	150	580	430	940	690	740	540	2340	530	1870	420	2340	530
		300	720	540	1170	860	920	680	2930	670	2340	530	2930	670
		600	1010	750	1630	1210	1280	950	4090	930	3270	740	4090	930
		900	1300	960	2100	1550	1650	1220	5270	1190	4210	950	5270	1190
		1500	1300	960	2100	1550	1650	1220	5270	1190	4210	950	5270	1190
		2500	1590	1170	2560	1890	2010	1490	6430	1450	5140	1160	6430	1450
100	4	150	960	710	1540	1140	1210	900	3020	680	2410	540	3020	680
		300	1190	880	1930	1420	1520	1120	3770	850	3010	680	3770	850
		600	1670	1230	2700	1990	2120	1560	5270	1190	4210	950	5270	1190
		900	2150	1580	3460	2560	2720	2010	6770	1530	5410	1220	6770	1530
		1500	2380	1760	3850	2840	3030	2230	7520	1690	6010	1350	7520	1690
		2500	2620	1930	4230	3120	3330	2460	8270	1870	6610	1490	8270	1870
150	6	150	2070	1530	3340	2460	2620	1940	4430	1000	3540	800	4430	1000
		300	3610	2670	5840	4310	4590	3380	7740	1750	6190	1400	7740	1750
		600	4640	3430	7500	5540	5900	4350	9950	2240	7960	1790	9950	2240
		900	5670	4190	9170	6760	7210	5320	12170	2740	9730	2190	12170	2740
		1500	6710	4950	10840	7990	8520	6280	14380	3240	11500	2590	14380	3240
		2500	7220	5330	11670	8610	9170	6760	15480	3490	12380	2790	15480	3490
200	8	150	3500	2580	5650	4170	4440	3280	5770	1300	4610	1040	5770	1300
		300	6120	4510	9890	7300	7770	5730	10080	2280	8060	1820	10080	2280
		600	8740	6450	14130	10420	11100	8190	14390	3240	11510	2590	14390	3240
		900	12230	9020	19780	14590	15540	11460	20150	4540	16120	3630	20150	4540
		1500	13980	10310	22600	16670	17760	13100	23030	5180	18420	4140	23030	5180
		2500	14860	10960	24010	17710	18870	13920	24470	5500	19570	4400	24470	5500

Table 2—Nozzle Allowable Forces and Moments at the Nozzle Neck to Shell/Channel Interface (Continued)

Nominal Diameter		Flange Rating	M_x		M_y		M_z		F_x		F_y		F_z	
DN	(NPS)		N·m	(lbf·ft)	N·m	(lbf·ft)	N·m	(lbf·ft)	N	(lbf)	N	(lbf)	N	(lbf)
250	10	150	5430	4010	8780	6480	6900	5090	7180	1620	5740	1290	7180	1620
		300	9500	7010	15360	11330	12070	8900	12570	2830	10050	2260	12570	2830
		600	13580	10010	21940	16180	17240	12720	17940	4040	14350	3230	17940	4040
		900	19000	14020	30720	22660	24140	17800	25120	5650	20090	4520	25120	5650
		1500	21720	16020	35110	25890	27580	20340	28700	6450	22960	5160	28700	6450
		2500	23070	17020	37300	27510	29310	21620	30490	6870	24390	5490	30490	6870
300	12	150	7640	5640	12350	9110	9700	7160	8520	1920	6810	1530	8520	1920
		300	13370	9860	21610	15940	16980	12520	14890	3350	11910	2680	14890	3350
		600	15280	11270	24690	18210	19400	14310	17030	3830	13620	3060	17030	3830
		900	17190	12680	27780	20490	21830	16100	19150	4320	15320	3450	19150	4320
		1500	21000	15490	33950	25040	26680	19680	23400	5270	18720	4210	23400	5270
		2500	22910	16900	37040	27320	29100	21460	25530	5740	20420	4590	25530	5740
350	14	150	11510	8490	18610	13720	14620	10780	11690	2630	9350	2100	11690	2630
		300	16120	11890	26050	19210	20470	15100	16350	3680	13080	2940	16350	3680
		600	23020	16980	37210	27440	29240	21560	23370	5250	18690	4200	23370	5250
		900	29930	22070	48380	35680	38010	28030	30370	6830	24290	5460	30370	6830
		1500	41430	30560	66980	49400	52630	38810	42040	9450	33630	7560	42040	9450
		2500	50640	37350	81860	60370	64320	47440	51380	11550	41100	9240	51380	11550
400	16	150	12030	8870	19440	14340	15280	11270	14240	3200	11390	2560	14240	3200
		300	21050	15520	34020	25090	26730	19720	24920	5600	19930	4480	24920	5600
		600	30070	22170	48600	35840	38190	28160	35590	8000	28470	6400	35590	8000
		900	42090	31040	68040	50180	53460	39430	49830	11200	39860	8960	49830	11200
		1500	48100	35480	77760	57350	61100	45060	56940	12800	45550	10240	56940	12800
		2500	51110	37690	82620	60930	64920	47880	60500	13600	48400	10880	60500	13600
450	18	150	15220	11230	24610	18150	19340	14260	16030	3600	12820	2880	16030	3600
		300	26640	19650	43060	31760	33830	24950	28030	6300	22420	5040	28030	6300
		600	38050	28060	61510	45360	48330	35640	40040	9000	32030	7200	40040	9000
		900	49470	36480	79970	58970	62830	46340	52050	11700	41640	9360	52050	11700
		1500	60880	44900	98420	72580	77330	57030	64070	14400	51250	11520	64070	14400
		2500	64690	47700	104570	77120	82160	60590	68070	15300	54450	12240	68070	15300

Table 2—Nozzle Allowable Forces and Moments at the Nozzle Neck to Shell/Channel Interface (Continued)

Nominal Diameter		Flange Rating	M_x		M_y		M_z		F_x		F_y		F_z	
DN	(NPS)		N·m	(lbf·ft)	N·m	(lbf·ft)	N·m	(lbf·ft)	N	(lbf)	N	(lbf)	N	(lbf)
500	20	150	18790	13860	30380	22400	23870	17600	17800	4000	14240	3200	17800	4000
		300	32890	24250	53160	39200	41770	30800	31140	7000	24910	5600	31140	7000
		600	42280	31180	68350	50400	53700	39600	40040	9000	32030	7200	40040	9000
		900	61070	45040	98720	72800	77570	57200	57830	13000	46260	10400	57830	13000
		1500	70460	51960	113910	84000	89500	66000	66730	15000	53380	12000	66730	15000
		2500	79860	58890	129100	95200	101430	74800	75630	17000	60500	13600	75630	17000
600	24	150	33820	24950	54680	40320	42960	31680	26700	6000	21360	4800	26700	6000
		300	47350	34920	76550	56450	60150	44360	37380	8400	29900	6720	37380	8400
		600	67640	49890	109350	80640	85920	63360	53390	12000	42710	9600	53390	12000
		900	87940	64850	142160	104840	111700	82370	69400	15600	55520	12480	69400	15600
		1500	121760	89790	196830	145160	154650	114050	96090	21600	76870	17280	96090	21600
		2500	148810	109740	240570	177410	189020	139400	117440	26400	93950	21120	117440	26400

7.7.2 Flanges for external girth joints shall be of the forged welding-neck type, unless otherwise specified or approved by the purchaser.

7.7.3 Nubbins shall not be used.

7.7.4 The design clearance between mating flanges shall not be less than 3 mm ($1/8$ in.) at the periphery of the flanged joint. After assembly of the girth flange joint, the measured clearance between the mating flanges shall not be less than 1.5 mm ($1/16$ in.). The clearance between flanges shall extend within the bolt circle to allow flanges to be checked for radial distortion caused by an excessive bolt load.

7.7.5 Spot facing or back facing of the bolting bearing surfaces shall be in accordance with ASME B16.5 and the pressure design code.

- 7.7.6** Hydraulic bolt tensioning shall be applied for all bolt diameters equal to or greater than 50 mm (2 in.), or in hydrogen service where bolt diameters are equal to or greater than 40 mm ($1\frac{1}{2}$ in.), or when specified by the purchaser. Alternate forms of tightening followed by bolt elongation verification (e.g. hydraulic torquing in combination with ultrasonic extensometer measurement) may be considered in lieu of tensioning, with approval of the purchaser.

7.7.7 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.

- 7.7.8** When bolt tensioning is used, the purchaser shall specify any special requirements necessary to allow for adequate clearance for the bolt-tightening device.

7.7.9 When either manual or hydraulic torquing is applied, through-hardened washers shall be provided under nuts for all bolts to improve the translation of torque into bolt preload by providing a smooth and low friction bearing surface for the nut, and to protect the contact surface of the flange from damage caused by a turning nut.

7.7.10 Washers shall conform to the requirements of ASME PCC-1, Appendix M. The washers shall be suitable for re-use as defined in ASME PCC-1, Appendix M, unless otherwise specified by the purchaser.

7.7.11 Stationary tubesheet flange assembly shall be designed with the same type of gasket on the tube side and shell side.

7.7.12 Allowable stresses that have been established on the basis of short-time tensile strength shall not be used for the design of girth flanges, gasketed tubesheets, and gasketed flat covers.

NOTE In ASME *BPVC, Section II*, the allowable stresses of some high nickel alloys have been established in this way. These stress values may result in dimensional changes due to permanent strain and shall not be used for flanges for gasketed joints where slight distortion can cause leakage.

7.7.13 Flange design shall be in accordance with the pressure design code.

7.7.14 The maximum allowable working pressure shall not be limited by flange bolting.

• **7.7.15** When specified by the purchaser, external 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.

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

7.7.16 Tongue and groove type configuration shall not be used, unless specified or agreed by the purchaser.

7.8 Girth Flange Joint Supplementary Design Requirements

- **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 one or both sides of the heat exchanger, when specified by the purchaser. Definition of terms and symbology contained within this section are consistent with ASME PCC-1. See A.4.5 for additional guidance.

7.8.2 The minimum permissible bolt stress, Sb_{min} , and the maximum permissible bolt stress, Sb_{max} , shall be 40 % and 70 %, respectively, of the listed yield values in the pressure design code at assembly conditions (i.e. ambient temperature).

7.8.3 At least one-half of the gasket pass-partition rib area shall be added to the peripheral ring gasket area, A_g , unless otherwise agreed with the purchaser.

7.8.4 The selected assembly bolt stress, Sb_{sel} , shall be established so as to ensure that the gasket stresses comply with Table 3. For gasket types not listed, the minimum and maximum gasket stresses shall be agreed between the purchaser and vendor.

7.8.5 The fraction of gasket load remaining after relaxation, ϕ_g , used in the calculations shall be 0.7, unless otherwise specified by the purchaser.

7.8.6 To minimize potential for flange rotation, the rigidity index as calculated in ASME *BPVC, Section VIII Division 1*, Mandatory Appendix 2, shall not exceed 1.0.

7.8.7 For stationary tubesheets with gaskets on both the shell and tube sides of the tubesheet, in Step 6 of ASME PCC-1, the following additional checks, as calculated by Equation (1) and Equation (2), shall be undertaken to verify that the selected assembly bolt stress include the effects of pressure acting from the opposing side of the tubesheet. In this case, the maximum design pressure, P_{max} , shall be taken as the design pressure difference between the two sides.

Table 3—Assembly Gasket Stress

Peripheral Gasket Type ^a	Maximum Permissible Gasket Stress, $S_{g_{max}}$ MPa (psi)	Minimum Gasket Seating Stress, $S_{g_{min-S}}$ MPa (psi)	Minimum Gasket Operating Stress, $S_{g_{min-O}}$ MPa (psi)
Grooved metal with soft facing	380 (55,000)	140 (20,000)	97 (14,000)
Corrugated metal with soft facing	275 (40,000)	140 (20,000)	97(14,000)
Spiral-wound	b	140 (20,000)	97 (14,000)

^a These stresses are based on the use of facing layers or filler materials, such as flexible graphite, PTFE, or other conformable materials, and excludes core materials of carbon steel, brass, copper, or aluminum alloys.

^b The maximum permissible gasket stress does not apply when a means to prevent over-compression of the gasket is employed (e.g. centering rings with spiral-wound gaskets).

Step 6a: Check selected assembly bolt stress is adequate for the shell side gasket:

$$S_{b_{sel}} \geq \frac{(S_{g_{min-o}} \times A_{g,S}) + \left[\frac{\pi}{4} \times (G_{ID,S})^2 \times (P_S - P_T) \right]}{(\phi_g \times n_b \times A_b)} \quad (1)$$

Step 6b: Check selected assembly bolt stress is adequate for the tube side gasket:

$$S_{b_{sel}} \geq \frac{(S_{g_{min-o}} \times A_{g,T}) + \left[\frac{\pi}{4} \times (G_{D,T})^2 \times (P_T - P_S) \right]}{(\phi_g \times n_b \times A_b)} \quad (2)$$

where

- $A_{g,S}$ is the shell side gasket area, expressed in mm² (in.²);
- $A_{g,T}$ is the tube side gasket area, expressed in mm² (in.²);
- $G_{ID,S}$ is the shell side gasket inner diameter, expressed in mm (in.);
- $G_{ID,T}$ is the tube side gasket inner diameter, expressed in mm (in.);
- n_b is the number of bolts;
- P_S is the design pressure on the shell side, expressed in MPa (psi);
- P_T is the design pressure on the tube side, expressed in MPa (psi);
- $S_{b_{sel}}$ is the selected assembly bolt stress, expressed in MPa (psi);
- $S_{g_{min-o}}$ is the minimum gasket operating stress, expressed in MPa (psi);
- ϕ_g is the fraction of gasket load remaining after relaxation.

7.8.8 If the requirements contained within this section require the bolt area to be increased or gasket geometry revised, then the pressure design code calculations shall be updated and the required flange thickness re-calculated accordingly.

7.8.9 Controlled bolt-tightening procedures shall be applied, and records provided, to demonstrate that the selected assembly bolt stress, $S_{b_{sel}}$, has been achieved.

7.9 Expansion Joints

7.9.1 Expansion joints in shells shall be thin-wall bellows or thick walled (e.g. flanged, or flanged and flued). Floating head tail pipe expansion joints shall be thin wall bellows type.

7.9.2 Expansion joints made of thin-walled bellows shall:

- a) be protected from internal damage with a metallic liner mounted flush with the inside of the shell. The liner material shall be compatible with the base material to which it is attached. Carbon steel liners shall be at least 6 mm ($1/4$ in.) thick. Liners of stainless steel or other alloys shall be at least 3 mm ($1/8$ in.) thick. For vertically mounted bellows, the liner shall be attached at the top and open at the bottom to allow for free drainage;
- b) be protected from external damage with a metallic cover that is designed to remain intact during shipping, handling, and operation;
- 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 1000 normal operating cycles;
- d) have the bellows formed from a cylinder having only a single longitudinal weld that shall be 100 % radiographed before forming. The acceptance criteria shall comply with the pressure design code;
- e) have bellows welds that are 100 % examined by the liquid-penetrant method including attachment welds. The acceptance criteria shall comply with the pressure design code;
- f) be designed with stays to prevent damage during shipping and handling. Stays that require removal or adjustment prior to operation must be clearly identified;
- g) for internal floating-head tailpipe expansion joints, be fitted with permanent stays that prevent damage 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 Flanged external girth joint gaskets and floating-head gaskets in hydrocarbon or steam service shall be double-jacketed metal with soft gasket filler, spiral-wound, grooved metal with soft gasket-seal facing, or corrugated metal with soft gasket-seal facing. Solid metal gaskets shall only be used with welded closures or self-energizing closures. See A.4.6 for additional guidance.

NOTE The term grooved is synonymous with the term serrated as applied to gasket type.

7.10.2 Double-jacketed gaskets shall not be used for the peripheral portion of the gasket in the following services:

- a) hydrogen service;
- b) operating temperatures above 205 °C (400 °F);

- c) cyclic service;
- d) sour or wet hydrogen sulfide service;
- e) design pressure equal to or greater than 2050 kPa (ga) (300 psig);
- f) shell diameter greater than 1200 mm (48 in.).

7.10.3 Pass-partition rib(s) shall be of the same material grade as the peripheral portion of the gasket.

7.10.4 Pass-partition ribs shall not be made from flat solid metal.

7.10.5 Pass-partition ribs shall be designed and constructed such that they do not inhibit the compression or seating of the peripheral portion of the gasket.

7.10.6 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 following:

- a) for double jacketed gaskets, one;
- b) for other gasket types, the greater of either two, or the ratio of gasket OD/610 mm (gasket OD/24 in.).

7.10.7 The gasket welds shall be as follows.

- a) The welds in the peripheral portion of the gasket shall be continuous and full-penetration. The cross-section, finish, and flatness of these welded areas must match the remainder of the peripheral gasket.
- b) The welds shall not inhibit the sealing or compression of the peripheral gasket or pass ribs.

7.10.8 When adhesives are used to bond facing materials (e.g. graphite) to grooved and corrugated metal gaskets, they shall be compatible with the metal core (e.g. chloride content).

7.10.9 Double jacketed gaskets shall be as follows.

- a) They shall be manufactured with the filler material completely enclosed in metal.
- b) Filler materials shall be selected to ensure no degradation occurs during manufacturing (e.g. welding).

7.10.10 Grooved metal gaskets shall be as follows.

- a) The top of the serrations at the weld shall be flat in comparison with the rest of the gasket. The grooves shall be dressed to match the standard profile.
- b) Thickness variations in the metallic core, after completion of gasket fabrication, shall not exceed 0.13 mm (0.005 in.).
- c) Where the outside diameter is less than 1 m (40 in.), they shall be manufactured with one-piece continuous facing materials (no joints). Facing joints in larger-diameter gaskets shall include a 1.5 mm (¹/₁₆ in.) to 3 mm (¹/₈ in.) overlap of the facing material; however, butt joints (gap free) are allowed for flexible graphite facings. Facing joints shall not be coincident with a facing joint on the opposite sealing face, or with any welds in the core.

7.10.11 Corrugated metal gaskets shall be as follows:

- a) minimum core thickness of 0.46 mm (0.018 in.);

- b) minimum width of 12 mm ($1/2$ in.);
- c) corrugations in the weld area that match the gasket profile;
- d) where the outside diameter is less than 1 m (40 in.), they shall be manufactured with one-piece continuous facing materials (no joints). Facing joints in larger-diameter gaskets shall include a 1.5 mm ($1/16$ in.) to 3 mm ($1/8$ in.) overlap of the facing material; however, butt joints (gap free) are allowed for flexible graphite facings. Facing joints shall not be coincident with a facing joint on the opposite sealing face or with any welds in the core.

7.10.12 Spiral-wound gaskets shall be provided with a flat inner ring to prevent over-compression and inward radial buckling. For flanges on shells with a diameter greater than 1000 mm (40 in.), or when the gasket is not confined on its OD, an outer metal ring shall also be provided. See A.4.6 for additional guidance.

7.10.13 The maximum gasket width shall be 50 mm (2 in.), except for non-metallic sheet type gaskets.

7.11 Handling Devices

7.11.1 The lifting device shall be a weld-on lug or ring provided with a hole not less than 38 mm ($1\frac{1}{2}$ in.) in diameter. Wherever possible, the lug or ring shall be located at the top of the component, above its center of gravity; otherwise, two suitably located lugs or rings shall be provided. The lifting device shall be designed to support at least twice the mass of the component.

7.11.2 For stacked heat exchangers, two lifting lugs or rings shall be provided on all covers, located at the top, approximately 45° from the vertical centerline.

7.11.3 Stationary tubesheets shall be provided with pulling lugs or tapped holes on their outer face for the insertion of eyebolts to aid removal of the tube bundle from the shell. Pulling lugs and tapped holes shall be designed for a pulling force equal to at least 150 % of the tube bundle mass. Each tapped hole shall be fitted with a threaded plug of the same material as the tubesheet face. The exposed section of the plug shall be at least 50 mm (2 in.) long.

7.11.4 All vertical heat exchangers shall be provided with lifting devices for the entire heat exchanger. The lifting devices shall be provided above the center of gravity of the heat exchanger.

7.12 Requirements for Hydrogen Service

7.12.1 Totally enclosed spaces between attachment welds and the pressure boundary shall be eliminated or vented with a hole of 6 mm ($1/4$ in.) in diameter.

- **7.12.2** The purchaser shall specify any supplemental requirements for low chrome steels in high temperature or high pressure hydrogen service (e.g. API RP 934-A, API RP 934-C).

NOTE See A.4.7 for information on the potential for leaks resulting from bolting relaxation.

8 Materials

8.1 General

8.1.1 Castings shall not be used, unless approved by the purchaser.

8.1.2 Material for external parts that are welded directly to the heat exchanger, such as pads, brackets, and lugs, shall be of the same nominal composition as the material to which they are welded.

8.1.3 If alloy linings are specified by the purchaser, they shall be weld overlay, integrally-clad, or explosion-bonded. Loose liners or sleeves shall not be used without the approval of the purchaser.

- **8.1.4** Purchaser shall specify materials for all components, including bolting and gaskets.

8.1.5 Tubesheets that are welded to the adjacent shell or channel cylinder by use of a corner joint can be provided as forged or plate materials. If plate material is used, it shall be 100 % ultrasonically examined for laminations and other defects prior to attachment to the cylinder.

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

8.2.1 Materials shall be supplied in the normalized condition, unless otherwise approved by the purchaser. The acceptability of hot-formed material shall be subject to approval of the purchaser.

8.2.2 Pressure-retaining components shall be supplied with a Certified Material Test Report (CMTR). The CMTR shall include the unspecified elements chromium (Cr), columbium (Cb) [also known as niobium (Nb)], nickel (Ni), vanadium (V), molybdenum (Mo), and copper (Cu) that are used in the formula to calculate the carbon equivalent (CE) as defined by NACE MR0175 (all parts) or NACE MR0103.

- **8.2.3** The maximum allowable carbon equivalent shall be agreed with the purchaser prior to purchase of materials for use in fabrication. Restrictions on other residual elements and micro-alloying elements can also apply depending on the severity of the service. The purchaser shall specify all such restrictions.

8.3 Gaskets

8.3.1 Gaskets shall not contain asbestos.

8.3.2 Material for metal-jacketed, grooved-metal, corrugated-metal, or solid-metal gaskets shall have a corrosion resistance at least equal to that of the gasket contact surface material.

8.3.3 Metal windings of spiral-wound gaskets shall be of austenitic stainless steel, unless otherwise specified or approved by the purchaser. Where materials of construction are a higher alloy, then the metal windings shall be the same alloy material.

8.3.4 Grooved, or metal-jacketed gaskets, shall be softer than the gasket contact surface.

8.3.5 Gasket material, including filler and facing material, shall be selected to withstand the maximum design temperature. See A.5.1 for additional information on gasket material.

8.3.6 Compressed sheet type gaskets shall not be used in hydrocarbon, steam, hydrogen, sour or wet hydrogen sulfide service.

8.4 Tubes

8.4.1 Integrally finned tubes of copper alloy shall be furnished in the annealed-temper condition, such as described in ASTM B359/B359M.

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

9 Fabrication

9.1 Shells

9.1.1 All longitudinal and circumferential welds of shells for other than kettle-type heat exchangers shall be finished flush with the inner contour for ease of tube bundle insertion and withdrawal. For kettle-type heat exchangers, this

requirement shall not apply to welds in the enlarged section, unless they are in the bottom quadrant of the shell. See A.6.1 for additional guidance.

9.1.2 For removable-bundle heat exchangers, the permissible out-of-roundness of a completed shell, after all welding and any required heat treatment, shall allow a metal template to pass through the entire shell length without binding. The template shall consist of two rigid disks (each with a diameter equal to the diameter of the transverse baffle or support plate) rigidly mounted perpendicularly on a shaft and spaced not less than 300 mm (12 in.) apart.

9.1.3 Transverse baffle-to-shell clearances greater than those indicated in TEMA, Table RCB-4.3, shall not be used, unless approved by the purchaser.

9.2 Pass-partition Plates

Pass-partition plates for forged or welded 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 full-penetration welds.

9.3 Connection Junctions

Nozzles and couplings shall not protrude beyond the inside surface of the shell, channel, or head to which they are attached.

9.4 Tubes

9.4.1 All tubes, including U-tubes, shall be formed from a single length and shall have no circumferential welds, unless approved by the purchaser.

9.4.2 No tubes or tube holes shall be plugged without notifying the purchaser. The method and procedure of plugging shall be subject to approval of the purchaser.

9.5 Welding

9.5.1 Welds can be made by any welding process other than oxyacetylene gas welding.

9.5.2 Category A and B welded joints shall be full-penetration welds.

9.5.3 All welds attaching connections to cylinders or to heads shall fully penetrate the total thickness of the component wall or the connection wall forming the attachment.

9.5.4 Backing strips that remain in place on the inside of a component after completion of welding shall not be used, unless approved by the purchaser.

9.5.5 The method used to position a tube in advance of tube-end welding shall be done in such a way as to prevent the trapping of gases during the welding process.

9.5.6 Strength-welded tube-to-tubesheet welds shall have a minimum of two weld passes and be produced by gas tungsten arc welding (GTAW) using filler material, unless otherwise specified or approved by the purchaser.

9.5.7 The qualification of the weld procedure for a strength-welded tube-to-tubesheet joint shall be in accordance with the requirements of the pressure design code, with the following additional requirements.

a) The minimum leak path (i.e. the distance from the root of the weld to the 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.

9.5.8 Welds attaching nonpressure external attachments (such as lugs or structural steel supports) shall be continuous, except for insulation support rings.

9.5.9 Repair-associated welding procedures shall be submitted to the purchaser for review before the start of repair.

9.5.10 Full-penetration welds shall be used for all internal attachments to the pressure boundary components that will be exposed to hydrogen service.

- **9.5.11** The purchaser shall specify whether weld procedure qualifications for carbon steel in sour or wet hydrogen sulfide service, including tube-to-tubesheet welds, shall include a micro-hardness survey performed on a weld cross-section, including the heat affected zone (HAZ), and transverse to the weld centerline. The micro-hardness testing and acceptance criteria shall be in accordance with NACE SP0472 or NACE MR0175 (all parts), as applicable. Any additional restrictions on residual elements or micro-alloying elements for the qualification test material shall be specified by the purchaser.
- **9.5.12** When specified by the purchaser, weld procedure qualifications for duplex stainless steels, including tube-to-tubesheet welds, shall include a micro-hardness survey performed on a weld cross-section (including HAZ) and transverse to the weld centerline. The micro-hardness testing and acceptance criteria shall be as agreed with the purchaser.

NOTE See API TR 938-C and API RP 582 for guidance on welding of duplex stainless steels.

9.6 Heat Treatment

9.6.1 Machined contact surfaces, including any threaded connections, shall be suitably protected to prevent scaling or loss of finish during heat treatment.

- **9.6.2** The purchaser shall specify if heat treatment is required after bending of U-tubes for process reasons.

9.6.3 Unless otherwise specified by the purchaser, the following shall be subject to heat treatment after tube bending:

- a) Carbon steel, carbon-molybdenum, and low chromium steel U-bends (C - 0.5 % Mo through 5 % Cr steels) in sour or wet hydrogen sulfide service.
- b) U-bends in brass alloys (e.g. per ASME SB-395/395M).
- c) Unstabilized austenitic stainless steels with a mean radius smaller than 5 times the nominal outside diameter of the tube.

9.6.4 Unstabilized austenitic stainless steel tubing subjected to heat treatment after bending shall be supplied with 0.05 % maximum carbon content or be dual certified as low carbon grade.

- **9.6.5** For ferritic and martensitic stainless steels, stabilized austenitic stainless steels, duplex stainless steels, copper, copper-nickel, and high nickel alloys (Ni > 30 %), heat treatment of U-tubes shall be applied if cold working can induce susceptibility to stress corrosion. The purchaser shall specify when heat treatment is required in such cases.

NOTE See API TR 938-C for guidance on heat treatment of duplex stainless steel U-bends.

9.6.6 U-bend heat treatment shall be in accordance with the pressure design code. When applied, U-bend heat treatment shall be completed by electric resistance or furnace methods. Open flame heat treatment is not permitted. The procedure used for heat treatment shall be agreed between the purchaser and vendor.

9.6.7 For electric resistance or induction heating, the heat-treated portion of the U-bend shall extend at least 150 mm (6 in.) beyond the tangent point. For furnace heating, the heat treatment shall extend at least 600 mm (24 in.) beyond the tangent point.

- **9.6.8** When specified by the purchaser, the heat treated portion of U-tubes shall receive a de-scaling treatment.

9.6.9 Postweld heat treatment of fabricated carbon steel and low-alloy (maximum 9 % chromium) steel channels and bonnets shall be performed for the following:

a) channels and bonnets with six or more tube passes;

b) channels and bonnets whose nozzle-to-cylinder internal diameter ratios are 0.5 or greater, except where a conical reducer is used in place of the channel or bonnet.

- **9.6.10** The purchaser shall specify if postweld heat treatment is required for weld-overlaid channels and bonnets.

9.6.11 Postweld heat treatment shall be performed for all carbon steel and low-alloy (maximum 9 % chromium) steel floating-head covers that are fabricated by welding a dished-only head into a ring flange.

- **9.6.12** The purchaser shall specify if postweld heat treatment of shell side or tube side components is required for process reasons.

9.6.13 For sour or wet hydrogen sulfide service, the minimum postweld heat treatment requirements for carbon steel construction shall be in accordance with NACE SP0472. The minimum hold time shall be in accordance with the pressure design code, or 1 h, whichever is greater.

9.7 Dimensional Tolerances

9.7.1 Manufacturing tolerances shall be such that nominally identical parts are interchangeable.

9.7.2 Heat exchangers that will be stacked in series shall be stacked in the shop to check connection alignment.

9.7.3 For stacked heat exchangers, mating nozzle flanges shall not be out-of-parallel with each other by more than 1 mm ($1/32$ in.), measured across any diameter. Separation of mating nozzle flanges shall not exceed 3 mm ($1/8$ in.) after installation of the gasket. Bolts shall be capable of being inserted and removed freely without binding. Shims shall be installed as required between the supports and shall be tack-welded in place.

9.7.4 Flattening tolerances after bending of U-tubes shall not exceed 10 % of the tube outside diameter.

9.8 Gasket Contact Surfaces Other Than Nozzle Flange Facings

9.8.1 Gasket contact surfaces shall have finishes as shown in Table 4.

9.8.2 The flatness tolerance (maximum deviation from a plane) on peripheral gasket contact surfaces shall be 0.8 mm ($1/32$ in.).

9.8.3 The flatness tolerances on peripheral gasket contact surfaces shall be as specified in Table 5 when any of the following apply:

- a) steam service, with operating pressures above 1035 kPa (ga) (150 psig);

Table 4—Gasket Contact Surface Finishes

Type	Surface Roughness R_a^a
Solid flat metal gaskets	1.6 (63) ^b maximum
Double jacketed gaskets	1.6 to 3.2 (63 to 125)
Spiral-wound gaskets	3.2 to 6.3 (125 to 250)
Grooved or corrugated metal gaskets with soft gasket-seal facing	
^a R_a is roughness average.	
^b Dimensions are in micrometers (micro-inches).	

- b) hydrogen service;
- c) operating temperatures above 205 °C (400 °F);
- d) cyclic service;
- e) sour or wet hydrogen sulfide service;
- f) design pressure equal to or greater than 6900 kPa (ga) (1000 psig);
- g) shell diameter greater than 1200 mm (48 in.);
- h) when specified by the purchaser.

Table 5—Flatness Tolerance on Peripheral Gasket Contact Surfaces

Dimensions in millimeters (inches)

Heat Exchanger Nominal Diameter	Tolerance
< 375 (15)	± 0.08 (0.003)
375 to 750 (15 to 30)	± 0.15 (0.006)
751 to 1125 (31 to 45)	± 0.20 (0.008)
> 1125 (45)	± 0.20 (0.008)

9.8.4 The flatness of gasket contact surfaces shall be measured with a dial gauge. However, the flatness of the pass-partition grooves and mating pass-partition plate edges can be measured with a straight edge.

9.8.5 Pass-partition plates and grooves shall be designed and constructed such that they do not inhibit the compression or seating of the peripheral gasket. The difference in height between the pass-partition surface and the peripheral gasket contact surface of the flange face shall be +0.15 mm –0.65 mm (+0.006 in. –0.025 in.).

9.8.6 Flange flatness tolerance and surface finish shall be measured after the flange has been welded to the component cylinder or the cover and after any postweld heat treatment.

9.8.7 The flatness of tubesheet gasket-contact surfaces shall be measured after the tube-to-tubesheet joints have been completed, including any heat treatment.

9.9 Tube Holes

9.9.1 Tube hole grooves shall be square-edged, concentric, and free from burrs.

9.9.2 If austenitic stainless steel, duplex stainless steel, titanium, cupronickel, or nickel alloy tubes are specified, the tube holes shall be machined in accordance with TEMA, Table RCB-7.21, column (b) (Special Close Fit).

9.10 Tube-to-Tubesheet Joints

9.10.1 If roller-expanded joints are utilized, the tube wall thickness reduction shall be in accordance with Table 6.

Table 6—Maximum Allowable Tube Wall Thickness Reduction for Roller-expanded Tube-to-Tubesheet Joints

Material	Maximum Tube Wall Thickness Reduction %
Carbon steel and low-alloy (max. 9 % chromium) steel	8 ^a
Stainless and high alloy steel	6 ^a
Duplex stainless steels	b
Titanium and work hardening nonferrous	5 ^a
Nonferrous non-work hardening (e.g. admiralty brass)	8 ^a
^a These can be increased by a further 2 %, if approved by the purchaser. ^b To be agreed between purchaser and vendor. Tube expansion may increase hardness significantly. For more information, see API TR 938-C.	

9.10.2 If welded-and-expanded joints are specified, tube wall thickness reduction should begin at least 6 mm (1/4 in.) away from welds.

9.10.3 The minimum length of expansion shall be in accordance with TEMA Section 5, Paragraph RCB-7.1. 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** For shell side clad (or weld overlay) tubesheets, the tube shall be expanded to seal against the cladding material for a minimum distance of 6 mm (1/4 in.). The purchaser shall specify if a groove is required within the shell side cladding.

9.10.5 For tube side clad (or weld overlay) tubesheets with either strength-welded or seal-welded and expanded tube-to-tubesheet joints, tube hole grooves, when provided, shall be located in the base material and not in the applied cladding or weld overlay.

9.10.6 For welded-and-expanded tube-to-tubesheet joints requiring postweld heat treatment, the tubes shall be expanded after postweld heat treatment.

9.10.7 Tubes shall be flush with or extended by no more than 5 mm (3/16 in.) beyond the face of the tubesheet, except in vertical exchangers when tubes shall be flush with the top tubesheet, unless otherwise specified by the purchaser.

9.11 Assembly

9.11.1 Match marks or dowels shall be provided to prevent mis-assembly of the following bolted joints:

- a) floating-head cover to tubesheet;
- b) channel to tubesheet;
- c) grooved channel cover to channel;
- d) stationary tubesheet to shell.

9.11.2 The threads of external studs and nuts shall be coated with a suitable anti-seize compound to prevent galling.

10 Inspection and Testing

10.1 Quality Control

10.1.1 For pressure containing welds inspection and testing shall be performed in accordance with the pressure design code. The following additional requirements apply.

- a) At least one spot-radiograph shall be made of each accessible butt-welded joint. Nozzle-to-shell welds are exempt from this requirement, unless required by the pressure design code.
- b) Spot radiographs shall include each start and stop of welds made by the automatic submerged-arc welding process.
- c) Spot radiographs shall be at least 250 mm (10 in.) long or shall be full length if the weld is less than 250 mm (10 in.) long.
- d) Weld porosity limits for spot radiographs shall be as stated in the pressure design code for fully radiographed joints.
- e) 100 % radiographic examination shall be performed on any welded seam in any component that has been subjected to severe working (e.g. a ratio of thickness to local radius greater than 5 %) after welding.
- f) If set-on connections are used and the pressure envelope is plate, after welding of the connections, 100 % ultrasonic examination on the attachment welds and the plate shall be completed for at least 100 mm (4 in.) from the connection.

10.1.2 If set-on connections are used, the edge of the hole in the plate to which the connections are attached shall also be examined by the magnetic-particle or liquid penetrant method prior to welding. Subject to agreement with the purchaser, indications found shall be cleared to sound metal and then repair-welded.

10.1.3 The magnetic-particle examination method, extent, and acceptance criteria shall comply with the pressure design code.

10.1.4 For nonmagnetic materials, a liquid-penetrant examination shall be used in place of any required magnetic-particle examination.

10.1.5 The liquid-penetrant examination method, extent, and acceptance criteria shall comply with the pressure design code.

10.1.6 Production weld-hardness testing of pressure-retaining welds shall be in accordance with the pressure design code, or the following requirements, whichever is the more stringent.

- a) Welds in components made of carbon, Cr-Mo, 11/13/17 % chromium steels, and duplex stainless steels shall be hardness tested. Hardness testing of the heat affected zone shall be conducted if required by the pressure design code, or when specified by the purchaser.
- b) If postweld heat treatment is required, examination shall be made after the post-weld heat treatment is completed.
- c) Unless otherwise agreed between the vendor and purchaser, the weld hardness shall not exceed the values listed in Table 7.

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)	to be agreed with purchaser
Super Duplex Stainless Steel (25 % Cr)	to be agreed with purchaser
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).	

- d) Hardness readings shall be taken with a portable Brinell hardness tester. Other hardness testing techniques can be employed if approved by the purchaser. When access is available, tests shall be performed on the side of the weld in contact with the process fluid.
- e) One longitudinal weld, one circumferential weld, and each connection-to-component weld if the connection is DN 50 (NPS 2) or larger, shall be tested.
- f) If more than one welding procedure is used to fabricate longitudinal or circumferential welds, hardness readings shall be made on welds deposited by each procedure.
- g) Hardness test results and locations shall be recorded.

10.1.7 At welded joints in alloy-clad construction, the weld in the base metal and the area adjacent to the weld where the cladding has been stripped back shall be examined by magnetic-particle or liquid-penetrant inspection before weld overlay of the joint.

10.1.8 All finished carbon steel welds where postweld heat treatment is specified for process reasons (e.g. to prevent environmental cracking), and low-alloy steel welds in all services, shall be examined after postweld heat treatment (unless the pressure design code specifies examination after hydrostatic testing) by the magnetic-particle method. The wet-fluorescent method shall be used to inspect accessible process-wetted surfaces of welds and heat affected zones in sour or wet hydrogen sulfide service.

10.1.9 Final welds in all nonmagnetic materials, whether of solid alloy or alloy-clad plate and all bimetallic welds between nonmagnetic and magnetic materials shall be examined by the liquid-penetrant method after any required postweld heat treatment.

10.1.10 A final visual weld inspection shall be performed after any postweld heat treatment.

10.1.11 After cladding, but prior to fabrication, integrally-clad material shall be subjected to an ultrasonic examination from the clad side in accordance with the pressure design code.

10.1.12 Overlay weldments, back-cladding, and attachment welds to overlay weldments shall be liquid-penetrant examined after any postweld heat treatment.

10.1.13 For duplex stainless steel pressure retaining welds, bimetallic welds using austenitic stainless steel filler metal, and the final weld overlay layer in duplex or austenitic stainless steels, the ferrite content of all accessible completed production welds shall be measured prior to any postweld heat treatment.

10.1.14 For austenitic stainless steel pressure retaining welds, requirements for any ferrite testing shall be specified by the purchaser.

10.1.15 When ferrite testing is applied, a minimum of three tests shall be made on each 1.5 m (5 ft) of weld, with at least three tests made on each circumferential seam, three tests on each longitudinal weld seam, and three tests on each nozzle weld. The acceptance criteria for the minimum and maximum ferrite content shall be agreed between the purchaser and vendor.

- **10.1.16** The purchaser shall specify whether all carbon steel plate in sour or wet hydrogen sulfide service shall be subjected to an ultrasonic lamination check (e.g. to EN 10160 grade S2E2 or ASME SA-578, acceptance level A supplementary requirement S1).

10.1.17 If tube-to-tubesheet joints are roller expanded (not welded), the tube wall thickness reduction shall be randomly checked and recorded. A minimum of 2 % of the joints per tube bundle, with a minimum of 5 joints, shall be checked (see 9.10.1).

10.1.18 When weld deposit overlay is applied on pressure retaining components, production weld chemistry tests shall be performed at the specified depth as follows.

- a) Weld overlay test samples (including weld overlay restoration) shall be taken at a depth of at least 1.5 mm ($1/16$ in.) from the finished surface, unless otherwise specified by the purchaser.
- b) When weld overlay is applied to the surface of exchanger shell or channel cylinders, at least two deposit analyses shall be made for every 10 m² (100 ft²) of overlay surface, or fraction thereof, for each welding procedure applied. The analysis shall be taken from each end of the cylinder at locations that are diametrically opposed.
- c) When weld overlay is applied to the surface of formed heads, channel covers, girth and floating-head flanges and tubesheets, at least one deposit analysis shall be made for each welding procedure used and for each component manufactured.
- d) For tubesheets that are weld overlaid on both sides, at least one deposit analysis is required on each side of the tubesheet.
- e) When weld overlay is applied on nozzle assemblies, at least one deposit analysis shall be made for each welding procedure used. Where multiple nozzle assemblies are manufactured with the same welding procedure, the deposit analysis shall be taken from the smallest diameter nozzle manufactured for each welding procedure.
- f) When weld overlay is applied to restore the clad area of weld joints between integrally clad components, at least one deposit analysis shall be taken per welding procedure for each main longitudinal or circumferential weld seam.

- g) When weld overlay is applied for the surface repair of clad components or for the restoration of surfaces (other than weld seams) where the cladding has been removed, at least one deposit analysis shall be taken for each welding procedure used.
- h) Production test locations shall be restored after testing.

10.2 Pressure Testing

10.2.1 In the case of welded-and-expanded tube-to-tubesheet joints, the tube weld integrity shall be verified before final expansion of the tubes by a pneumatic test from the shell side at a gauge pressure of between 50 kPa (7.5 psi) and 100 kPa (15 psi), using a soap-water solution to identify leaks.

- **10.2.2** If specified by the purchaser, tube-to-tubesheet joint integrity shall be tested after final expansion of the tubes by a helium leak test (e.g. per ASME *BPVC, Section V*). See A.7 for additional guidance.

10.2.3 When pneumatic testing of the tube-to-tubesheet joints from the shell side is not practical (i.e. replacement tube bundles without shells, floating-head exchangers with integral shell heads or without test rings, etc.), the integrity of the tube-to-tubesheet joint can be tested either by a tube side hydrostatic test or by a vacuum test of the tube bundle.

10.2.4 Except for differential-pressure designs, an independent hydrostatic test of the shell side and the tube side shall be performed. The minimum fluid temperature for hydrostatic testing shall be as required by the pressure design code.

10.2.5 The water used for hydrostatic testing shall be potable and the test pressure shall be maintained for at least 1 h.

10.2.6 The chloride content of the test water used for equipment with austenitic stainless steel materials that would be exposed to the test fluid shall not exceed 50 mg/kg (50 parts per million by mass). Upon completion of the hydrostatic test, the equipment shall be promptly drained and cleared of residual test fluid.

- **10.2.7** Any additional requirements for equipment drying or preservation shall be specified by the purchaser.

10.2.8 The shell side hydrostatic test shall be conducted with the bonnet or channel cover removed.

10.2.9 Nozzle reinforcement pads shall be pneumatically tested between 100 kPa (ga) (15 psig) and 170 kPa (ga) (25 psig).

10.2.10 For safety considerations, any supplementary pneumatic test shall be performed at a nominal pressure of 170 kPa (ga) (25 psig).

10.2.11 Flanged joints that have been taken apart after the final pressure test shall be reassembled with new gaskets and re-pressure tested. Self-energizing seals can be reused, subject to approval of the purchaser.

10.2.12 Paint or other external coatings shall not be applied over welds before the final pressure test, unless otherwise agreed by the purchaser.

10.2.13 Heat exchangers that are to be stacked in service with directly interconnecting nozzles shall be hydrostatically tested in the stacked position.

10.3 Nameplates and Stampings

10.3.1 An austenitic stainless steel nameplate shall be permanently attached to the heat exchanger in such a manner that it is visible after insulation has been installed.

10.3.2 The nameplate shall be located on the shell, near the channel end.

10.3.3 The following parts shall be stamped with the manufacturer's serial number:

- a) shell flange;
- b) shell cover flange;
- c) channel or bonnet flange;
- d) channel cover;
- e) stationary tubesheet;
- f) floating tubesheet;
- g) floating-head cover flange;
- h) floating-head backing device;
- i) test ring flange and gland.

11 Preparation for Shipment

11.1 Protection

11.1.1 All liquids used for cleaning or testing shall be drained from heat exchangers before shipment. See A.8.1 for additional information.

11.1.2 Heat exchangers shall be free of foreign matter prior to shipment.

11.1.3 All openings in heat exchangers shall be suitably protected to prevent damage and possible entry of water or other foreign material.

11.1.4 All flange-gasket surfaces shall be coated with an easily removable rust preventative and shall be protected by suitably attached durable covers of such material as wood, plastic, or gasketed steel.

11.1.5 All threaded connections shall be protected by metal plugs or caps of compatible material.

11.1.6 Connections that are beveled for welding shall be suitably covered to protect the bevel from damage.

- **11.1.7** The purchaser shall specify if there are requirements for surface preparation and protection (e.g. painting).

11.1.8 Exposed threads of bolts shall be protected with an easily removable rust preventative to prevent corrosion during testing, shipping, and storage. Tapped holes shall be plugged with grease.

11.1.9 Tie-rods or tie-bars installed on shell expansion joints for protection during shipping shall be painted in a contrasting color and clearly tagged to specify their removal before commissioning.

- **11.1.10** The purchaser shall specify if inert gas (e.g. nitrogen, argon) purge and fill is required. Positive pressure shall be indicated by a pressure gage. Gages shall be suitably protected from damage during transportation. The purchaser shall maintain the positive pressure of the inert gas during storage.

11.1.11 When an inert gas fill is used, the vendor shall apply a label or wired metal tag on all openings that states, "Contents are under <Inert gas> pressure and must be depressurized before opening." All transport regulations must also be complied with.

11.2 Identification

11.2.1 The item number, shipping mass, and purchaser's order number shall be clearly marked on the heat exchanger.

11.2.2 All boxes, crates, or packages shall be identified with the purchaser's order number and the item number.

11.2.3 The words "DO NOT WELD" shall be stenciled (in at least two places 180° apart) on the parts of equipment that have been postweld heat-treated.

12 Supplemental Requirements

12.1 General

- The purchaser shall specify if the additional requirements in Section 12 shall be applied to one or both sides of the heat exchanger. These supplemental requirements should be considered by the purchaser if the cylinder thickness of a heat exchanger component exceeds 50 mm (2 in.) or if the service is considered critical.

12.2 Design

12.2.1 The attachment of welded nozzles and other connections to components shall have integral reinforcement. The nozzles or other connections shall be attached using full-penetration groove weld with additional fillet or butt welds. They can be set-on, set-in, or integrally reinforced forging type inserts. Set-on type connections shall not be welded to plate that contains laminations or other defects and shall only be used if the component is pipe or forged or if the component plates are ultrasonically examined in the area of attachment. In this case the examination for laminations and other defects shall be carried out for a radial distance of at least twice the thickness of the component.

12.2.2 Tubesheet attachment welds to shell or channel cylinders shall be butt welds.

12.3 Examination

12.3.1 All material for formed heads or cylinders exceeding 50 mm (2 in.) in thickness shall be ultrasonically examined. Non-destructive examination procedures and acceptance criteria shall comply with the pressure design code.

12.3.2 All forgings, except standard flanges designed as described in 7.6, shall be ultrasonically examined in accordance with the pressure design code. Non-destructive examination procedures and acceptance criteria shall comply with the pressure design code and shall be agreed by the purchaser.

12.3.3 For ultrasonic examination of welds, plates and forgings, the purchaser shall be supplied with a report providing diagrams of the surfaces scanned and indications obtained, the areas repaired, the nature of defects repaired, and the repair procedures used. The following information shall also be provided:

- a) pulse-echo instrument manufacturer's name and model and the damping control setting;
- b) search unit manufacturer, model, dimensions, and the substance (such as oil or water) that is used to couple the transducer with the material being inspected;
- c) frequency used and the test angle to the component's surface;

d) the wedge medium for angle-beam examination.

12.3.4 Magnetic-particle examination shall be performed on all pressure-containing plate edges and openings before welding. Any defects found shall be removed and any necessary repairs performed. Liquid penetrant examination shall be substituted for nonmagnetic materials.

12.3.5 Magnetic-particle examination shall be performed on all pressure-retaining welds and weld repairs, after any postweld heat treatment. If accessible, the back side of the root pass shall be examined after being prepared for final welding. Both sides of accessible completed welds shall be examined. Liquid penetrant examination shall be substituted for nonmagnetic materials.

12.3.6 Magnetic-particle examination shall be performed on all pressure-boundary attachment welds.

12.3.7 Magnetic-particle examination shall be performed on areas where temporary lugs have been removed. These areas shall be prepared by grinding them before the examination. Liquid penetrant examination shall be substituted for nonmagnetic materials.

12.3.8 After the hydrostatic test, a magnetic-particle examination shall be performed on all external pressure-retaining welds and all internal nozzle welds that are accessible without disassembling the heat exchanger.

12.3.9 For components subject to full radiography, nozzle-attachment welds that cannot be radiographed shall be examined for the presence of cracks by the magnetic-particle method or by the liquid-penetrant method. Examination shall apply to the root pass after back-chipping or after flame-gouging, if applicable, and to the completed weld. Any defects revealed shall be removed before the weld is finished. For liquid-penetrant examination of austenitic stainless steel, neither the penetrant nor the developer shall contain any chlorides.

12.3.10 Full radiographic examination shall be performed on all pressure-retaining butt welds.

12.3.11 Ultrasonic examination shall be performed on all pressure-retaining butt welds for components over 50 mm (2 in.) thick, after any postweld heat treatment. Ultrasonic examination shall comply with the pressure design code. The entire volume of deposited weld metal shall be examined from two directions. Before the welds are examined, the adjacent base material shall be examined by means of longitudinal beam with a 100 % scan for a distance of twice the plate thickness back from the weld. A diagram shall be prepared indicating all areas larger than 12 mm (1/2 in.) in diameter that show a loss of back-reflection of 50 % or more. The acceptance criteria shall be agreed by the purchaser and the vendor.

13 Supplemental Requirements for Services Subject to High Temperature Hydrogen Service (HTHS)

13.1 General

- **13.1.1** The purchaser shall specify if the additional HTHS requirements in Section 13 shall be applied to the shell and/or tube side of the heat exchanger. See A.9 for additional guidance.

13.1.2 The requirements in previous sections of this document that address hydrogen service shall be applied.

13.2 Design Temperature

- **13.2.1** Material selection temperatures for each side subjected to HTHS shall be specified by the purchaser. See A.9.2.1.

13.2.2 Design temperatures shall not vary across a single heat exchanger shell, or from inlet channel to outlet channel of a single heat exchanger, unless otherwise specified by the purchaser. When variable design temperatures are specified, temperature monitoring points shall be provided at the design temperature breaks. See A.9.2.2.

13.2.3 For a heat exchanger unit arranged in series, different design temperatures for each shell shall not be used unless otherwise specified by the purchaser. See A.9.2.2.

13.3 Materials

- **13.3.1** Materials, including pressure-retaining internal components such as tubes, tubesheets, floating heads, and internal bellows, shall be specified by the purchaser in accordance with API RP 941, including any design margins to be applied based on integrity operating window (IOW) limits. See A.9.3 and A.9.4.

13.3.2 When the shell side is in HTHS, the nominal composition of construction of the wetted surfaces shall not vary across a single heat exchanger shell, unless otherwise specified by the purchaser. When the tube side is in HTHS, channels shall be of the same nominal composition unless otherwise specified by the purchaser. When different materials are used, temperature monitoring points shall be provided at the material breaks. See A.9.3.4.

13.3.3 For heat exchangers arranged in series, nominal material composition shall not vary between the different shells, unless specified by the purchaser.

13.4 Connections for Temperature Indication

13.4.1 For a heat exchanger unit arranged in series, where there are varying design temperatures or metallurgy, flanged connections for temperature indication shall be provided in the interconnecting nozzles or interconnecting piping. These connections shall be provided for the side(s) in HTHS. See A.9.5.

- **13.4.2** When specified by the purchaser, skin (metal) temperature-measuring devices, beyond what is required by 13.2.2, shall be provided. The quantity, location, and type of device shall be agreed with the purchaser.

13.5 Fabrication

13.5.1 Weld details used on components in HTHS, including tubesheet to cylinder welds and nozzle assembly butt welds, shall be full-penetration, full-fusion butt welds that can be 100 % volumetrically examined for the entire length.

13.5.2 Nozzle connections for components in HTHS shall be full-penetration, full-fusion welds.

13.5.3 All components constructed of carbon steel shall be post-weld heat treated after completion of fabrication.

13.5.4 Dissimilar metal welds shall not be allowed in a single shell in HTHS, except as allowed in 13.3.2. When dissimilar materials are used, the welding and PWHT procedure shall be agreed between the vendor and purchaser, taking account of the varying microstructure of the weld.

13.6 Inspection and Testing

13.6.1 All materials other than carbon steel used for construction of the pressure retaining envelope and heat transfer tubes shall be verified by positive material identification. The extent and method shall be agreed between purchaser and vendor.

13.6.2 All butt welds shall be 100 % volumetrically examined after any required post-weld heat treatment.

13.6.3 Wet fluorescent magnetic particle examination shall be performed on accessible wetted surfaces, for all carbon or low-alloy steel pressure-retaining welds, after any required post-weld heat treatment. When the component is clad, the base material weld shall be wet fluorescent magnetic particle examined prior to restoration of the cladding. When the minimum required preheat temperature is above the limits of wet fluorescent magnetic particle solution, a dry magnetic particle method may be used prior to the restoration of the cladding.

13.6.4 Production hardness testing for all pressure-retaining welds and heat-affected zones exposed to HTHS shall be performed in accordance with 10.1.6.

- **13.6.5** When specified by the purchaser, welds subject to HTHS shall be provided with baseline UT examination reports. The extent, locations, and type of ultrasonic examination shall be as agreed with the purchaser. See API RP 941, Annex E for ultrasonic examination inspection methods.
- **13.6.6** When specified by the purchaser, clad and weld overlay construction shall be tested for susceptibility to hydrogen disbonding. The testing requirements and acceptance criteria shall be agreed between the purchaser and vendor.

Annex A (informative)

Recommended Practices

A.1 Introduction

This annex has been prepared to give advice to the designer. The advice is offered for guidance only.

The descriptions and the numbers following are those of sections in the main body of this standard.

A.2 General

A.2.1 Cyclic Design—Guidance to 4.9

A.2.1.1 The following is guidance to assist in identifying a potential cyclic service application:

- 20 % variance in normal operating pressure, and/or;
- 20 % variance in process flow rate, and/or;
- variation in normal operating temperature that exceeds 110 °C (200 °F).

One cycle is where the variance occurs in a time frame of less than 24 h and the number of cycles exceeds 12 per year.

NOTE The variation in the normal operating temperature is suggested by API RP 571, Section 4.2.9.3 c), Thermal Fatigue.

A.2.1.2 For assistance in specifying cyclic conditions, it is suggested that the purchaser follow the guidance of ASME *BPVC, Section VIII, Division 2*, and complete a User Design Specification. Methodologies are also available in other pressure design codes, including EN 13445 (all parts).

A.2.1.3 The vendor can use the screening method provided in ASME *BPVC, Section VIII, Division 2*, to determine whether a fatigue analysis is required for the given cyclic loading. If required, rules for performing a full fatigue analysis are included. Methodologies are also available in other pressure design codes including EN 13445 (all parts).

A.2.2 Sour or Wet Hydrogen Sulfide Service—Guidance to 4.10

A.2.2.1 NACE MR0103 establishes material requirements for resistance to sulfide stress cracking (SSC) in sour petroleum refining and related process environments which contain hydrogen sulfide either as a gas or dissolved in an aqueous (liquid-water) phase, with or without the presence of hydrocarbon. SSC is defined as cracking of a metal under the combined action of tensile stress and corrosion in the presence of water and hydrogen sulfide. Other forms of wet hydrogen sulfide cracking, environmental cracking, and severely corrosive and/or hydrogen charging conditions that can lead to failures by mechanisms other than SSC are outside the scope of NACE MR0103.

A.2.2.2 Compared to the high pH environments of refinery sour service, oil and gas production sour environments are covered by NACE MR0175 (all parts). This is because many wet sour streams in oil and gas production facilities also contain carbon dioxide and hence exhibit a lower pH. In addition, chloride ion concentrations tend to be significantly lower in refinery sour services than in oil and gas production sour services.

A.2.2.3 NACE MR0175 (all parts) provides requirements and recommendations for the selection and qualification of metallic materials for service in equipment used in oil and gas production and natural gas processing plants in

hydrogen sulfide containing environments. Mechanisms of cracking that can be caused by hydrogen sulfide include sulfide stress cracking, stress corrosion cracking (SCC), hydrogen-induced cracking (HIC), step-wise cracking (SWC), stress-oriented hydrogen-induced cracking (SOHIC), soft zone cracking (SZC), and galvanically induced hydrogen stress cracking (GHSC).

A.2.2.4 Factors affecting the susceptibility of metallic materials to cracking in oil and gas production facilities in hydrogen sulfide containing environments include the hydrogen sulfide partial pressure, in-situ pH, the concentration of dissolved chlorides or other halides, the presence of elemental sulfur or other oxidants, temperature, galvanic effects, mechanical stress and the duration of contact with a liquid water phase.

A.2.2.5 There are many process service environments which can expose carbon steel materials and weldments to potentially damaging corrosion cracking mechanisms. For some of these environments (including HIC and SOHIC in hydrogen sulfide and amine services) wet fluorescent magnetic-particle testing (WFMT) is the only inspection technique that is considered to be highly effective in managing the material degradation risk during service (for additional guidance see API RP 581).

A.2.2.6 In order to be able to apply the WFMT inspection technique, the inside wetted surface of welds must be accessible to the technician after the heat exchanger has been fabricated. When the shell side fluid service is prone to produce cracking in carbon steel, the following design guidelines can be applied to ensure that the wetted weld surfaces will be accessible for WFMT inspection, both after the initial fabrication and post-weld heat treatment, as well as for future in-service inspections.

- Fixed tubesheet heat exchangers should not be used.
- The minimum shell diameter should be DN 200 (8 NPS).
- For shells with nominal diameters between DN 200 (8 NPS) and DN 600 (24 NPS), the following should apply:
 - rear shell covers should be the removable type;
 - all nozzles should be located at the ends of the shell cylinder;
 - the shell cylinder should be a single length of seamless pipe; rolled plate should only be used if there is sufficient access to the internal surfaces of longitudinal and circumferential welds to allow them to be ground flush.
- Shell side distributor belts should not be used.
- The minimum nozzle size should be DN 50 (2 NPS).
- Nozzles DN 150 (6 NPS) and smaller should be long weld neck type.

A.3 Outline Drawings and Other Supporting Data

A.3.1 Corrosion Allowance—Guidance to 6.1.1 j)

Corrosion allowance should be in accordance with TEMA if not otherwise specified by the purchaser. High alloy materials are often specified with, or assumed to have, a zero corrosion allowance. For these materials, when considering selection of component thickness, adding 0.4 mm ($1/64$ in.) above the pressure design code minimum required thickness might be beneficial to assist fabrication and/or handling.

A.3.2 Flow-induced Vibration—Guidance to 6.1.2

A.3.2.1 Background

The following guidance is to assist the designer in minimizing the risk of damage resulting from flow-induced vibration in a shell-and-tube heat exchanger.

Tubes and the shell side fluid are susceptible to flow-induced vibrations from the unsteady pressures acting on the surfaces of the tubes.

Tube vibration mechanisms in order of their increasing severity are turbulent buffeting, vortex shedding and fluid-elastic instability. Excessive tube vibrations caused by turbulent buffeting or vortex shedding resonances can result in thinning and eventual failure of tubes at the baffles or leaks at the tube-to-tubesheet joints. Fluid elastic instability tends to have a run-away effect; once cross-flow velocities approach a critical velocity the tubes may vibrate uncontrollably and can fail very rapidly.

The shell side may be subjected to acoustic resonances termed “acoustic vibrations.” Acoustic vibrations can vibrate the shell and the exchanger’s foundations, but are more often associated with high levels of radiated sound.

The prediction and control of the vibration response of a shell-and-tube heat exchanger requires the characterization of the system attributes and the excitation.

A.3.2.2 Characterization of the System Attributes

A.3.2.2.1 Tube Characteristics

The natural frequencies of a tube are functions of:

- the modulus of elasticity of the tube material;
- the moment of inertia of the tubular section;
- the number and length of spans;
- the effective tube mass, which includes the mass of the tube, the tube side fluid and a portion of the shell side fluid.

The lowest natural frequency is termed the “fundamental frequency.” In general, higher order natural frequencies are not integer multiples of the fundamental frequency.

In a heat exchanger, vibrational energy dissipation or damping is desirable, but not affected much by conventional design choices. Dampening depends on the fluid density, viscosity, and surface tension, the vapor volume fraction, the tube diameter, number and thickness of tube supports, the tube mass, and the fundamental natural frequency of the tube.

A.3.2.2.2 Shell Side Fluid Volume Characteristics

The natural frequencies of the shell side gas volume are dictated by the speed of sound and the size of the exchanger. The most offending mode is transverse to the longitudinal axes of the tubes and perpendicular to the cross-flow. The wavelength of this mode is twice the shell diameter. As the diameter increases, the resonant frequency of the transverse mode decreases, and opposite sides of the shell approach parallel planes. Both of these effects increase the likelihood of a standing wave. Higher order diametral modes have natural frequencies that are integer multiples of this fundamental frequency. The geometry of the shell also leads to a large number of higher order cylindrical and longitudinal modes that can be problematic in rare circumstances. The speed of sound in a gas filled

exchanger, assuming ideal behavior, is a function of the pressure, the ratio of specific heats, the density, and the geometry of the tube bundle. Sound travels much faster in liquids compared to gases so resonant frequencies are much higher and generally beyond the range of excitation. In two-phase flows, the speed of sound is somewhat ambiguous, but clearly diminished relative to both the all-liquid and all-vapor values; fortunately, the abundance of vapor-liquid interfaces provides acoustic damping.

A.3.2.2.3 Characterization of Excitation

When fluid flows over the tube surfaces, pressures oscillating at the boundary result in unsteady forces that lead to turbulent buffeting. The frequency, content, and intensity of these pressure oscillations is a function of the velocity magnitude and direction and the layout of the tubes. The intensity of the pressure oscillations on the tubes is substantially greater for cross-flow compared to parallel flow.

In cross-flow, the principal excitation frequency is a function of the cross-flow velocity, tube diameter, and the dimensionless Strouhal number. Measurements of Strouhal numbers are available for standard layout angles and pitch ratios. In a nonlinear fluid-structure interaction phenomenon termed "lock-on," the principal frequency of the unsteady pressures on the tube surface will actually tune itself to the fundamental natural frequency of the tube. This high amplitude, resonant response, is termed "vortex shedding" and is primarily a concern in isolated cylinders or possibly tubes on the bundle perimeter. Potentially, the most destructive tube vibration mechanism and thus the principal design concern is fluid-elastic instability. As the cross-flow velocity is increased, the excitation energy may exceed dissipation so that excessive vibration amplitudes result in tube failures (see A.4.1).

Oscillating pressures in the wakes of the tubes can also excite an acoustic resonance of the shell side gas volume. The lock-on phenomenon is possible if the excitation and resonant frequencies are close in value. In this case, the principal frequency of the oscillating pressures can shift to a resonant acoustic frequency as well.

A.3.2.2.4 Vibration Evaluation

Evaluation of the vibration potential requires the determination of several important parameters: tube natural frequencies, acoustic natural frequencies, turbulent buffeting frequency, vortex shedding frequency, acoustic vibration frequency, and the ratio of excitation frequencies to natural frequencies along with the vibration amplitude. Excitation frequencies within a range of $\pm 20\%$ of the natural frequency have "lock-on" potential, and may lead to mechanical or acoustical resonance. Additionally, the critical velocity, which is the threshold for fluid-elastic instability, and the cross-flow velocities at both the mid-span and at the baffle tips are important parameters to understand. Vulnerable tubes can include those at the bundle entrance and exit, at the baffle tips, in the window region (where tubes are supported at every second baffle), and at the bundle perimeter.

It should be noted that vibration analysis is not an exact science and that allowances should be made for uncertainties in some key parameters such as local shell side velocities.

A.3.2.3 Vibration Mitigation

A.3.2.3.1 Tube Vibration Mitigation

At the design stage, excessive tube vibrations can be dampened by shortening the span lengths that increase the natural frequencies of the tubes. Intermediate supports in vulnerable areas like the inlet or the U-bend region can be very effective and have minimal thermal hydraulic effect. The selection of the baffle type, e.g. NTIW (no tube in the window) or rod supports, and adequate baffle spacing, can keep tube vibrations within acceptable limits.

For operating units, tube vibration problems can be addressed by stiffening the tubes with stakes, clips, or inserts of various types. Removing vulnerable tubes, reducing shell side flow rate, and replacing the tube bundle are additional mitigation techniques.

A.3.2.3.2 Acoustic Vibration Mitigation

Deresonating baffles can successfully mitigate acoustic vibration problems by detuning the resonant frequency of the gas volume with respect to the excitation frequencies. The baffles are positioned coplanar with the cross-flow and the axes of the tubes. These baffles partition the shell volume into several smaller volumes of higher natural frequency, provided the baffles have sufficient acoustic impedance (thickness and density). Since the diametral acoustic waves stand across the diameter of the shell, full extension of the deresonating baffles wall-to-wall is unnecessary and can lead to maldistribution. For higher order cylindrical and longitudinal mode resonances, deresonating baffles are also effective since the shell loses its cylindrical symmetry. Multiple, asymmetrically spaced deresonating baffles can mitigate the fundamental transverse diametral wave as several harmonics. However, a misplaced deresonating baffle may tune the system and create a resonant condition.

A.3.3 Design Calculations—Guidance to 6.2.4

In calculating the effective heat transfer area, the purchaser and vendor should agree as to whether the “U” bend region should be included.

A.4 Design

A.4.1 Tube Failure in High Pressure Units—Guidance to 7.5.1.1

The effects of potential overpressure on the low pressure side of the heat exchanger caused by tube rupture should be considered.

In certain extreme circumstances, the large volume of vapor that will be released during a tube failure scenario may lead to excessive size of the relief valve or rupture disk. An option in such a case is to consider using smaller diameter tubes (e.g. 16 mm [⁵/₈ in.]).

NOTE For further information, see API 521.

A.4.2 Transverse Baffles and Support Plates—Guidance to 7.5.3

Segmental baffles are conventional in shell-and-tube heat exchangers, as described in 7.5.3. Alternate types of baffled (or non-baffled) designs can be permitted if agreed with the purchaser.

A.4.3 Tube Bundle Skid Bars—Guidance to 7.5.6

A.4.3.1 For tube bundles with mass and dimensions outside the range of conventional bundle-pulling devices, alternative means of bundle removal should be considered. For example, if the bundle mass exceeds 18,150 kg (40,000 lb), the diameter exceeds 1220 mm (48 in.), or the length exceeds 7.3 m (24 ft), the following options can be considered:

- a) bundle rollers;
- b) skid bars on a rail;
- c) removable shell.

A.4.3.2 Skid bars should not obstruct tube lanes or pass-partition lanes if 45° or 90° tube layouts are used.

A.4.4 Tube-to-Tubesheet Joint—Guidance to 7.5.7

A.4.4.1 If there is potential for crevice corrosion on the shell side, tubes should be expanded to within 3 mm (1/8 in.) from the shell side face of the tubesheet.

A.4.4.2 Where work hardening of the tube material during rolling could result in the potential for environmental cracking, a strength-welded tube-to-tubesheet joint should be applied, and a light expansion (1 % to 3 % wall reduction) should be applied (as per A4.4.1) if crevice corrosion from the shell side fluid is a concern.

A.4.4.3 Strength-welded tube-to-tubesheet joints should be considered by the purchaser for the following conditions.

- a) If the design pressure on either side exceeds 7000 kPa (ga) (1000 psig).
- b) If duplex stainless steel tubes are used in wet hydrogen sulfide service.
- c) If titanium tubes are used (provided the wall thickness is adequate for strength welding).
- d) Where austenitic stainless steel tubes and a ferritic steel tubesheet are used and the metal temperature is above 205 °C (400 °F).
- e) For fixed tubesheet exchangers used in sulfur plant applications (e.g. waste heat exchangers, sulfur condensers, reheaters, acid gas preheaters, etc.).
- f) In heat transfer fluid services with operating temperatures exceeding 205 °C (400 °F).
- g) In cyclic service.
- h) In a service where sudden temperature excursions can occur.
- i) When the f_y ratio of tubesheet *SMYS* to tube *SMYS*, as defined in ASME *BPVC, Section VIII Division 1, Non-Mandatory Appendix A, "Basis for Establishing Allowable Loads for Tube-to-Tubesheet Joints"* is less than 0.6. For clad tubesheets, the tubesheet yield stress used in the calculation of f_y should be that of the base material.

A.4.4.4 Seal-welded or strength-welded tube-to-tubesheet joints should be considered by the purchaser for the following conditions.

- a) Where leakage from the high pressure side to the low pressure side is not acceptable for process reasons (e.g. where contamination of the lower pressure side would be detrimental to the process or pose an unacceptable hazard to utility systems such as steam/condensate or cooling water).
- b) For exchangers handling steam or boiler feed-water at design conditions exceeding class 150 flange rating.

A.4.4.5 For heat exchangers in hydrogen service the tube-to-tubesheet joints should be strength-welded and expanded when either of the following cases apply:

- a) When the design pressure of the exchanger is 7000 kPa (ga) (1000 psig) or higher.
- b) When the design temperature is in excess of 230 °C (450 °F).

A.4.4.6 Tube-to-tubesheet joints for tubesheets with clad or weld overlay on both sides of the tubesheet should be strength-welded to the tube side cladding or weld overlay, and also expanded through the full thickness of the tubesheet to within 3 mm (1/8 in.) of the shell side cladding or weld overlay. Where grooves are used, they should be located in the base metal and not in the shell side cladding or weld overlay.

A.4.4.7 If welded tube-to-tubesheet joints are specified for dissimilar tubes and tubesheet material, weld overlay or cladding should be considered on the tubesheet to eliminate bimetallic welds. The overlay or cladding should have the same metallurgy as the tubes.

A.4.5 Girth Flange Joint Supplementary Design Requirements—Guidance to 7.8

A.4.5.1 Since flanges that have been designed based on allowable stress limits alone may not be sufficiently rigid to control leakage, additional flanged joint design verification in accordance with ASME PCC-1, Appendix O, as outlined in section 7.8, is recommended whenever any of the following conditions apply:

- a) hydrogen service;
- b) maximum operating temperature greater than 186 °C (366 °F);
- c) cyclic service;
- d) sour or wet hydrogen sulfide service;
- e) design pressure equal to or greater than 6900 kPa (ga) (1000 psig);
- f) steam service, with operating pressures above 1035 kPa (ga) (150 psig);
- g) shell diameter greater than 1200 mm (48 in.);
- h) when specified by the purchaser.

A.4.5.2 By the very nature of their design, flanged joint assemblies in heat exchangers can result in operating temperature gradients either around the circumference of a single girth flange, or as a temperature differential between the two flanges that together make up the joint. The effects of these temperature gradients or differences on the design and leak tightness of the flanged joint are not normally considered by conventional pressure vessel code analysis, or by the additional flange analysis that is included in Section 7.8.

Large temperature gradients or differentials should be avoided whenever possible. When it is not possible to do so, additional analysis of the flanged joint may be required in order to assure design adequacy and leak tightness. Additional analysis should be considered when any of the following conditions might exist.

- a) Flanged joints subject to rapid operating temperature changes.
- b) Operating temperature differences between the inlet and outlet nozzles of multi-pass channels which exceed 110 °C (200 °F).
- c) Tubesheet designs employing a gasket on each side of the tubesheet where the operating temperature difference between the channel side and the shell side, at any location, exceed 110 °C (200 °F).

The method of analysis and additional requirements to be applied should be specified or agreed upon with the purchaser.

A.4.5.3 In heat exchangers with stationary or fixed tubesheets and bolted flanges made of dissimilar materials, the selection of solid stainless steel or high alloy tubesheets should be limited to applications where the maximum diametral differential thermal expansion in each pair of tubesheet and flange does not exceed 2.5 mm (0.1 in.), unless otherwise approved by the purchaser.

A.4.6 Gaskets—Guidance to 7.10

Spiral-wound gaskets are not recommended for use in floating-head flanges as the centering rings may result in an increase in the floating head flange diameter, and the shell diameter for pull-through (TEMA T-type) floating heads.

A.4.7 Requirements for Hydrogen Service—Guidance to 7.12

To prevent excessive relaxation of bolting and reduce potential for leaks, girth flanges should not be covered with insulation. Note that the default 0.7 gasket relaxation fraction included in PCC-1 Appendix O may not be valid if bolting is covered with insulation.

A.5 Materials

A.5.1 Gaskets—Guidance to 8.3

When using a gasket containing graphite, it should be considered that it is almost the noblest material in the table of galvanic series. Some metals can be sacrificed when combined with graphite in certain environments. If graphite is to be used in contact with the flange in a service where the fluid contains sulfur, chlorides, halogens, or similar impurities, the purchaser should consider alternate filler or facing materials.

A.6 Fabrication

A.6.1 Shells—Guidance to 9.1

Openings and attachments (including pads and support pads) should clear weld seams by at least 50 mm (2 in.). If this is not possible, the seam weld should be ground flush and radiographed for a distance of 100 mm (4 in.) on either side of the opening or for the full length covered by an attachment plus 100 mm (4 in.) on either side prior to welding the nozzle or attachment to the heat exchanger.

A.7 Pressure Testing—Guidance to 10.3

Helium leak testing should be applied for tube-to-tubesheet joints in hydrogen service with a design pressure greater than 6900 kPa (g) (1000 psig).

A.8 Preparation for Shipment

A.8.1 Protection—Guidance to 11.1

A.8.1.1 If water residues cannot be tolerated, equipment should be dried by one of the following methods.

- a) Blowing dry air or nitrogen, of relative humidity less than 15 % (usually dehumidified), through the heat exchanger and monitoring the outlet air until the relative humidity falls below 30 %.
- b) Evacuating the heat exchanger with a vacuum pump to an absolute pressure of between 0.4 kPa (0.06 psi) and 0.5 kPa (0.075 psi).

A.8.1.2 After draining and drying, internal surfaces can be protected against corrosion by the addition of a desiccant (e.g. silica gel), by the addition of a volatile corrosion inhibitor, or by blanketing with an inert gas such as nitrogen [typically at gauge pressures up to 100 kPa (15 psi)].

A.9 Additional Considerations for Specifying Parameters for High Temperature Hydrogen Service

A.9.1 Introduction

HTHA is a potential material degradation mechanism that can result in surface decarburization, internal decarburization, fissuring, or cracking of carbon and low-alloy steels when subject to high temperature hydrogen service. For more information on HTHA, refer to API RP 571.

A.9.2 Setting Maximum Operating or Design Temperature—Guidance to 13.2

A.9.2.1 Material selection temperatures should be made with considerations made for normal operating conditions, applied safety margins, alternate operating conditions, and non-uniform fouling.

A.9.2.2 Most exchangers in services that are subject to HTHA are also subject to non-uniform fouling where the highest rate of the fouling occurs at the hot end of the process. In practice, design fouling factors used for initial design do not reflect this phenomena, and fouling is applied as uniform across the exchanger. Operating data, if available, should be evaluated for non-uniform fouling trends and be applied to designs in similar services. Where historical data is not available, the designer should consider the effects of higher rates of hot-end fouling when predicting maximum exposure temperatures.

Similarly, if there are heat exchangers in series in high temperature service, designers sometimes assume operating conditions over the life of the plant based on the maximum expected degree of fouling. However, if the hottest exchanger in the series fouls more than expected and no longer cools the process stream sufficiently, the next exchanger(s) in the series might see higher temperatures than it was designed for. It may then become susceptible to HTHA or other damage mechanisms for which the materials of construction may not be suitable. For additional information on damage mechanisms, see API RP 571.

A.9.2.3 Clean exchanger performance should be evaluated in the temperature analysis. When operating in the clean condition, the cold stream would be expected to exit the heat exchanger at temperatures above the expected process operating temperature unless external temperature controls are used.

A.9.2.4 When a hot bypass is required for process conditions (i.e. temperature control around the exchanger), the exchanger on the downstream side of the reintroduction of the bypass of the hot fluid requires detailed analysis to account for the uncooled material flowing through the bypass line. If a flow bypass is not accounted for, the downstream equipment on the hot fluid side may be exposed to unanticipated and undetected material degradation. Analysis of temperatures are required in both clean and fouled operating conditions.

A.9.2.5 When a cold bypass is required for hot stream outlet temperature control, in addition to A.9.2.4, the equipment requires a detailed analysis to account for the additional heating and higher outlet temperature of the cold fluid that passes through the exchanger, prior to remixing with the bypass stream. This can result in the exchanger operating above the material limits since the cooling fluid has been limited. Temperatures should be analyzed in both clean and fouled operating conditions.

A.9.3 Materials Selection for HTHA Services—Guidance to 13.3

A.9.3.1 Materials in contact with the process fluid in HTHS should be selected in accordance with API RP 941. All other applicable damage mechanisms should also be reviewed for the final materials selection. For additional information on damage mechanisms, see API RP 571.

A.9.3.2 All operating modes should be considered to define the temperature and hydrogen partial pressure to be used in selecting materials per API RP 941.

A.9.3.3 A safety margin may be applied when using the API RP 941 curves, primarily due to the fact that the curves are based on experience-based data. This margin can, where available, be based on user experience or practices. If a clad or weld overlaid material is used, the base material should be resistant to the hydrogen conditions, with no credit taken for the cladding or overlay.

A.9.3.4 Material breaks are not recommended for exchangers operating in high temperature hydrogen service.

A.9.3.5 For catalytic reforming feed effluent heat exchangers (commonly known as Texas towers) that typically have shell lengths greater than 15 m (50 ft) and a large operating temperature change from inlet to outlet, a material break in the shell is sometimes used. Operators should monitor the shell temperature by use of redundant temperature indicators located on the hot side of the material break. The location, quantity, and type of temperature indicator, e.g. thermowells or skin temperature, should be specified by the purchaser.

A.9.4 Establishing Integrity Operating Window (IOW) for Services Subject to HTHA—Guidance to 13.3.1

A.9.4.1 The establishment, monitoring, and maintaining of IOWs is a vital component of integrity management to control and prevent material degradation and assist in the exchanger inspection planning process, including risk-based inspection. See API RP 941 and API RP 584.

A.9.4.2 Monitoring of equipment subject to HTHA requires that both chemical and physical operating parameters be examined including operating pressure, hydrogen partial pressure, and temperatures at specific locations of interest based on the exchanger and system design parameters and metallurgy.

A.9.4.3 As HTHA is a time-dependent degradation mechanism, a standard IOW limit is typically applied. If this limit is exceeded over a specified period of time, increased degradation rates or new damage mechanisms could be experienced. Therefore, exceeding standard IOW limits may be acceptable over a specified (limited) period of time. All such cases should be tracked to understand the cumulative effect.

There may be cases where the exchanger mechanical design temperature(s) are higher than the temperatures indicated in the equipment IOWs. Care must be exercised to refer to the IOW temperature limits and not only the mechanical design temperatures when considering operating temperature changes for exchangers in high temperature hydrogen service.

IOW critical limits are also applied; if this limit is exceeded, rapid deterioration could occur. When IOW critical limits are exceeded, an alarm is generated, and immediate action is required to return the process variable(s) to within their IOW.

A.9.4.4 The establishment of IOW parameter limits for new heat exchangers in terms of operating temperature and hydrogen partial pressure for exchangers in HTHS depends upon many factors, including the following:

- a) materials of construction and any heat treatment applied.
- b) previous history of HTHA for the intended service.
- c) safety margins that are applied to the API RP 941 guidelines for the selection of materials.
- d) purchaser's philosophy with respect to allowable duration of short-term exceedances of operating parameters used for material selection, e.g. end of run operation or catalyst sulfiding, etc.
- e) the length of time that equipment will be exposed to extreme or off normal operating conditions.
- f) location and accuracy of temperature monitoring devices with respect to critical locations of temperature and/or materials of construction breaks, including influence of hot/cold stream bypasses.

- g) effectiveness and rigor of the heat exchanger/process monitoring program with respect to being able to accurately predict metal temperatures at specific locations where direct temperature indication is not available, including the consideration of non-linear heat exchanger fouling.

For more information on IOWs, refer to API RP 584.

A.9.5 Intermediate Temperature Connections—Guidance to 13.4

The installation of temperature recording devices is essential for monitoring temperature trends between shells (or channels) of a heat exchanger unit to ensure operating within the IOW limits.

Annex B (informative)

Shell-and-Tube Heat Exchanger Checklist

The checklist (Table B.1) is used to record the specific requirements the purchaser shall make in response to the sections in this standard alongside which bullets (●) are used to indicate that more information is required or it is necessary to make a decision.

Completion of the checklist is the responsibility of the purchaser.

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	
6.1.2	Is vibration analysis to be submitted for review?	Yes	No	
6.2.2	Copies required of applicable welding procedure specifications, procedure qualifications and weld map.	For review	For record	Not required
6.2.5	Copies required of mechanical design calculations for supports, lifting and pulling devices.	For review	For record	Not required
6.3	Specify the format and quantities for the listed final documents.			
7.1.1	Specify the maximum design temperature and a minimum design metal temperature (MDMT) for shell and tube side.			
7.3.6	Specify if supports on the shell shall be analyzed for local stresses. If yes, provide detailed information.	Yes	No	
7.4.11	Specify if girth flanges, channel covers, and floating-head flanges shall be provided with future machining allowance on the gasket contact seating surfaces.	Yes	No	
7.5.2.5	Specify if tubesheets shall be provided with future machining allowance on the gasket contact seating surface.	Yes	No	
7.5.7.3	When strength welds are applied, the degree of expansion and use of grooves shall be specified or agreed.			

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

Section	Item	Requirement	
		Yes	No
7.6.1	Required flange design code.	State flange design code.	
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	Are studded-in bolts permitted for channel and shell external girth joints?	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	Specify if future machining allowance on the girth flange gasket contact seating surface shall be provided.	Yes	No
7.8.1	Specify if the joint component approach per ASME PCC-1, App. O shall be applied to the girth flange design. If yes, shall they be applied to one or both sides of the heat exchanger?	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.		
8.2.3	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.		
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
9.6.2	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 postweld heat treatment of weld-overlaid channels and bonnets is required.	Yes	No
9.6.12	Is postweld heat treatment required for process reasons on the shell side?	Yes	No
	Is postweld heat treatment required for process reasons on the tube side?	Yes	No

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

Section	Item	Requirement	
		Yes	No
9.10.4	Is a groove required within the shell side tubesheet cladding?	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
10.2.2	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
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
13.1.1	Are the additional requirements specified in Section 13 required for the shell side?	Yes	No
	Are the additional requirements specified in Section 13 required for the tube side?	Yes	No
13.2.1	Specify the design temperatures for each side subjected to HTHS.		
13.3.1	Specify if the nominal composition of construction of the wetted surfaces of either, or both, the shell side and tube side vary. If yes, provide detailed information.	Either	Both
13.4.2	Specify if skin (metal) temperature measuring devices are required. If yes, detailed information to be agreed.	Yes	No
13.6.5	Specify if welds shall be provided with baseline UT examination reports. If yes, detailed information to be agreed.	Yes	No
13.6.6	Specify if clad or weld overlay construction shall be tested for hydrogen disbonding. If yes, provide detailed information.	Yes	No

Annex C (informative)

Shell-and-Tube Heat Exchanger Datasheets ⁵

The following datasheets are provided to assist the designer, vendor, and purchaser to specify the data necessary for the design of a shell-and-tube heat exchanger for petroleum, petrochemical and natural gas services.

Completion of the datasheet is a joint responsibility of the purchaser and vendor. The purchaser (owner or contractor) is responsible for the process data, which define the purchaser's explicit requirements.

After the exchanger has been fabricated, the vendor should complete the datasheets to make a permanent record that accurately describes the equipment "as-built."

Additional datasheets may be required to define the shell-and-tube heat exchanger and examples are included in Figure C.1 and Figure C.2.

- Connection schedule (see page 2 of Figure C.1 and Figure C.2), materials of construction (see page 2 of Figure C.1 and Figure C.2): gaskets (see page 2 of Figure C.1 and Figure C.2). These are used if the designer/user requires such level of detail to define materials for individual components. These sections may not be necessary if page one defines the information sufficiently.
- Additional information, remarks, sketches, etc. (see page 3 of Figure C.1 and Figure C.2). These are used for additional remarks if sufficient space is not available on pages 1 or 2. These are also used for schematic sketches to illustrate required features of the design and tube layouts, if necessary, to provide this information to the manufacturer.
- Additional process information (see page 4 of Figure C.1 and Figure C.2). One or two pages can be necessary if boiling and/or condensing fluids with ranges of physical properties occur.
- Additional process information for thermal expansion design conditions (see page 5 of Figure C.1 and Figure C.2). This is required only for exchangers such as fixed tubesheet or single-pass floating-head type exchangers where thermal expansion must be considered for the mechanical design. This optional page should be included if operating information is supplied to the designer for determination of the metal temperatures necessary for expansion joint reviews.
- Additional cyclic service design data (see page 6 of Figure C.1 and Figure C.2). This is required only for exchangers where the unit is subject to cyclic service.

⁵ Users of this Annex should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein. Where applicable, authorities having jurisdiction should be consulted.

Company		SHELL-AND-TUBE HEAT EXCHANGER			Engineering contractor		
DATA SHEET (SI UNITS)							
P.O. No.:		Doc. No.:			Page 1 of		
1 Client:		Location:					
2 Process unit:		Item No.:					
3 Job No.:		Fabricator:					
4 Service of unit:				No. of units:			
5 Size:		TEMA Type:		Connected in:		Parallel Series	
6 Effective surface per unit (plain/finned):			m	Shells/unit:		Effective surface per shell: m ²	
7 PERFORMANCE OF ONE UNIT				SHELL SIDE		TUBE SIDE	
				Inlet		Outlet	
8 Fluid name:							
9 Fluid quantity, total:		kg/h					
10 Vapor (relative molecular mass):		kg/h					
11 Liquid:		kg/h					
12 Steam:		kg/h					
13 Water:		kg/h					
14 Non-condensable (relative molecular mass):		kg/h		/		/	
15 Temperature:		°C					
16 Density (vapor/liquid):		kg/m ³					
17 Viscosity (vapor/liquid):		mPa·s					
18 Specific heat (vapor/liquid):		kJ/(kg·K)					
19 Thermal conductivity (vapor/liquid):		W/(m·K)					
20 Specific latent heat:		kJ/kg @ °C		@		@	
21 Inlet pressure:		kPa (ga)					
22 Velocity:		m/s					
23 Pressure drop (allowable/calculated):		kPa		/		/	
24 Fouling resistance:		m ² ·K/W					
25 Average film coefficient:		W/(m ² ·K)					
26 Heat exchanged:		kW		Mean temperature difference (MTD): °C		corrected/weighted	
27 Heat transfer rate:		W/(m ² ·K)		Required:		Fouled: Clean:	
28 pV ² :		kg/(m ² ·s ²)		Inlet nozzle:		Bundle entrance: Bundle exit:	
29 Hydrogen Service:		Tube Side (Y/N) Shell Side (Y/N)		Sour Service: Tube Side (Y/N) Shell Side (Y/N)		Cyclic Service: (Y/N)	
31 CONSTRUCTION PER SHELL							
32 Tube Number:		OD: mm		NOZZLES – Number, Size and Rating			
33 Tube Wall Thickness:		mm		minimum wall/average wall		SHELL SIDE TUBE SIDE	
34 Tube Pitch:		mm		Tube layout:		Inlet: Outlet:	
35 Tube Length:		m		Tube type: plain/finned/other			
36 Tube to tubesheet joint:				Intermediate:			
37 Shell diameter:		mm (ID/OD)		/		Vent: Drain:	
38 Cross-baffle type:				Pressure relief:			
39 Baffle Spacing: c/c		mm		No. of cross passes:			
40 Baffle Cut:		%		vertical/horizontal		Design pressure: kPa (ga)	
41 Tube support type:				Vacuum: kPa (abs)			
42 Longitudinal baffle seal type:				Design temp. (Max/MDMT): °C		/ /	
43 Bypass seal type:				Number of passes per shell:			
44 Impingement protection: (Y/N)		Type:		Corrosion allowance: mm			
45 MATERIALS OF CONSTRUCTION							
46 Shell:		Tubes:		GASKETS			
47 Shell cover:				Shell side:			
48 Channel or bonnet:				Tube side:			
49 Channel cover:				Floating head:			
50 Floating head cover/bolts:				Spare Gaskets required:			
51 Tubesheet: Stationary:		Floating:		Test ring required: (Y/N)			
52 Baffles: Cross:		Longitudinal:		Insulation - shell: mm			
53 Tube support material:				Insulation - channel: mm inlet/outlet			
54 Expansion joint type:				Expansion joint material:			
55 Pressure design code:		Stamp:		Calculate MAWP: (Y/N)		TEMA Class:	
56 REMARKS:							
57							
58							
Rev. No.		Description		Date		Prepared by Reviewed by	

Company		SHELL-AND-TUBE HEAT EXCHANGER CONNECTIONS AND MATERIALS DATA SHEET (SI UNITS)			Engineering contractor	
P.O. No.:		Doc. No.:			Page 2 of	
1 Client:		Location:				
2 Process unit:		Item No.:				
3 Job No.:		Fabricator:				
CONNECTION SCHEDULE (Optional)						
Mark	Number required	Size	Rating	Facing	Description	
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16					Chemical Cleaning	
MATERIALS OF CONSTRUCTION (Optional)						Corrosion allowance
17 Shell:						mm
19 Head:						mm
20 Pipe/stub ends:						mm
21 Nozzle necks:						mm
22 Nozzle flanges:						mm
23 Body flanges:						mm
24 Expansion joint:						mm
25 Support:						mm
26 Bolting (internal):						mm
27 Bolting (external):						mm
28 Nozzle reinforcement:						mm
29 Tubes:						
30 Tubesheets:						mm
31 Bonnet/channel:						mm
32 Bonnet head(s):						mm
33 Channel cover(s):						mm
34 Body flanges:						mm
35 Pipe/stub ends:						mm
36 Bolting (internal):						mm
37 Bolting (external):						mm
38 Nozzle reinforcement:						mm
39 Nozzle necks:						mm
40 Nozzle flanges:						mm
41 Baffles, spacers, tie rods:						mm
42						
43						
44						
45						
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47						
48						
GASKETS (Optional)				MECHANICAL DATA (Optional)		
50 Shell side:		Thickness: mm		MAWP (hot and corroded): kPa (ga)		
51 Y =		Pa		m =		MAP (new and cold): kPa (ga)
52 Tube side:		Thickness: mm		Hydrotest pressure:		
53 Y =		Pa		m =		Field: kPa (ga) Shop: kPa (ga)
54 Floating head:		Thickness: mm		Mass:	Empty: kg	Bundle: kg
55 Y =		Pa		m =		Full of water: kg
Rev. No.		Revision		Date		Prepared by
						Reviewed by

Company	SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL INFORMATION DATA SHEET (SI UNITS)	Engineering contractor
P.O. No.:	Doc. No.:	Page 3 of
1 Client:	Location:	
2 Process unit:	Item No.:	
3 Job No.:	Fabricator:	
4	ADDITIONAL REMARKS, SKETCHES, ETC. (Optional)	
5		
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Rev. No.	Revision	Date
		Prepared by
		Reviewed by

Company	SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (SI UNITS)	Engineering Contractor
P.O. No.:	Doc. No.:	Page 4 of
1 Client:	Location:	
2 Process unit:	Item No.:	
3 Job No.:	Fabricator:	
4		
5		
6		
7		
8		
9 Fluid Name: _____ Reference Pressure 1: _____ kPa (abs)	Heat Release Curve	
10 Pressure Temp. Enthalpy Vapor Mass		
11 kPa (abs) °C kJ/kg Fraction		
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26 Density Density Viscosity Viscosity Thermal Thermal Sp. Heat Sp. Heat Surface Liquid Liquid		
27 Vapor Liquid Vapor Liquid Cond. Vap. Cond. Liq. Vapor Liquid Tension Crit. Press. Crit. Press.		
28 kg/m³ kg/m³ mPa s mPa s W/m-°K W/m-°K kJ/kg-°K kJ/kg-°K N/m kPa (abs) °C		
29		
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37		
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39		
40		
41 Fluid Name: _____ Reference Pressure 1: _____ kPa (abs)	Heat Release Curve	
42 Pressure Temp. Enthalpy Vapor Mass		
43 kPa (abs) °C kJ/kg Fraction		
44		
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46		
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58 Density Density Viscosity Viscosity Thermal Thermal Sp. Heat Sp. Heat Surface Liquid Liquid		
59 Vapor Liquid Vapor Liquid Cond. Vap. Cond. Liq. Vapor Liquid Tension Crit. Press. Crit. Press.		
60 kg/m³ kg/m³ mPa s mPa s W/m-°K W/m-°K kJ/kg-°K kJ/kg-°K N/m kPa (abs) °C		
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Company	SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (SI UNITS)				Engineering contractor
P.O. No.:	Doc. No.:			Page 5 of	
1 Client:	Location:				
2 Process unit:	Item No.:				
3 Job No.:	Fabricator:				
4					
5					
6					
7	DESIGN CONDITIONS FOR EXPANSION JOINT (Optional)				
8					
9					
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21					
22	Determine the mean shell and tube metal temperatures at the listed cases. Evaluate the need for an expansion joint based on the metal temperatures at these conditions with either or both sides clean or with specified fouling.				
23	Unless otherwise stated, operation in accordance with the recommendations of the TEMA Standards, paragraph E3.2, "Operating Procedures", is assumed.				
24	^a A case which may affect design (e.g. steam-out, upset, etc.).				
25	^b F = flowing (specify flow rate), S= stagnant, E = empty.				
26	^c Outlet temperature if known, thermal designer determines for other conditions.				
27	^d Specify design pressure for operating conditions. Use maximum actual pressure at other conditions.				
28	^e Mean metal temperature to be specified by thermal designer.				
29	^f Number of cycles that will occur during life of the exchanger for each case.				
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Company		SHELL-AND-TUBE HEAT EXCHANGER			Engineering contractor		
DATA SHEET (US CUSTOMARY UNITS)							
P.O. No.:		Doc. No.:			Page 1 of		
1	Client:			Location:			
2	Process unit:			Item No.:			
3	Job No.:			Fabricator:			
4	Service of unit:			No. of units:			
5	Size:	TEMA Type:		Connected in:		Parallel Series	
6	Effective surface per unit (plain/finned):		ft ²	Shells/unit:	Effective surface per shell: ft ²		
7	PERFORMANCE OF ONE UNIT			SHELL SIDE		TUBE SIDE	
8				Inlet	Outlet	Inlet	Outlet
9	Fluid name:			lb/h			
10	Fluid quantity, total:			lb/h			
11	Vapor (relative molecular mass):			lb/h			
12	Liquid:			lb/h			
13	Steam:			lb/h			
14	Water:			lb/h			
15	Non-condensable / relative molecular mass:			lb/h		/	
16	Temperature:			°F			
17	Density (vapor/liquid):			lb/ft ³			
18	Viscosity (vapor/liquid):			cP			
19	Specific heat (vapor/liquid):			Btu/(lb·°F)			
20	Thermal conductivity (vapor/liquid):			Btu/(h·ft·°F)			
21	Specific latent heat:			Btu/lb @ °F		@	
22	Inlet pressure:			psig			
23	Velocity:			ft/s			
24	Pressure drop (allowable/calculated):			psi		/	
25	Fouling resistance:			h·ft ² ·°F/Btu			
26	Average film coefficient:			Btu/(h·ft ² ·°F)			
27	Heat exchanged:			Btu/h		Mean temperature difference (MTD): °F corrected/weighted	
28	Heat transfer rate:		Btu/(h·ft ² ·°F)	Required:		Fouled: Clean:	
29	pV ² :		lb/(ft·s ²)	Inlet nozzle:		Bundle entrance: Bundle exit:	
30	Hydrogen Service:		Tube Side (Y/N) Shell Side (Y/N)	Sour Service:		Tube Side (Y/N) Shell Side (Y/N)	Cyclic Service: (Y/N)
31	CONSTRUCTION PER SHELL						
32	Tube Number:		OD:	in		NOZZLES – Number, Size and Rating	
33	Tube Wall Thickness:		in	minimum wall/average wall		SHELL SIDE TUBE SIDE	
34	Tube Pitch:		in	Tube layout:		Inlet: Outlet:	
35	Tube Length:		ft	Tube type: plain/finned/other		Intermediate: Vent: Drain:	
36	Tube to tubesheet joint:						
37	Shell diameter:		in (ID/OD)	/			
38	Cross-baffle type:						
39	Baffle Spacing: c/c		in	No. of cross passes:		Pressure relief:	
40	Baffle Cut:		%	vertical/horizontal		Design pressure: psig	
41	Tube support type:			Vacuum: psia			
42	Longitudinal baffle seal type:			Design temp. (Max/MDMT): °F / /			
43	Bypass seal type:			Number of passes per shell:			
44	Impingement protection:		(Y/N) Type:			Corrosion allowance: in	
45	MATERIALS OF CONSTRUCTION						
46	Shell:		Tubes:		GASKETS		
47	Shell cover:			Shell side:			
48	Channel or bonnet:			Tube side:			
49	Channel cover:			Floating head:			
50	Floating head cover/bolts:			Spare Gaskets required:			
51	Tubesheet: Stationary:		Floating:		Test ring required: (Y/N)		
52	Baffles: Cross:		Longitudinal:		Insulation - shell: in		
53	Tube support material:			Insulation - channel: in inlet/outlet			
54	Expansion joint type:			Expansion joint material:			
55	Pressure design code:		Stamp:		Calculate MAWP: (Y/N)		TEMA Class:
56	REMARKS:						
57							
58							
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Company		SHELL-AND-TUBE HEAT EXCHANGER CONNECTIONS AND MATERIALS DATA SHEET (US CUSTOMARY UNITS)			Engineering contractor	
P.O. No.:		Doc. No.:			Page 2 of	
1	Client:			Location:		
2	Process unit:			Item No.:		
3	Job No.:			Fabricator:		
4	CONNECTION SCHEDULE (Optional)					
	Mark	Number required	Size	Rating	Facing	Description
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						Chemical cleaning
16	MATERIALS OF CONSTRUCTION (Optional)					Corrosion allowance
17	Density (vapor/liquid):					in
18	Viscosity (va Head):					in
19	Specific heat Pipe/stub ends:					in
20	Thermal con: Nozzle necks:					in
21	Nozzle flanges:					in
22	Body flanges:					in
23	Expansion joint:					in
24	Support:					in
25	Bolting (internal):					in
26	Bolting (external):					in
27	Nozzle reinforcement:					in
28	Tubes:					
29	Tubesheets:					in
30	Bonnet/channel:					in
31	Bonnet head(s):					in
32	Channel cover(s):					in
33	Body flanges:					in
34	Pipe/stub ends:					in
35	Bolting (internal):					in
36	Bolting (external):					in
37	Nozzle reinforcement:					in
38	Nozzle necks:					in
39	Nozzle flanges:					in
40	Baffles, spacers, tie rods:					in
41						
42						
43						
44						
45						
46						
47						
48	GASKETS (Optional)			MECHANICAL DATA (Optional)		
49	Shell side:	Thickness:	in	MAWP (hot and corroded):	psig	
50	Y =	psi	m =	MAP (new and cold):	psig	
51	Tube side:	Thickness:	in	Hydrotest pressure:		
52	Y =	psi	m =	Field:	psig	Shop: psig
53	Floating head:	Thickness:	in	Mass: Empty:	lb	Bundle: lb
54	Y =	psi	m =	Full of water:	lb	
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Company	SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL INFORMATION DATA SHEET (US CUSTOMARY UNITS)	Engineering contractor		
P.O. No.:	Doc. No.:	Page 3 of		
1 Client:	Location:			
2 Process unit:	Item No.:			
3 Job No.:	Fabricator:			
4	ADDITIONAL REMARKS, SKETCHES, ETC. (Optional)			
5	<div style="margin-left: 40px;">Vapor (relative molecular mass):</div>			
6				
7				
8				
9				
10				
11				
12				
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14				
15				
16				
17 Density (vapor/liquid):				
18 Viscosity (vapor/liquid):				
19 Specific heat (vapor/liquid):				
20 Thermal conductivity (vapor/liquid):				
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Company	SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (US CUSTOMARY UNITS)	Engineering Contractor
P.O. No.:	Doc. No.:	Page 4 of
1 Client:	Location:	
2 Process unit:	Item No.:	
3 Job No.:	Fabricator:	
4		
5		
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7		
8		
9 Fluid Name: _____ Reference Pressure 1: _____ psia	Heat Release Curve	
10 Pressure _____ Temp. _____ Enthalpy _____ Vapor Mass		
11 Vapor (relative to °F) _____		
12		
13		
14		
15		
16		
17		
18		
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20		
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23		
24		
25		
26 Density _____ Density _____ Viscosity _____ Viscosity _____ Thermal _____ Thermal _____ Sp. Heat _____ Sp. Heat _____ Surface _____ Liquid _____ Liquid _____		
27 Vapor _____ Liquid _____ Vapor _____ Liquid _____ Cond. Vap. _____ Cond. Liq. _____ Vapor _____ Liquid _____ Tension _____ Crit. Press. _____ Crit. Press. _____		
28 lb/ft ³ _____ lb/ft ³ _____ cP _____ cP _____ Btu/h-ft ² -°F _____ Btu/h-ft ² -°F _____ Btu/lb-°F _____ Btu/lb-°F _____ dyne/cm _____ psia _____ °F _____		
29		
30		
31		
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41 Fluid Name: _____ Reference Pressure 1: _____ psia	Heat Release Curve	
42 Pressure _____ Temp. _____ Enthalpy _____ Vapor Mass		
43 psia _____ °F _____ Btu/lb _____ Fraction _____		
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58 Density _____ Density _____ Viscosity _____ Viscosity _____ Thermal _____ Thermal _____ Sp. Heat _____ Sp. Heat _____ Surface _____ Liquid _____ Liquid _____		
59 Vapor _____ Liquid _____ Vapor _____ Liquid _____ Cond. Vap. _____ Cond. Liq. _____ Vapor _____ Liquid _____ Tension _____ Crit. Press. _____ Crit. Press. _____		
60 lb/ft ³ _____ lb/ft ³ _____ cP _____ cP _____ Btu/h-ft ² -°F _____ Btu/h-ft ² -°F _____ Btu/lb-°F _____ Btu/lb-°F _____ dyne/cm _____ psia _____ °F _____		
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Company		SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (US CUSTOMARY UNITS)				Engineering contractor						
P.O. No.:		Doc. No.:				Page 5 of						
1	Client:				Location:							
2	Process unit:				Item No.:							
3	Job No.:				Fabricator:							
4												
5												
6												
7	DESIGN CONDITIONS FOR EXPANSION JOINT (Optional)											
8	Case ^a	SHELL SIDE				TUBE SIDE						
9		Flow condition ^b	Fluid temperature		Pressure ^d	Mean metal temp. ^e	Number of cycles ^f	Flow condition ^b	Fluid temperature		Pressure ^d	Mean metal temp. ^e
10	Vapor (relative molecular mass):	Inlet °F	Outlet ^c °F	psig	°F		Inlet °F	Outlet ^c °F	psig	°F		
11												
12												
13												
14												
15												
16												
17	Density (vapor/ liquid):											
18	Viscosity (vapor/ liquid):											
19	Specific heat (vapor/ liquid):											
20	Thermal conductivity (vapor/ liquid):											
21												
22	Determine the mean shell and tube metal temperatures at the listed cases. Evaluate the need for an expansion joint based on the metal temperatures at these conditions with either or both sides clean or with specified fouling.											
23	Unless otherwise stated, operation in accordance with the recommendations of the TEMA Standards, paragraph E3.2, "Operating Procedures", is assumed.											
24	^a A case which may affect design (e.g. steam-out, upset, etc.).											
25	^b F = flowing (specify flow rate), S= stagnant, E = empty.											
26	^c Outlet temperature if known, thermal designer determines for other conditions.											
27	^d Specify design pressure for operating conditions. Use maximum actual pressure at other conditions.											
28	^e Mean metal temperature to be specified by thermal designer.											
29	^f Number of cycles that will occur during life of the exchanger for each case.											
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Company	SHELL-AND-TUBE HEAT EXCHANGER CYCLIC SERVICE INFORMATION DATA SHEET (US CUSTOMARY UNITS)	Engineering Contractor
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1	Client:	Location:
2	Process unit:	Item No.:
3	Job No.:	Fabricator:

Description of Cyclic Service Operation

	Condition	Time (h/m)	Duration (h/m)	Composition	Flow Rate (lb/h)
10	Vapor (relative m				
11	Initial	0.0			
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					

	Condition	Time (h/m)	Duration (h/m)	Temperature (°F)	Pressure (psig)
32	Vapor (relative m				
33	Initial	0.0			
34					
35					
36					
37					
38					
39					
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41					
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⁶ European Committee for Standardization (CEN-CENELEC), Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.

⁷ The Welding Research Council, P.O. Box 201547, Shaker Heights, Ohio 44122, www.forengineers.org.

⁸ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.



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