

Shell-and-Tube Heat Exchangers

API STANDARD 660
NINTH EDITION, MARCH 2015

ADDENDUM 1, AUGUST 2020



Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Users of this Standard 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.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Copyright © 2015 American Petroleum Institute

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the specification.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

	Page
1 Scope	1
2 Normative References	1
3 Terms and Definitions	1
4 General	3
5 Proposal Information Required	4
6 Drawings and Other Required Data	5
6.1 Outline Drawings and Other Supporting Data	5
6.2 Information Required After Outline Drawings Are Reviewed	6
6.3 Reports and Records	7
7 Design	8
7.1 Design Temperature	8
7.2 Cladding for Corrosion Allowance	8
7.3 Shell Supports	9
7.4 Stationary and Floating Heads	9
7.5 Tube Bundle	10
7.6 Nozzles and Other Connections	15
7.7 Flanged External Girth Joints	16
7.8 Girth Flange Joint Supplementary Design Requirements	20
7.9 Expansion Joints	22
7.10 Gaskets	22
7.11 Handling Devices	24
7.12 Requirements for Hydrogen Service	24
8 Materials	24
8.1 General	24
8.2 Requirements for Carbon Steel in Sour or Wet Hydrogen Sulfide Service	25
8.3 Gaskets	25
8.4 Tubes	25
9 Fabrication	25
9.1 Shells	25
9.2 Pass-partition Plates	26
9.3 Connection Junctions	26
9.4 Tubes	26
9.5 Welding	26
9.6 Heat Treatment	27
9.7 Dimensional Tolerances	28
9.8 Gasket Contact Surfaces Other Than Nozzle Flange Facings	28
9.9 Tube Holes	30
9.10 Tube-to-Tubesheet Joints	30
9.11 Assembly	31

Contents

	Page
10 Inspection and Testing	31
10.1 Quality Control	31
10.2 Pressure Testing	34
10.3 Nameplates and Stampings	34
11 Preparation for Shipment	35
11.1 Protection	35
11.2 Identification	36
12 Supplemental Requirements	36
12.1 General	36
12.2 Design	36
12.3 Examination	36
13 Supplemental Requirements for Services Subject to High Temperature Hydrogen Service (HTHS) ...	37
13.1 General	37
13.2 Design Temperature	37
13.3 Materials	38
13.4 Connections for Temperature Indication	38
13.5 Fabrication	38
13.6 Inspection and Testing	38
Annex A (informative) Recommended Practices	40
Annex B (informative) Shell-and-Tube Heat Exchanger Checklist	51
Annex C (informative) Shell-and-Tube Heat Exchanger Datasheets	54
Bibliography	67
Figures	
1 Minimum Thickness of Tubes	10
2 Clearance Between Tube Holes and Transverse Baffle Edge with Longitudinal Baffle	12
3 Typical Cross-sections of Tube Bundle Showing Locations of Bypass Sealing Devices	14
4 Directions of Moments and Forces on Nozzles	16
Tables	
1 Typical Designs for Floating-head Covers	11
2 Nozzle Allowable Forces and Moments at the Nozzle Neck to Shell/Channel Interface	17
3 Assembly Gasket Stress	21
4 Gasket Contact Surface Finishes	29
5 Flatness Tolerance on Peripheral Gasket Contact Surfaces	29
6 Maximum Allowable Tube Wall Thickness Reduction for Roller-expanded Tube-to-Tubesheet Joints .	30
7 Hardness Limits	32
B.1 Checklist for Shell-and-Tube Heat Exchangers	51

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 B16.5 ¹, *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*

EJMA ², *Standards of the Expansion Joint Manufacturers Association*

NACE MR0103 ³, *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 ⁴, 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****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.

3.10**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.

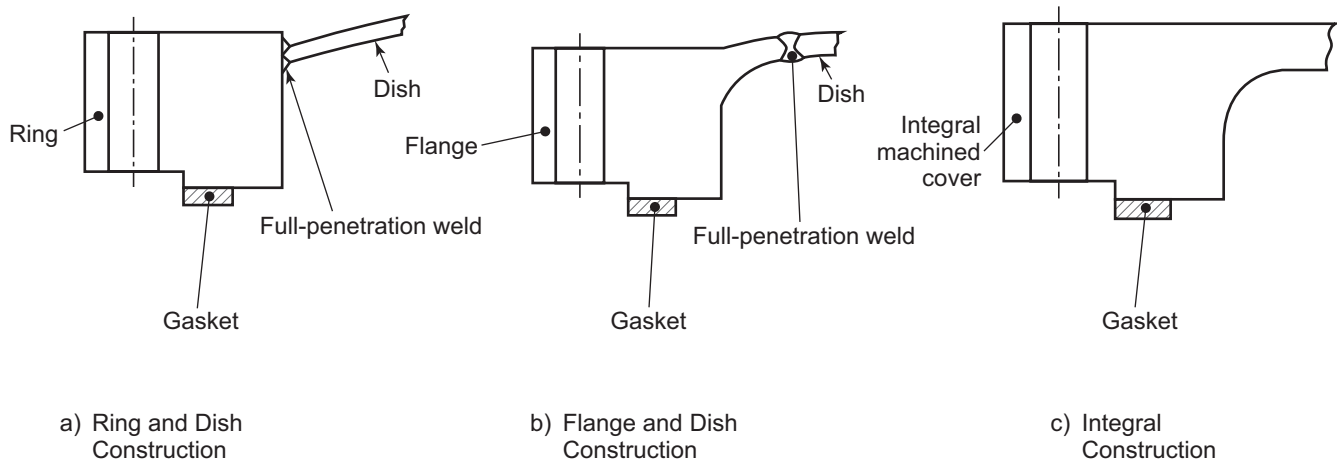


Figure 1—Typical Designs for Floating-head Covers

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 (1½ 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.

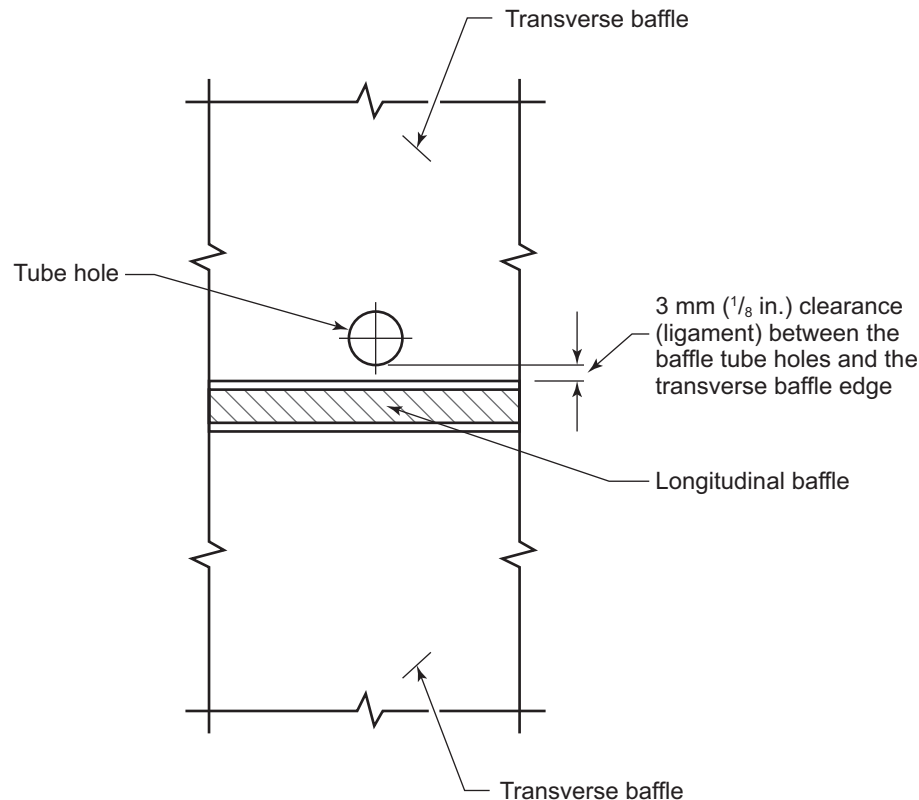


Figure 2—Clearance Between Tube Holes and Transverse Baffle Edge with Longitudinal Baffle

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 ($\frac{1}{4}$ 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 ($\frac{3}{4}$ 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 ($\frac{5}{8}$ in.) and shall be located as follows.

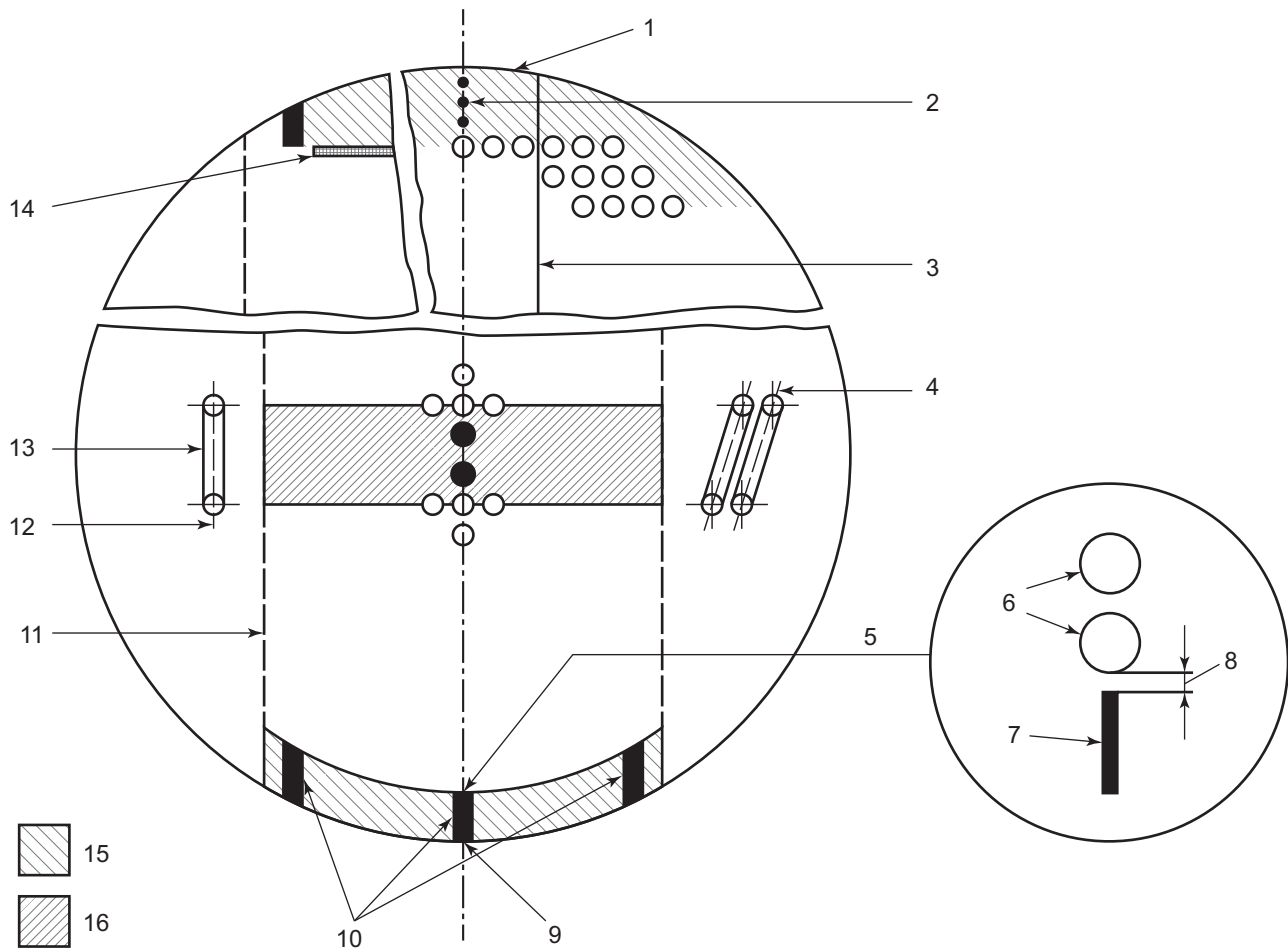
- a) If the distance between baffle-cut edges is six tube pitches or less, a single seal located approximately halfway between the baffle cut shall be provided.
- b) If the distance between baffle-cut edges exceeds six tube pitches, multiple seals shall be provided. A seal shall be located every five 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 ($\frac{1}{4}$ 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.

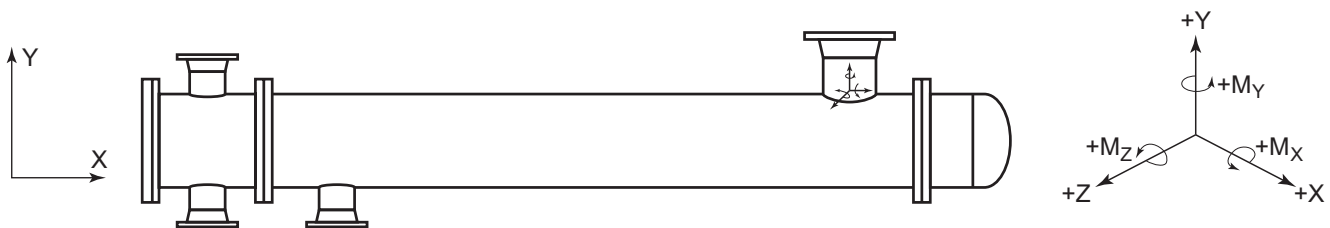


Figure 4—Directions of Moments and Forces on Nozzles

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.