

Hairpin Type Heat Exchangers

API STANDARD 663
SECOND EDITION, AUGUST 2022



American
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May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

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Introduction

Users of this standard should be aware that further or differing requirements may 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 an innovative or developing technology. Where an alternative is offered, it is the responsibility of the vendor to 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 or subsection 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.

Hairpin Type Heat Exchangers

1 Scope

This standard specifies requirements and gives recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation for shipment of hairpin heat exchangers for use in the petroleum, petrochemical, and natural gas industries. Hairpin heat exchangers include double-pipe and multi-tube heat exchangers.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

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

API Standard 521, *Pressure-relieving and Depressuring Systems*

API Technical Report 938-C, *Use of Duplex Stainless Steels in the Oil Refining Industry*

ASME B16.25,¹ *Butt welding Ends*

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

NACE MR0103,² *Petroleum, Petrochemical and Natural Gas Industries—Metallic 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*

TEMA,³ *Standards of the Tubular Exchanger Manufacturers Association*, Tenth Edition

3 Terms and Definitions

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

3.1

annular distributor

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

3.2

cyclic service

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

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

² NACE International (formerly the National Association of Corrosion Engineers), 15835 Park Ten Place, Houston, Texas 77084, U.S.A., www.nace.org.

³ Tubular Exchanger Manufacturers Association, 25 North Broadway, Tarrytown, New York 10591, U.S.A., www.tema.org.

3.3

double-pipe

Hairpin heat exchanger consisting of a single pipe (or tube) within a shell.

3.4

effective heat transfer area

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

3.5

front closure

Closure that connects the tube side to purchaser's tube side piping and fixes the tube bundle or tube element to the shell.

3.6

full-penetration weld

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

3.7

hairpin heat exchanger

Double-pipe (pipe-in-pipe) or multi-tube heat exchanger of two-leg bundle where each leg has its own separate shell.

NOTE Figure 1 shows typical components of a hairpin heat exchanger.

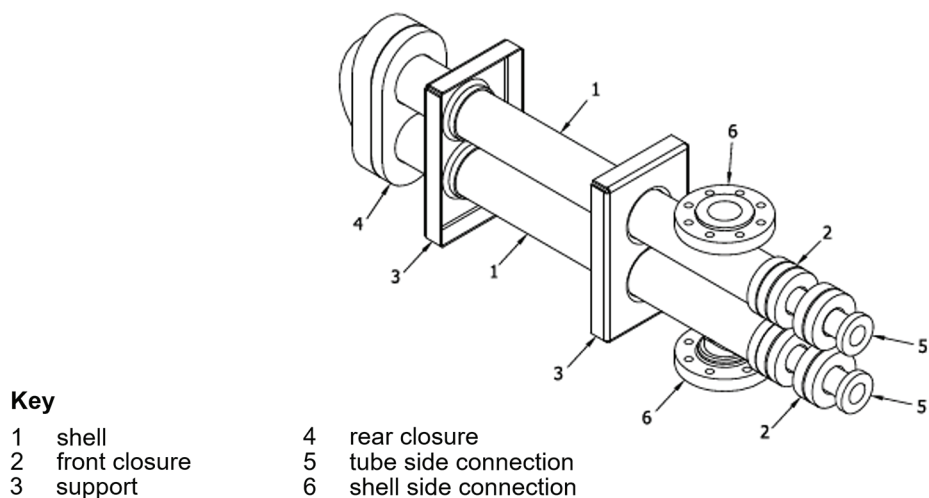


Figure 1—Typical Components of a Hairpin Heat Exchanger

3.8

hairpin section

One U-tube bundle or element with two shell legs.

3.9

heat exchanger unit

One or more hairpin sections arranged in series or parallel for a specified service that work together to perform the intended duty.

3.10

high temperature hydrogen attack

HTHA

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.

3.11**high temperature hydrogen service****HTHS**

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

3.12**hydrogen service**

Service that contains hydrogen at a partial pressure greater than 350 kPa (50 psi) absolute.

3.13**item number**

Purchaser's identification number for a hairpin heat exchanger.

3.14**minimum design metal temperature****MDMT**

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

EXAMPLE Ambient temperature or process fluid temperature.

3.15**multi-tube**

Hairpin heat exchanger consisting of multiple tubes within a shell.

3.16**pressure design code**

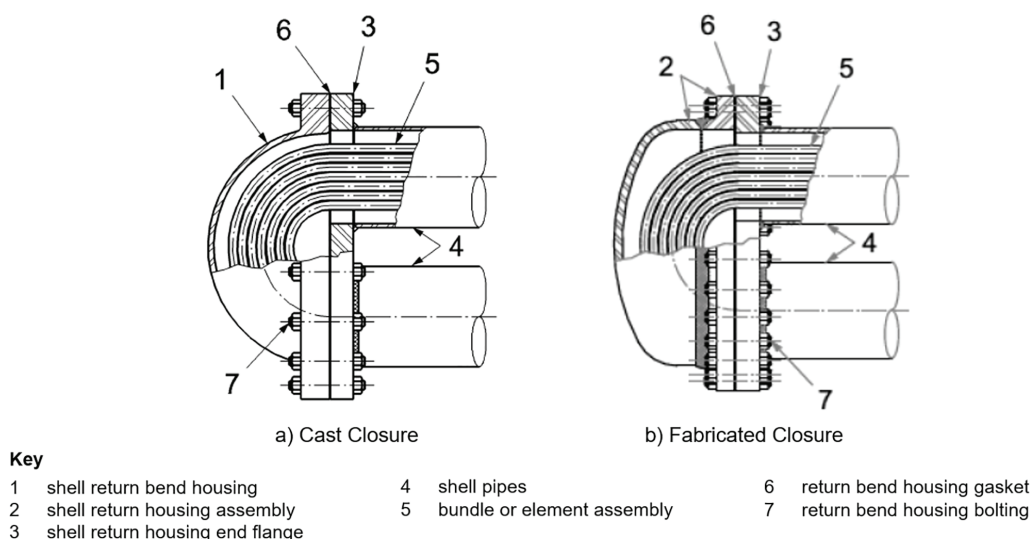
Recognized pressure vessel standard specified or agreed to by the purchaser.

EXAMPLE ASME BPVC, Section VIII, Division 1; EN 13445 (all parts).

3.17**rear closure**

Closure used at the return end of the heat exchanger.

NOTE Figure 2 shows a typical rear closure.



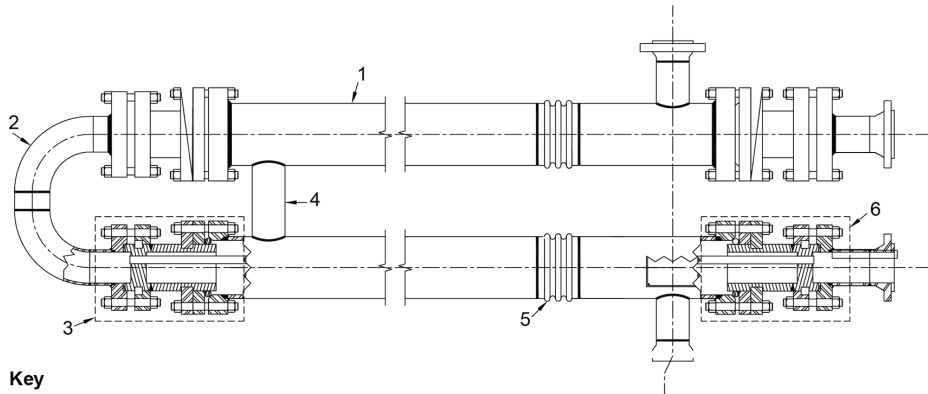
NOTE These are only two typical configurations for removable rear closures. Other configurations are equally acceptable. For nonremovable rear closures flanges, bolting and gaskets are eliminated.

Figure 2—Typical Rear Closures

3.18**rod-through closure**

Rear closure type using straight tubes and tubesheets/closures at the return end of each shell leg.

NOTE Figure 3 shows a typical rod-through closure exchanger.

**Key**

- 1 shell
- 2 tube side cross-over assembly
- 3 rear closure (typical closure assembly shown but may vary depending upon the unit configuration and fabricator)
- 4 shell side cross-over connection
- 5 expansion joint (if required)
- 6 front closure (typical closure assembly shown but may vary depending upon the unit configuration and fabricator)

NOTE 1 These are typically used only when straight tubes are required which may or may not have an expansion joint.

NOTE 2 Restraint details that are used to protect the expansion joint during hydrostatic test and shipping/handling are not shown.

Figure 3—Typical Rod-through Rear Closure

3.19**sealing ring**

Special gasket that provides a seal on the OD of tubesheet and the shell/tube side flange.

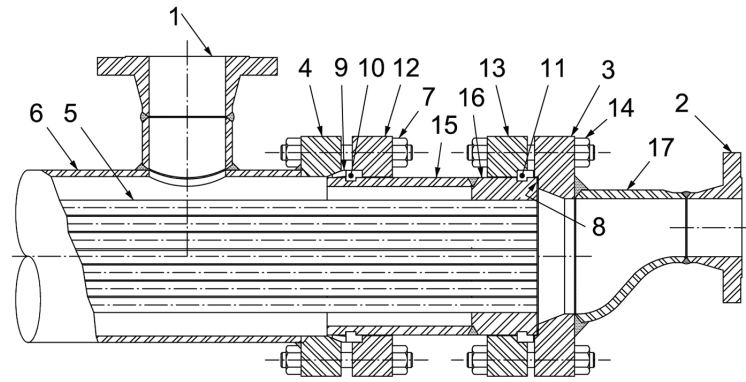
3.20**seal-welded**

Weld of unspecified strength applied between the tubes and tubesheet for the sole purpose of reducing the potential for leakage.

3.21**separated head front closure**

Closure using independent sets of bolting for the shell and tube side closure gasket seating.

NOTE Figure 4 shows a typical separated head front closure.

**Key**

1	shell side nozzle flange	7	shell closure bolting	13	tube fitting flange
2	tube side nozzle flange	8	tube side gasket	14	tube closure bolting
3	tube side flange	9	sealing ring	15	tubesheet skirt
4	shell side end flange	10	shell closure split ring	16	tubesheet
5	tube bundle or element	11	tube closure split ring	17	reducer
6	shell pipe	12	compression flange		

NOTE This is a typical configuration for removable type bundles. Other configurations are equally acceptable, e.g. the front closure can have a concentric reducer, an eccentric reducer orientated flat-bottom or no reducer at all. Similarly, key item 2 can be absent with the joint being a simple butt-welded preparation.

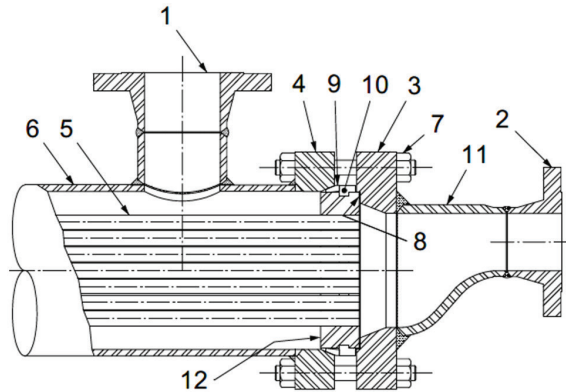
Figure 4—Typical Separated Head Front Closure

3.22

standard front closure

Closure using a single common set of bolting for the shell and tube side closure gasket seating. This may or may not include a threaded center flange.

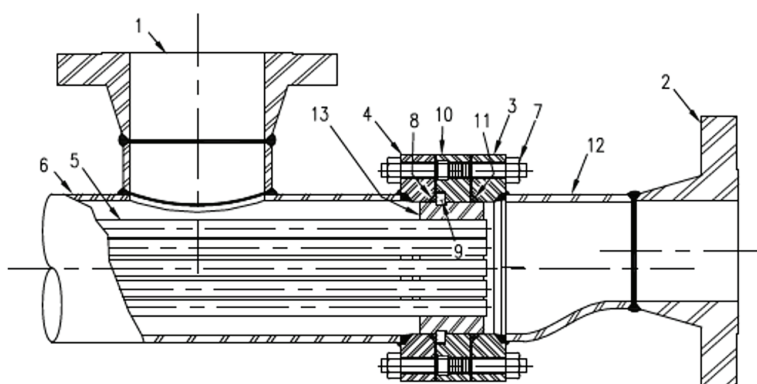
NOTE Figures 5 and 6 show typical standard front closures.

**Key**

1	shell side nozzle flange	5	tube bundle or element	9	sealing ring
2	tube side nozzle flange	6	shell pipe	10	shell closure split ring
3	tube side flange	7	closure bolting	11	reducer
4	shell side end flange	8	tube side gasket	12	tubesheet

NOTE This is a typical configuration for removable type bundles. Other configurations are equally acceptable, e.g. the front closure can have a concentric reducer, an eccentric reducer orientated flat-bottom or no reducer at all. Similarly, key item 2 can be absent with the tube side connection being a simple butt-welded preparation. For nonremovable front closures, flanges, bolting, and gaskets are eliminated.

Figure 5—Typical Standard Front Closure

**Key**

1 shell side nozzle flange	6 shell pipe	10 center flange (threaded)
2 tube side nozzle flange	7 shell closure bolting	11 tube side sealing ring
3 tube side flange	8 shell side sealing ring	12 reducer
4 shell side flange	9 shell closure split ring	13 tubesheet
5 tube bundle or element		

NOTE This is a typical configuration for removable type bundles. Other configurations are equally acceptable, e.g. the front closure can have a concentric reducer, an eccentric reducer orientated flat-bottom or no reducer at all. Similarly, key item 2 can be absent with the joint being a simple butt-welded preparation.

Figure 6—Typical Standard Front Closure with Threaded Center Flange

3.23

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.

3.24

tube bundle

Assembly of U-tubes, tubesheet and baffles used with multi-tube hairpin heat exchangers.

3.25

tube element

Assembly of inner pipe, with U-bends, used with double-pipe hairpin heat exchangers.

3.26

welded front closure

Closure for nonremovable bundles with tubesheet integrally welded to the shell.

4 General

- [•] **4.1** The pressure design code shall be specified or agreed to by the purchaser. Pressure components shall comply with the pressure design code and the supplemental requirements in this standard.

4.2 Where the use of Tubular Exchanger Manufacturers Association (TEMA) Standard is specified within this standard, the 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 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 datasheets.

[•] **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, different modes of operation 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 if the service 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 carbon steel material and welds 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 and/or tube side is in hydrogen service.

[•] **4.12** The purchaser shall specify if the requirements of high temperature hydrogen service, as included in Section 13, apply to the shell and/or tube side.

[•] **4.13** The purchaser shall specify if the supplemental requirements of Section 12 apply to the shell and/or tube side.

4.14 Hairpin heat exchangers typically do not require expansion joints. However, it can be necessary to evaluate some units (e.g. exchangers with straight tubes/rod-through designs) to assess the requirement for an expansion joint. For such cases, the purchaser and vendor shall agree to all relevant design, fabrication, inspection, and testing requirements. For additional guidance on expansion joints, see A.2.3.

5 Proposal Information Required

5.1 For each heat exchanger unit, the vendor's proposal shall include completed datasheets similar to those appearing in Annex C.

5.2 For components that are not fully identified by Section 3, the vendor shall describe the details of construction and assembly. For fixed tubesheet exchangers, the proposal shall include expansion joint details, location, material, and type, where applicable.

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 and bolting for interconnecting supports;
- c) external, interconnecting tube side piping.

5.5 The vendor shall supply a recommended spare parts list for each hairpin 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, maximum design temperature, minimum design metal temperature (MDMT), 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, individual front closure and rear closure);
- j) specified corrosion allowance for each side of the heat exchanger (See A.3);
- k) references to the applicable code and the purchaser's specification;
- l) requirements for postweld heat treatment;
- m) requirements for nondestructive examination (NDE);
- n) requirements for material impact testing;
- o) requirements for surface preparation and painting;
- p) gasket materials;
- q) insulation thickness;
- r) location and orientation of nameplates, lifting lugs, grounding clips, or other attachments;
- s) location of the center of gravity of the heat exchanger (empty and full of water);
- t) forces and moments on connections;
- u) material specifications including grades for all components;
- v) when applicable, location of expansion joints, annular distributors, and any other special components or closures.

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

6.2 Information Required After Outline Drawings Are Reviewed

6.2.1 The vendor shall submit gasket details, including type and material. For proprietary closures, general gasket information shall be provided including type, material, and coating.

6.2.2 The vendor shall submit copies of applicable welding procedure specifications, welding procedure qualifications, and weld map for review or record unless otherwise specified by the purchaser.

6.2.3 Upon receipt of the purchaser's review comments on the outline drawings, the vendor shall submit copies of all detailed (nonproprietary) drawings and relevant documentation 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, including tube bundle details with dimensions and materials;
- b) tube bundle details, including the following:
 - tube layout;
 - number of baffles, type, and description (for segmental baffles include cross-baffle cut, layout, and orientation in a view that shows the cut);
 - details and locations of baffle;
 - nonproprietary details of tubesheet including tube-to-tubesheet joints, tube holes, and cladding or weld overlay if required;
 - impingement protection device details, if applicable;
 - details and locations of all sealing strips and skid bars.
- c) details of each pressure-retaining weld, weld nominal thickness, weld location, and applicable nondestructive 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 specifications and part numbers for all proprietary components;
- f) details of annular distributors, expansion joints, or any other special components where applicable;
- g) details of cladding and weld overlay;
- h) details of tube-to-tubesheet joints, including procedures for installation, welding, expansion, inspection, and testing;
- i) flange-face finish;
- j) special installation, assembly, and maintenance instructions including lifting and handling.

- [•] **6.2.4** The purchaser shall specify whether the vendor shall furnish, for the purchaser's review or record, the following documentation:

- a) Mechanical design calculations for shell thickness, tube thickness, nozzle reinforcement, and other nonproprietary 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 equations in the applicable sections of the pressure design code and TEMA shall be referenced.
- b) Minimum required thicknesses for all pressure-retaining components, whether they are proprietary or nonproprietary.
- c) Maximum allowable working pressure (MAWP) calculations.
- d) Design calculations based on seismic, wind, transportation, and piping loads, if these loads are provided by the purchaser.
- e) 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.
- f) Design calculations for thermal loads imposed on nozzles of stacked heat exchangers.
- g) Flow-induced vibration analysis.
- h) Design calculations for supports, lifting, and pulling devices.
- i) Design calculations for expansion joints if applicable.

【●】 **6.2.5** The purchaser shall specify if the vendor shall provide a detailed inspection and test plan.

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 nonproprietary detail drawings, marked “CERTIFIED AS-BUILT”;
- c) certified record of all impact tests performed;
- d) Certified material test reports (CMTRs) for all pressure-retaining parts, including tubes (each material test report shall be identified by a part number). For wet hydrogen sulfide service, CMTRs shall comply with the requirements of 8.2.2;
- 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 as-built mechanical design calculations;
- j) nondestructive 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-wall reduction results;
- m) tube-to-tubesheet leak test results;
- n) hydrostatic test records in the form of a chart or certification;
- o) installation and maintenance instructions including lifting, handling, and bundle removal.

7 Design

7.1 Design Temperature

- [•] **7.1.1** The purchaser shall specify a maximum design temperature and a minimum design metal temperature.

NOTE The design temperature chosen may not be the same as the material selection temperature for high temperature hydrogen service.

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 design temperature.

7.2 Design Pressure

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

7.2.2 If the purchaser specifies that a calculation of maximum allowable working pressure (MAWP) is required, there shall be no restrictions on what components can limit the MAWP of the hairpin heat exchanger. The MAWP shall be as defined in the applicable pressure design code and shall be based on all simultaneously applied external loads such as nozzle loads.

7.3 Shell

7.3.1 The minimum thickness of the shell shall conform to TEMA. For shell diameters smaller than those covered by TEMA, at least Schedule 40 for carbon steel and low-alloy steel and Schedule 10S for high-alloy material shall be used.

7.3.2 Spiral welded pipe shall not be used.

7.4 Front Closure

7.4.1 Typically, front closures are of a proprietary design. The configuration of the front closure shall be agreed upon with the purchaser. Following are typical types of front closures:

- a) standard closure;
- b) separated head closure;
- c) welded closure.

7.4.2 Separated head closure shall be used in the following conditions:

- a) for services where the differential temperature (design or operating, whichever is greater) across the tubesheets is greater than 140 °C (250 °F);
- b) design pressure for either side exceeds 7000 kPa (ga) (1000 psig);

- c) cyclic service;
- d) hydrogen service;
- e) when specified by the purchaser.

7.4.3 For standard closure and welded closure using bolting, the design temperature used for the bolting shall be the more severe of the shell side or tube side design temperature. For such units, if the manufacturer's design uses an intermediate or center flange with threaded bolt holes (as shown in Figure 6), this center flange shall be designed for the more severe of the shell side or tube side design temperature, as well as the higher of the shell side or tube side design pressure.

7.4.4 Corrosion allowances shall not be applied to split rings.

7.5 Rear Closure

7.5.1 Two typical rear closure arrangements are shown in Figure 2.

7.5.2 The minimum clearance between the tubes and the rear closure, under any of the specified conditions, shall be 6 mm (1/4 in.).

7.5.3 For hydrogen, sour or wet hydrogen sulfide service, a confined gasket construction in accordance with TEMA shall be provided for the rear closure.

7.6 Tube Bundle

7.6.1 Tubes

7.6.1.1 The inner pipe or tube bundle of the heat exchanger shall be removable through the use of bolted closure joints unless an all-welded design is approved by the purchaser.

7.6.1.2 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.

7.6.1.3 For tube bundles where the tube bundle or tube element is manufactured from tubing, the minimum tube thickness shall be as listed in Table 1 unless otherwise specified or approved by the purchaser.

Table 1—Minimum Thickness of Tubes

Tube Material	Minimum Thickness ^{a b} mm (in.)
Carbon steel, low-alloy material (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 For low-fin tubing, this shall be the minimum thickness at the root diameter.	
^b Average wall tubes can be used, provided the tube thickness is not less than that specified.	

7.6.1.4 For tube bundles where the tube bundle or tube element is manufactured from pipe, the minimum wall thickness shall be Schedule 40 for carbon steel and low-alloy steel and Schedule 5S for high-alloy material.

7.6.1.5 Tube pitch shall comply with the requirements of TEMA, unless otherwise specified or approved by the purchaser.

- [•] **7.6.1.6** The purchaser shall specify when a hairpin heat exchanger has been selected to mitigate a complete tube rupture scenario, which would otherwise require a provision for pressure relief in accordance with API Standard 521. In such cases, the hairpin heat exchanger shall meet the following requirements:

- A double-pipe (pipe-in-pipe) configuration shall be used. A multi-tube exchanger shall not be permitted.
- The inner element shall be made from pipe and shall be of the same schedule as, or thicker than, the connecting piping. The purchaser shall specify the connecting pipe schedule on the datasheet.
- The minimum required wall thickness calculations for the inner pipe shall include the full hot side and cold side corrosion allowance, as specified on the datasheet.

- [•] **7.6.1.7** The purchaser shall specify any plot limitations including the consideration for the bundle removal space.

7.6.1.8 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.

7.6.1.9 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.

7.6.2 Transverse Segmental Baffles and Tube Supports

7.6.2.1 The thickness of segmental baffles and support plates shall be in accordance with TEMA. Where the shell diameter is less than 150 mm (6 in.), then the thickness for 150 mm (6 in.) diameter shells shall be used.

7.6.2.2 Transverse baffles and support plates shall have notches that are 6 mm (1/4 in.) high to facilitate drainage for shell nominal diameters up to and including 406 mm (16 in.). Above this diameter, notches shall be 10 mm (3/8 in.) high.

7.6.2.3 The maximum unsupported tube spans for bare and low-fin tubes shall be in accordance with TEMA.

7.6.3 Impingement Protection

7.6.3.1 If required by TEMA, impingement protection shall be provided by impingement sleeves, plate or rods on the tube bundle, an annular distributor, or another means agreed upon by the purchaser and the vendor. A typical impingement sleeve is shown in Figure 7.