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**Petroleum, petrochemical and natural gas  
industries — Shell-and-tube heat  
exchangers**

*Industries du pétrole, de la pétrochimie et du gaz naturel — Échangeurs  
de chaleur à faisceaux*

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# Contents

Page

Foreword.....	v
Introduction .....	vi
1 Scope .....	1
2 Normative references .....	1
3 Terms and definitions.....	2
4 General.....	3
5 Proposals.....	3
6 Drawings and other required data .....	4
6.1 Outline drawings and other supporting data.....	4
6.2 Information required after outline drawings are reviewed .....	5
6.3 Reports and records.....	6
7 Design .....	7
7.1 Design temperature .....	7
7.2 Cladding for corrosion allowance.....	7
7.3 Shell supports .....	7
7.4 Stationary head .....	8
7.5 Floating head.....	8
7.6 Tube bundle.....	9
7.7 Nozzles and other connections .....	12
7.8 Flanged external girth joints.....	13
7.9 Expansion joints .....	13
7.10 Gaskets .....	14
7.11 Handling devices .....	15
7.12 Hydrogen service.....	15
8 Materials .....	15
8.1 General.....	15
8.2 Gaskets .....	16
8.3 Tubes.....	16
9 Fabrication.....	16
9.1 Shells .....	16
9.2 Pass-partition plates.....	16
9.3 Connection junctions .....	16
9.4 Tubes.....	17
9.5 Welding .....	17
9.6 Heat treatment.....	17
9.7 Dimensional tolerances .....	18
9.8 Gasket contact surfaces other than nozzle-flange facings.....	18
9.9 Tube holes .....	19
9.10 Tube-to-tubesheet joints .....	19
9.11 Assembly .....	19
10 Inspection and testing.....	20
10.1 Quality assurance .....	20
10.2 Quality control.....	20
10.3 Pressure testing .....	21
10.4 Nameplates and stampings .....	22

<b>11</b>	<b>Preparation for shipment .....</b>	<b>22</b>
<b>11.1</b>	<b>Protection.....</b>	<b>22</b>
<b>11.2</b>	<b>Identification .....</b>	<b>23</b>
<b>12</b>	<b>Supplemental requirements.....</b>	<b>23</b>
<b>12.1</b>	<b>General .....</b>	<b>23</b>
<b>12.2</b>	<b>Design .....</b>	<b>23</b>
<b>12.3</b>	<b>Examination .....</b>	<b>23</b>
<b>Annex A</b>	<b>(informative) Recommended practices.....</b>	<b>25</b>
<b>Annex B</b>	<b>(informative) Shell-and-tube heat exchanger checklist .....</b>	<b>27</b>
<b>Annex C</b>	<b>(informative) Shell-and-tube heat exchanger data sheets .....</b>	<b>28</b>
<b>Annex D</b>	<b>(informative) Responsibility data sheet.....</b>	<b>39</b>
<b>Bibliography</b>	<b>.....</b>	<b>41</b>

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16812 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 6, *Processing equipment and systems*.

This second edition cancels and replaces the first edition (ISO 16812:2002), which has been technically revised.

## Introduction

Users of this International Standard should be aware that further or differing requirements may be needed for individual applications. This International 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 may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this International Standard and provide details.

Annex A provides some optional recommended practices.

A bullet (●) at the beginning of a clause or subclause indicates a requirement for the purchaser to make a decision or provide information (see checklist in Annex B).

In this International Standard, where practical, US Customary (USC) units are included in parentheses for information.

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# Petroleum, petrochemical and natural gas industries — Shell-and-tube heat exchangers

## 1 Scope

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

This International 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.

ISO 15156 (all parts), *Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production*

ASME B 16.5<sup>1)</sup>, *Pipe Flanges and Flanged Fittings*

ASME B 16.11, *Forged Fittings, Socket-Welding and Threaded*

ASME B 1.20.1, *Pipe Threads, General Purpose (Inch)*

EJMA<sup>2)</sup>, *Standards of the Expansion Joint Manufacturers Association*

NACE MR0103<sup>3)</sup>, *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

TEMA Standards Set<sup>4)</sup>, 8<sup>th</sup> Edition, *Standards of the Tubular Exchanger Manufacturers Association*

1) ASME International, 3 Park Avenue, New York, NY 10016-5990, USA.

2) Expansion Joint Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591, USA.

3) NACE International, P.O. Box 218340, Houston, TX 77218-8340, USA.

4) Tubular Exchanger Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591, USA.

### 3 Terms and definitions

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

**3.1 annular distributor**  
additional chamber incorporated into a shell side nozzle to more evenly distribute shell side fluids entering or exiting the tube bundle

**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

EXAMPLES Sump, annular distributor.

**3.5 effective surface**  
outside surface area of the tubes that contributes to heat transfer

**3.6 full-penetration weld**  
welded joint that results in weld metal through the entire thickness of the components being joined

**3.7 heat-exchanger unit**  
one or more heat exchangers for a specified service that may include alternative operating conditions

**3.8 hydrogen service**  
service that contains hydrogen at a partial pressure exceeding 700 kPa (100 psi) absolute

**3.9 item number**  
purchaser's identification number for a heat-exchanger unit

**3.10 nubbin**  
projection on the flange gasket surface, positioned at the centre of the gasket, used to concentrate the bolt load on the gasket

**3.11 pressure design code**  
recognized pressure vessel standard specified or agreed by the purchaser

EXAMPLES ASME Section VIII, EN 13445.

**3.12****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

**3.13****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 International Standard.
- 4.2** Heat-exchanger construction shall conform to TEMA (8<sup>th</sup> edition), 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 International Standard are addressed.
- 4.6** Annex C provides examples of data sheets.
- 4.7** Annex D includes a recommended division of responsibility for completing the data sheet.

**5 Proposals**

- 5.1** The vendor's proposal shall include, for each heat exchanger unit, completed data sheets such as those given in Annex C or, if a data sheet is included in the inquiry, a statement indicating complete compliance with that data sheet.
- 5.2** Designs that are not fully defined by the nomenclature in TEMA (8<sup>th</sup> edition), Section 1, shall be accompanied by sketches that are sufficient to describe the details of construction.
- 5.3** If an annular distributor is provided, the vendor shall define the type of construction proposed.
- 5.4** The vendor shall determine the need for, and if required, include expansion joints based on all conditions supplied by the purchaser. The vendor shall state the type of construction proposed.
- 5.5** The proposal shall include a detailed description of all exceptions to the requirements of the purchaser's inquiry.
- 5.6** 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.

5.7 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 (8<sup>th</sup> edition), Figure E-4.13-2 or equivalent, for each heat exchanger or group of similar heat exchangers with floating heads;
- b) one spare set of gaskets per heat-exchanger unit.

## 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 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;
- 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;
- k) references to the applicable code and the purchaser's specification;
- l) requirements for post-weld heat treatment;
- m) requirements for radiographic examination;
- 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 centre of gravity of the heat exchanger;
  - u) forces and moments on connections as specified by the purchaser.
- **6.1.2** The vendor shall submit flow-induced vibration analysis, if specified by the purchaser.

## **6.2 Information required after outline drawings are reviewed**

**6.2.1** Gasket details, including type and material, shall be shown on a separate drawing. This drawing shall not be marked with any restrictions for use.

- **6.2.2** Qualified welding procedure specifications and procedure qualification records as required by the pressure design code shall be submitted for review, if 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 drawings. 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) bundle details, including the following:
  - tube layout,
  - tube description and number in each pass,
  - number of baffles, 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,
  - gasket drawings,
  - details of pass-partition plates;
- 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 non-pressure 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 on a computer, 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/or 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.

- **6.2.5** The vendor shall submit design calculations for supports or 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" data sheet;
  - 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 post-weld 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.

## 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 (e.g. in the form shown in Annex C).
- 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 shell side or tube side design temperature, whichever is the more severe.
- **7.1.3** The input data needed to design an expansion joint shall be provided by the purchaser (e.g. in the form shown in Annex C).

### 7.2 Cladding for corrosion allowance

- 7.2.1** If cladding (including weld overlay) is used, the full thickness of the cladding shall be used as corrosion allowance unless specified otherwise or approved by the purchaser.
- 7.2.2** The minimum cladding 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. The minimum cladding thickness on the shell side face shall not be less than 10 mm (3/8 in). Weld overlays shall have sufficient thickness to provide the specified chemical composition to a depth of at least 1,5 mm (1/16 in).

### 7.3 Shell supports

- 7.3.1** The fixed shell support of removable-bundle heat exchangers shall be designed to withstand a longitudinal force equal to 150 % of the bundle mass applied at the heat exchanger bundle centreline. 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) The 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) The saddle-bearing plates shall be provided with vent holes 6 mm (1/4 in) in diameter, located at the vertical centreline.
  - e) The 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 can 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).

**7.4 Stationary head**

7.4.1 Structural bracing shall not be used to retain pressure.

7.4.2 The pressure differential used to calculate the pass-partition plate thickness in accordance with TEMA (8<sup>th</sup> edition), RCB-9.132, shall be the allowable tube-side pressure drop of the entire exchanger unit.

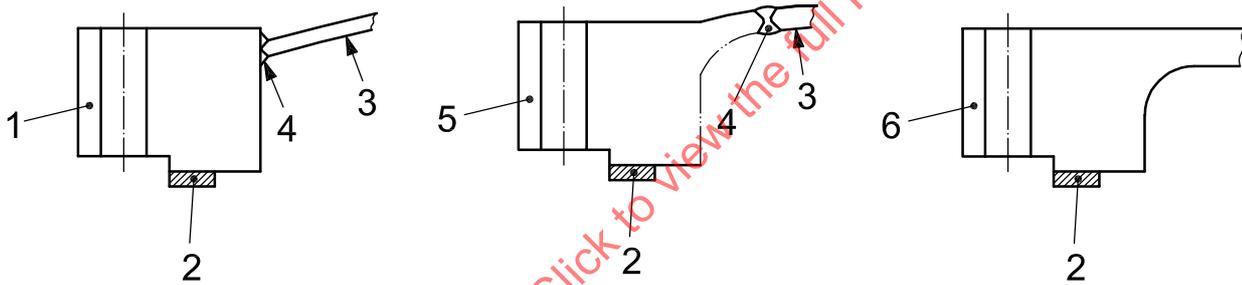
**7.5 Floating head**

7.5.1 Floating-head cover bolting shall comply with TEMA (8<sup>th</sup> edition), Section 5, Paragraph RCB-11. Bolt spacings and clearances shall be not less than the minimum recommended by TEMA.

7.5.2 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.

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

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



a) Ring and dish construction    b) Flange and dish construction    c) Integral construction

**Key**

- 1 ring
- 2 gasket
- 3 dish
- 4 full-penetration weld
- 5 flange
- 6 integral machined cover

**Figure 1 — Typical designs for floating-head covers**

7.5.5 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.

## 7.6 Tube bundle

### 7.6.1 Tubes

**7.6.1.1** The minimum outside diameter of the tubes shall be 19,05 mm (3/4 in) unless otherwise specified or approved by the purchaser.

**7.6.1.2** The tube-wall thickness shall be as listed in Table 1, or thicker if required by the design conditions, unless otherwise specified or approved by the purchaser.

**Table 1 — Minimum wall thickness of tubes**

Dimensions in millimetres (inches)

Tube material	Minimum wall thickness <sup>a</sup>
Carbon steel, low-alloy steel (max. 9 % chromium), aluminium and aluminium alloy	2,11 (0,083)
Copper and copper alloys	1,65 (0,065)
High-alloy [austenitic, ferritic and austenitic/ferritic (duplex)] steel and other non-ferrous materials	1,473 (0,058)
Titanium	1,067 (0,042)
<sup>a</sup> For low-fin tubing, this shall be the minimum thickness at the root diameter.	

**7.6.1.3** The mean radius of U-bends shall be not less than 1,5 times the nominal outside diameter of the tube.

### 7.6.2 Tubesheets

**7.6.2.1** For a vertical heat exchanger where the stationary tubesheet is at the bottom, a suitable means of holding the bundle in place shall be provided. 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.

**7.6.2.2** The distance between the edge of the tube holes and the edge of all gasket grooves shall be not 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 seal-welded or strength-welded tube-to-tubesheet joints.

**7.6.2.3** Tubesheets shall be designed for design pressure on either side, with atmospheric pressure or vacuum, if specified, on the other side unless otherwise specified or approved by the purchaser.

**7.6.2.4** A full-diameter stationary tubesheet shall be provided for removable bundle exchangers with bonnets [see TEMA (8<sup>th</sup> edition), Figure N-1.2, Type B stationary head]. The tubesheet shall be designed to maintain the gasket seal through the use of collar studs or tapped tubesheet holes and allow hydrotesting of the shell side without the bonnet installed.

### 7.6.3 Baffles and support plates

**7.6.3.1** The thickness of carbon steel or low-alloy steel (max. 9 % chromium) transverse baffles and support plates shall be not less than twice the specified shell side corrosion allowance.

**7.6.3.2** Transverse baffles and support plates shall have notches that are 10 mm (3/8 in) high to facilitate drainage.

**7.6.3.3** If shell-side longitudinal baffles are used, the minimum clearance between the longitudinal baffle and the adjacent tubes shall be 3 mm (1/8 in).

#### 7.6.4 Impingement protection

**7.6.4.1** If required by TEMA (8<sup>th</sup> edition), 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 upon by the purchaser and the vendor.

**7.6.4.2** If an impingement plate baffle is used, it shall extend at least 25 mm (1 in) beyond the projection of the nozzle bore.

**7.6.4.3** If an impingement plate baffle is used, the shell entrance and bundle entrance areas (as defined by TEMA) shall be not less than the flow area of the inlet nozzle.

**7.6.4.4** The nominal thickness of the impingement plate baffle shall be not less than 6 mm (1/4 in).

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

**7.6.4.6** Perforated impingement plate baffles shall not be used.

#### 7.6.5 Bypass-sealing devices

**7.6.5.1** Bypass-sealing devices (such as seal bars, dummy tubes or tie-rods as shown in Figure 2) shall be used for non-isothermal service 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 cuts, 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.

**7.6.5.2** 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.

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

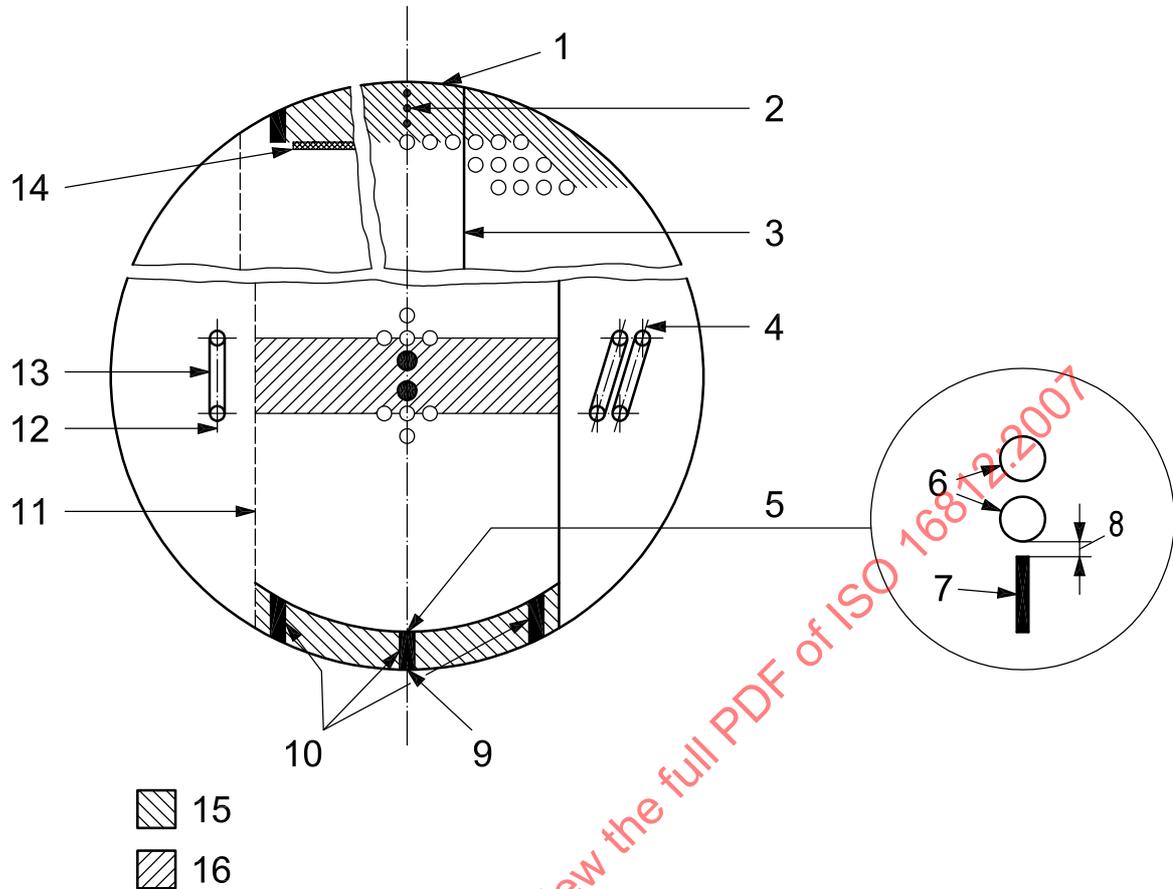
**7.6.5.4** Bypass sealing devices shall either be located to minimize obstruction of mechanical cleaning lanes or shall be readily removable. Continuous cleaning lanes shall be maintained for square (90°) and rotated-square (45°) pitch.

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

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

**7.6.5.7** 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 bundle.

**7.6.5.8** Peripheral bypass-seal strips shall not restrict the bundle inlet or outlet flows.



### Key

- |   |  |    |                               |
|---|--|----|-------------------------------|
| 1 | peripheral edge of baffle                                | 9  | single seal on centreline     |
| 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 2 — Typical cross-sections of tube bundle showing locations of bypass sealing devices**

### 7.6.6 Bundle skid bars

**7.6.6.1** For all removable bundles with a mass of more than 5 450 kg (12 000 lb), continuous sliding surfaces shall be provided to facilitate bundle removal.

**7.6.6.2** If skid bars are used, the following shall apply.

- a) A minimum of two skid bars shall be provided.
- b) They shall not be situated in the projected area of the nozzles.
- c) They shall be welded to the transverse baffles and support plates.

- d) They shall protrude 0,8 mm (1/32 in) beyond the outside diameter of baffle and support plates.
- e) Their leading and trailing edges shall be provided with a radius or a bevel to prevent damage to the shell when inserting or removing the bundle.

#### 7.6.7 Tube-to-tubesheet joint

The tube-to-tubesheet joint shall be expanded only, unless otherwise specified or approved by the purchaser. If welded joints are specified, the joint shall be made by one of the following methods:

- a) strength-welded only;
- b) strength-welded and expanded;
- c) seal-welded and expanded.

#### 7.7 Nozzles and other connections

- **7.7.1** Connections DN 40 (NPS 1½) and larger shall be flanged. The purchaser shall specify the required flange design code (e.g. ASME B16.5).

**7.7.2** If welded connections are specified, they shall be bevelled.

**7.7.3** Non-flanged connections smaller than DN 40 (NPS 1½) shall be forged couplings with an equivalent rating to ASME B 16.11 class 6000 or shall be integrally reinforced welding fittings with tapered threads equivalent to ASME B 1.20.1, and shall comply with the pressure design code. Threaded connections shall not be used in hydrogen or sour service.

**7.7.4** 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 7.7.5.

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

- a) design pressure greater than 2 100 kPa (300 psi) gauge;
- b) design temperature greater than 400 °C (750 °F);
- c) corrosion allowance greater than 3 mm (1/8 in);
- d) hydrogen service;
- e) cyclic service, if the pressure design code requires fatigue analysis.

- **7.7.6** The projection of flanged connections shall allow through-bolting to be removed from either side of the flange without removing the insulation. The insulation thickness shall be specified by the purchaser.

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

- **7.7.8** If chemical-cleaning connections are specified by the purchaser, their nominal size shall be not less than DN 50 (NPS 2).

- **7.7.9** The design of connections shall be suitable to withstand the loads and moments specified by the purchaser.

## 7.8 Flanged external girth joints

7.8.1 Channel and shell external girth joints shall be of through-bolted construction.

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

7.8.3 Nubbins shall not be used unless approved by the purchaser, in which case nubbins shall be located on the female (grooved) flange.

7.8.4 The nominal clearance between flanges after assembly shall be not less than 3 mm (1/8 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.

7.8.5 Flanges shall be spot-faced or back-faced to the extent required by ASME B 16.5 or the pressure design code.

7.8.6 Hardened washers shall be provided under nuts for all bolts having diameters of 38 mm (1 1/2 in) or larger. The washers shall be at least 6 mm (1/4 in) thick.

- 7.8.7 If the use of bolt-tightening devices is specified by the purchaser, nozzles or girth flanges shall be designed to allow adequate clearance.

7.8.8 Stationary tubesheet flange assembly shall be designed with the same type of gasket on the tube side and shell side, i.e. with similar compressive characteristics.

7.8.9 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 1 These allowable stresses can cause permanent deformation.

NOTE 2 In ASME Section II, the allowable stresses of some high-nickel alloys have been established in this way.

## 7.9 Expansion joints

7.9.1 Expansion joints shall be thin-wall bellows or thick walled (e.g. flanged or flanged and flued).

7.9.2 Expansion joints made of thin-walled bellows shall comply with the following.

- a) They shall 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) They shall be protected from external damage with a metallic cover that is designed to remain intact during shipping, handling and operation.
- c) They shall 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 1 000 normal operating cycles.
- d) They shall have the bellows formed from a cylinder that has only longitudinal weld seams.
- e) Bellow welds, including attachment welds, shall be 100 % examined by the liquid-penetrant method. The acceptance criteria shall comply with the pressure design code.

- f) They shall be designed with stays to prevent damage during shipping and handling. Stays that require removal or adjustment prior to operation shall be clearly identified.
- g) Floating-head tailpipe expansion joints shall 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** Gaskets in hydrocarbon or steam service shall be double-jacketed metal with a soft gasket filler, solid metal, serrated metal with a soft gasket-seal facing, corrugated metal with a soft gasket-seal facing or spiral-wound.

**7.10.2** Pass partition rib(s) for double-jacketed, solid-metal, serrated-metal and corrugated-metal gaskets shall be of the same materials as the perimeter portion of the gasket. Pass partition ribs shall be designed and constructed such that they do not inhibit the compression or seating of the perimeter gasket.

**7.10.3** If the gasket OD is less than or equal to 610 mm (24 in), the perimeter 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 perimeter portion shall not exceed the following.

- a) Double-jacketed gaskets shall have no more than one weld in the perimeter portion.
- b) Other gasket types shall have no more than two welds in the perimeter portion, or no more than the ratio of gasket OD / 610 mm (24 in), whichever is greater.

**7.10.4** The gasket welds shall comply with the following.

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

**7.10.5** If adhesives are used to attach facings, they shall be compatible with the core (e.g. chloride content).

**7.10.6** Double-jacketed gaskets shall comply with the following.

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

**7.10.7** Serrated gaskets shall comply with the following.

- 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 their metallic core shall not exceed 0,13 mm (0,005 in) along a 25,4 mm (1 in) band. If welds are present, the centre of the bands shall be located at the centre of the welds.
- c) They shall have no facing joints coincident with a facing joint on the opposite sealing face or coincident with any welds in the core.
- d) They shall have one-piece continuous facing materials (no joints) if the outside diameter is less than 1 m (40 in).
- e) There shall be an overlap of the facing material of 1,5 mm (1/16 in) to 3 mm (1/8 in) if the outside diameter is 1 m (40 in) or larger, except that butt joints (gap-free) may be used for flexible-graphite facings.

**7.10.8** Corrugated metal gaskets shall comply with the following.

- a) They shall have a minimum core thickness of 0,46 mm (0,018 in).
- b) They shall have corrugations in the weld area that match the gasket profile.
- c) They shall have no facing joints coincident with a facing joint on the opposite sealing face or coincident with any welds in the core.
- d) They shall have one-piece continuous facing materials (no joints) if the outside diameter is less than 1 m (40 in).
- e) There shall be an overlap of the facing material of 1,5 mm (1/16 in) to 3 mm (1/8 in) if the outside diameter is 1 m (40 in) or larger, except that butt joints (gap-free) may be used for flexible-graphite facings.

**7.10.9** Spiral-wound gaskets shall be provided with a means to prevent over-compression or buckling.

## 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 1/2 in) in diameter. Wherever possible, the lug or ring shall be located at the top of the component, above its centre 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 centreline.

**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 bundle from the shell. Pulling lugs and tapped holes shall be designed for a pulling force equal to at least 150 % of the 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 positioned above the centre of gravity of the heat exchanger.

## 7.12 Hydrogen service

- If the purchaser specifies that the tube side and/or shell side will be exposed to hydrogen service, totally enclosed spaces between welds shall be eliminated or vented with a hole of 6 mm (1/4 in) in diameter.

# 8 Materials

## 8.1 General

- **8.1.1** The purchaser shall specify if the service is sour (i.e. if sulfide stress cracking is possible) in accordance with ISO 15156 (all parts) for oil and gas production facilities and natural gas sweetening plants, or in accordance with NACE MR0103 for other applications (e.g. oil refineries, LNG plants and chemical plants), in which case all materials in contact with the process fluid shall meet the requirements of that standard.

NOTE For the purpose of this provision NACE MR0175 is equivalent to ISO 15156.

**8.1.2** Castings shall not be used unless approved by the purchaser.

**8.1.3** 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.

8.1.4 Alloy cladding shall be weld-overlay, integrally clad or explosion-bonded. Loose liners or sleeves shall not be used without the approval of the purchaser.

## 8.2 Gaskets

8.2.1 Gaskets shall not contain asbestos.

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

8.2.3 Metal windings of spiral-wound gaskets shall be of austenitic stainless steel unless otherwise specified or approved by the purchaser.

8.2.4 Serrated- or solid-metal gaskets, including welds, shall be softer than the gasket contact surface.

8.2.5 Gasket material, including filler material, shall be selected to withstand the maximum design temperature.

## 8.3 Tubes

8.3.1 Integrally finned tubes of copper alloy shall be furnished in the annealed-temper condition, such as described in ASTM B 359/B 359M.

8.3.2 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 if they are not in the bottom quadrant of the shell.

9.1.2 For removable-bundle heat exchangers, the permissible out-of-roundness of a completed shell, after all welding and 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 (8<sup>th</sup> edition), 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

All tubes including U-tubes shall be formed from a single length and shall have no circumferential welds.

## 9.5 Welding

**9.5.1** Welds may be made using any welding process other than oxyacetylene gas welding.

**9.5.2** Category A welded joints and category 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** If connections abut a component fabricated from plate (e.g. in the case of a set-on nozzle), the edge of the hole in the plate to which the connections are attached shall be examined for laminations by means of the magnetic-particle or liquid-penetrant method. Subject to agreement with the purchaser, indications found shall be cleared to sound metal and then repair-welded.

**9.5.5** Backing strips that remain in place on the inside of a component after welding is completed shall not be used unless approved by the purchaser.

- **9.5.6** Tubes shall be welded to tubesheets if specified by the purchaser (e.g. for certain process conditions). The welding and testing procedures in these instances shall be mutually agreed upon by the purchaser and the vendor.

**9.5.7** It is not necessary that the welds attaching insulation support rings be continuous.

**9.5.8** Welds attaching other non-pressure attachments (such as lugs or structural steel supports) shall be continuous.

**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 are exposed to hydrogen service.

## 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** Requirements and procedures for heat treatment after bending the U-tubes shall be specified by the purchaser.

If the purchaser specifies heat treatment of U-bends of austenitic stainless steel, the procedure shall be as described in the pressure design code or shall be agreed between purchaser and vendor.

The U-bends of copper and copper alloy tubes, including copper-nickel alloys, shall be heat-treated as required by the pressure design code or shall be agreed between purchaser and vendor.

**9.6.3** The heat-treated portion of the U-bend shall extend at least 150 mm (6 in) beyond the tangent point.

**9.6.4** Post-weld heat treatment of fabricated carbon steel and low-alloy (max. 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.

- **9.6.5** The purchaser shall specify if post-weld heat treatment is required for weld-overlaid channels and bonnets.
- 9.6.6** Post-weld heat treatment shall be performed for all carbon steel and low-alloy (max. 9 % chromium) steel floating-head covers that are fabricated by welding a dished-only head into a ring flange.
- **9.6.7** The purchaser shall specify if heat treatment is required for process reasons.

**9.7 Dimensional tolerances**

- 9.7.1** Manufacturing tolerances shall be such that nominally identical parts are interchangeable.
- 9.7.2** Heat exchangers that are to be stacked in service 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 0,8 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.

**9.8 Gasket contact surfaces other than nozzle-flange facings**

- 9.8.1** Gasket contact surfaces shall have finishes as given in Table 2

**Table 2 — Gasket contact surface finishes**

Dimensions in micrometres (micro-inches)

Type	Surface roughness <i>Ra</i> <sup>a</sup>
Solid flat metal gaskets	1,6 (63) maximum
Double-jacketed gaskets	1,6 to 3,2 (63 to 125)
Spiral-wound gaskets	3,2 to 6,3 (125 to 250)
Serrated gaskets or corrugated-metal gaskets with soft gasket-seal facing	
<sup>a</sup> <i>Ra</i> is roughness average.	

- 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 purchaser shall specify if there is a special application such as high-pressure service, high-temperature service or hydrogen service. In such cases, the flatness tolerances on peripheral gasket contact surfaces shall be as given in Table 3.

**Table 3 — Flatness tolerance on peripheral gasket contact surfaces**

Dimensions in millimetres (inches)

Heat exchanger nominal diameter	Tolerance
≤ 375 (15)	± 0,08 (0,003)
> 375 to ≤ 750 (15 to 30)	± 0,15 (0,006)
> 51 to ≤ 1 125 (31 to 45)	± 0,20 (0,008)
> 1 125 (45)	± 0,20 (0,008)

**9.8.4** The flatness tolerance on pass-partition grooves and mating pass partition plate edges shall be 0,8 mm (1/32 in).

**9.8.5** 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 may be measured with a straight edge.

**9.8.6** Flange flatness tolerance and surface finish shall be measured after the flange has been attached to the component cylinder or the cover, and after any post-weld heat treatment.

**9.8.7** The flatness of tubesheet gasket contact surfaces shall be measured after the tube-to-tubesheet joints have been completed.

## 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, cupro-nickel or nickel-alloy tubes are specified, the tube holes shall be machined in accordance with TEMA (8<sup>th</sup> edition), Table RCB-7.41, 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 4.

**Table 4 — 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 <sup>a</sup>
Stainless and high-alloy steel	6 <sup>a</sup>
Titanium and work-hardening non-ferrous	5 <sup>a</sup>
Non-ferrous non-work-hardening (e.g. admiralty brass)	8 <sup>a</sup>
<sup>a</sup> These may be increased by a further 2 % if approved by the purchaser.	

**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** In no case shall the expansion encroach within 3 mm (1/8 in) of the shell side face of the tubesheet.

**9.10.4** For shell-side-clad tubesheets, the tube shall be expanded to seal against the cladding material for a minimum distance of 6 mm (1/4 in).

## 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 assurance

- 10.1.1 If specified by the purchaser, materials, fabrication, conformance with mechanical design and testing of heat exchangers shall be subject to inspection by the purchaser, a designated representative or both. The purchaser shall specify the required degree of involvement. Examples of this are as follows:
  - a) verification that qualified welding procedures and qualified welders and welding operators are being used by the manufacturer;
  - b) verification that the construction complies with the applicable drawings and with this International Standard;
  - c) review and/or examination of the results of any specified non-destructive examination;
  - d) witnessing of hydrostatic testing and any additional testing specified by the purchaser;
  - e) examination of required material certificates and the manufacturer's data reports.

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

### 10.2 Quality control

10.2.1 Radiography shall be performed in accordance with the pressure design code; however, the minimum shall be as follows.

- a) At least one spot radiograph shall be made of each category A welded joint and category B welded joint. Nozzle welds are exempt from this requirement.
- 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.

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

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

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

10.2.5 Weld-hardness testing shall be in accordance with the pressure design code or the following requirements, whichever is the more stringent.

- a) The weld metal and heat-affected zone of pressure-retaining welds in components shall be tested.
- b) Examination shall be made after any required post-weld heat treatment.

- c) Brinell hardness limits shall be in accordance with Table 5.
- d) Hardness shall be determined using a 10 mm diameter ball unless otherwise specified or approved by the purchaser.
- e) One longitudinal weld, one circumferential weld and, if the connection is DN 50 (NPS 2) or larger, each connection-to-component weld shall be tested.
- f) If more than one welding procedure is used to fabricate longitudinal or circumferential welds, hardness readings shall be made of welds deposited by each procedure.

Table 5 — Hardness limits

Material	Maximum Brinell hardness HBW
Carbon steel	225
Low-alloy steel (2 % Cr max.)	225
Low-alloy steel (> 2 % Cr to 9 % Cr)	240
High-alloy martensitic steels	240
High-alloy ferritic steels	240

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

**10.2.7** All finished welds in ferromagnetic steel shall be examined after post-weld heat treatment (unless the pressure design code specifies examination after hydrostatic testing) by the magnetic-particle method.

**10.2.8** Final welds in all non-magnetic materials, whether of solid alloy or alloy-clad plate, shall be examined by the liquid-penetrant method after any required post-weld heat treatment.

**10.2.9** Final visual weld inspection shall be performed after post-weld heat treatment.

**10.2.10** 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.

**10.2.11** Overlay weldments, back-cladding and attachment welds to overlay weldments shall be liquid-penetrant examined after post-weld heat treatment.

### 10.3 Pressure testing

**10.3.1** 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 between 50 kPa (7,5 psi) and 100 kPa (15 psi), using a soap-water solution to reveal leaks.

**10.3.2** 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.

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

**10.3.4** The chloride content of the test water used for equipment with austenitic stainless steel materials that are 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.

- **10.3.5** Any additional requirements for equipment drying or preservation shall be specified by the purchaser.
- 10.3.6** The shell side hydrostatic test shall be conducted with the bonnet or channel cover removed.
- 10.3.7** Nozzle reinforcement pads shall be pneumatically tested at 170 kPa (25 psi) gauge.
- 10.3.8** For safety considerations, any supplementary pneumatic test shall be performed at a nominal pressure of 170 kPa (25 psi) gauge.
- 10.3.9** Flanged joints that have been taken apart after a hydrostatic test shall be reassembled with unused gaskets and re-hydrotested.
- 10.3.10** Paint or other external coatings shall not be applied over welds before the final hydrostatic test.
- 10.3.11** Heat exchangers that are stacked in service shall be hydrotested stacked.

#### **10.4 Nameplates and stampings**

- 10.4.1** A stainless steel nameplate shall be permanently attached to the heat exchanger in such a manner that it is visible after insulation has been installed.
- 10.4.2** The nameplate shall be located on the shell near the channel end.
- 10.4.3** 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.
- 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 bevelled for welding shall be suitably covered to protect the bevel from damage.

- **11.1.7** The purchaser shall specify if there are additional 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 colour and clearly tagged to specify their removal before commissioning.

## 11.2 Identification

**11.2.1** The item number, shipping mass and purchaser's order number shall be painted 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 stencilled (in at least two places 180° apart) on the side of equipment that has been post-weld heat-treated.

## 12 Supplemental requirements

### 12.1 General

- This clause includes additional requirements for design, fabrication and examination that apply to one or both sides of the heat exchanger if specified by the purchaser. In general, these supplemental requirements should be considered if the cylinder thickness of a heat exchanger component exceeds 50 mm (2 in) or if a heat exchanger will be placed in a critical service. The purchaser shall specify if these supplemental requirements shall be applied.

### 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 a full-penetration groove weld with additional fillet or butt welds. They may be set-on, set-in or integrally reinforced forging-type inserts. Set-on type connections shall not be welded to a plate that contains laminations or other defects and shall only be used if the component is 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 and acceptance criteria shall comply with the pressure design code.

**12.3.2** All forgings, except standard flanges designed as described in 7.7, shall be ultrasonically examined in accordance with the pressure design code. The criteria for acceptance shall be agreed upon by the purchaser and the vendor.

**12.3.3** For ultrasonic examination of welds 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 surface;
- d) wedge medium for angle-beam examination.

**12.3.4** Magnetic-particle examination shall be performed on all plate edges and openings before welding. Any defects found shall be removed and any necessary repairs performed.

**12.3.5** Magnetic-particle examination shall be performed on all pressure-retaining welds. 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.

**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.

**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** On 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** A full radiographic examination shall be performed on all pressure-retaining butt welds.

**12.3.11** An ultrasonic examination shall be performed on all pressure-retaining butt welds after post-weld 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 a 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 upon by the purchaser and the vendor.

## Annex A (informative)

### Recommended practices

#### A.1 Introduction

This annex has been prepared to give advice to the designer in particular areas outside the scope of this International Standard. The advice is not mandatory and is offered for guidance only.

#### A.2 Design

##### A.2.1 Tube failure in high-pressure units — Guidance to Clause 7

The effects of potential overpressure caused by tube rupture should be considered.

NOTE 1 For further information, see ISO 23251.

NOTE 2 For the purpose of this provision API 521 is equivalent to ISO 23251.

##### A.2.2 Tube bundle and tubes — Guidance to 7.6.1

**A.2.2.1** For U-tube type bundles, if the mean bend radius is less than three times the tube outside diameter, the tube wall thickness should be increased to compensate for thinning in the bends. Such thinning can be as much as 17 %.

**A.2.2.2** In calculating the effective surface, the purchaser and vendor should agree as to whether the "U" bend region should be included.

##### A.2.3 Transverse baffles and support plates — Guidance to 7.6.3

Segmental baffles are conventional in shell-and-tube heat exchangers, as described in 7.6.3. Other designs such as rod-baffles, helical baffles, expanded-metal baffles and twisted tube designs may be permitted if agreed with the purchaser.

##### A.2.4 Tube bundle skid bars — Guidance to 7.6.6

**A.2.4.1** For 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 1 220 mm (48 in), or the length exceeds 7,3 m (24 ft), the following options may be considered:

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

**A.2.4.2** Skid bars should not obstruct tube lanes or pass-partition lanes if 45° or 90° tube layouts are used.

### A.2.5 Tube-to-tubesheet joint — Guidance to 7.6.7

**A.2.5.1** To minimize crevice corrosion on the shell side, tubes should be contact-expanded into the tubesheet for a length of tubesheet thickness minus 3 mm (1/8 in).

**A.2.5.2** For heat exchangers operating at a pressure above 7 000 kPa (1 000 psi) gauge, tube-to-tubesheet joints should be strength-welded. In addition, expansion of the tubes should be considered.

**A.2.5.3** For heat exchangers in hydrogen service, tube-to-tubesheet joints should be strength-welded and expanded.

## A.3 Fabrication

### A.3.1 Shell — Guidance to 9.1

Openings and attachments (including reinforcing pads and support pads) should clear weld seams by at least 50 mm (2 in). If this construction 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.3.2 Tube-to-tubesheet joints — Guidance to 9.10

**A.3.2.1** For welded-and-expanded tube-to-tubesheet joints requiring post-weld heat treatment, the tubes should be expanded after post-weld heat treatment.

**A.3.2.2** If welded tube-to-tubesheet joints are specified for dissimilar tubes and tubesheet material, weld overlay or cladding should be provided on the tubesheet to eliminate bimetallic welds. The overlay or cladding should have the same metallurgy as the tubes.

**A.3.2.3** If using titanium tubes, tube-to-tubesheet joints should be welded and expanded (if the tubes extend through the tubesheet).

## A.4 Preparation for shipment protection — Guidance to 11.1

**A.4.1** 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.4.2** After draining and drying, internal surfaces may 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)].

## Annex B (informative)

### Shell-and-tube heat exchanger checklist

The checklist is used to note the specific requirements the purchaser shall make in response to the clauses and subclauses in this International Standard alongside which bullets (●) are used to indicate that more information is required or a decision must be made.

Completion of the checklist is the responsibility of the purchaser.

Subclause	Item	Requirement	
4.1	Pressure design code to be used		
4.3	Applicable local regulations		
6.1.2	Flow-induced vibration analysis to be submitted	Yes	No
6.2.2	Welding procedures and qualifications to be submitted for review	Yes	No
6.2.5	Design calculations for supports or lifting and pulling devices to be submitted for review	Yes	No
6.3	Number of copies of reports and records required		
7.1.1	Maximum design temperature (Annex C, line 41)		
	Minimum design metal temperature (MDMT) (Annex C, line 41)		
7.1.3	Expansion joint conditions (Annex C)		
7.7.1	Required flange design code		
7.7.6	Insulation thickness: shell		
	Insulation thickness: channel		
7.7.8	Chemical-cleaning connections required	Yes	No
7.7.9	Loads and moments on connections specified	Yes	No
7.8.7	Design flanges for use of bolt-tightening devices	Yes	No
7.12	Is shell side in hydrogen service?	Yes	No
	Is tube side in hydrogen service?	Yes	No
8.1.1	Sour service (as defined by ISO 15156 or NACE MR0103, as applicable)	Yes	No
9.5.6	Welded tube-to-tubesheet joints required	Yes	No
9.6.2	Heat treatment requirements and procedures for U-tubes		
9.6.5	Post-weld heat treatment of weld-overlaid carbon steel channels and bonnets	Yes	No
9.6.7	Post-weld heat treatment for process reasons: shell side	Yes	No
	Post-weld heat treatment for process reasons: tube side	Yes	No
9.8.3	Special application requiring enhanced flatness tolerance on gasket contact surfaces	Yes	No
10.1.1	Extent of purchaser's inspection		
10.3.5	Additional equipment drying or preservation	Yes	No
11.1.7	Additional requirements for surface preparation and painting	Yes	No
12.1	Supplemental requirements apply to: shell side	Yes	No
	Supplemental requirements apply to: tube side	Yes	No

## Annex C (informative)

### Shell-and-tube heat exchanger data sheets

#### C.1 General

The data sheets in Clause C.2 (in SI units) and in Clause C.3 (in USC units) are provided to assist the designer, vendor and purchaser in specifying the data necessary for the design of a shell-and-tube heat exchanger for petroleum, petrochemical and natural gas services.

Completion of the data sheet 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. To assist in completion of the data sheets, Annex D indicates the minimum information to be provided by the purchaser.

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

Additional data sheets may be required to define the shell-and-tube heat exchanger and examples have been included:

- connection schedule (second page of data sheet), materials of construction (second page of data sheet), gaskets (second page of data sheet); used if the designer/user requires such level of detail to define materials for individual components; these sections may not be necessary if the first page defines the information sufficiently;
- additional remarks, sketches, etc. (third page of data sheet); used for additional remarks if sufficient space is not available on the first page; 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 (fourth page of data sheet); one or two pages can be necessary if boiling and/or condensing fluids with ranges of physical properties occur;
- thermal expansion design information (fifth page of data sheet); required only for exchangers, such as fixed tubesheet or single-pass floating-head type exchangers, where it is necessary for the mechanical design to take account of thermal expansion; this optional page should be included if operating information is supplied to the designer in order to determine the metal temperatures necessary for expansion joint reviews.

C.2 Data sheet (SI units)

Company		<b>SHELL-AND-TUBE HEAT EXCHANGER DATA SHEET (SI UNITS)</b>			Engineering contractor	
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 <sup>2</sup>		Shells/unit:	Effective surface per shell: m <sup>2</sup>		
7	<b>Performance of one unit</b>			Shell side		Tube side
8			Inlet	Outlet	Inlet	Outlet
9	Fluid name:					
10	Fluid quantity, total: kg/h					
11	Vapour: kg/h					
12	Liquid: kg/h					
13	Steam: kg/h					
14	Water: kg/h					
15	Non-condensable/relative molecular mass: kg/h			/	/	/
16	Temperature: °C					
17	Density (vapour/liquid): kg/m <sup>3</sup>			/	/	/
18	Viscosity (vapour/liquid): mPa·s			/	/	/
19	Specific heat (vapour/liquid): kJ/(kg·K)			/	/	/
20	Thermal conductivity (vapour/liquid): W/(m·K)			/	/	/
21	Specific latent heat: kJ/kg @ °C			@	@	@
22	Inlet pressure: kPa (ga)					
23	Velocity: m/s					
24	Pressure drop (allowable/calculated): kPa			/	/	/
25	Fouling resistance: m <sup>2</sup> ·K/W					
26	Average film coefficient: W/(m <sup>2</sup> ·K)					
27	Heat exchanged: kW		Mean temperature difference (MTD): °C		corrected/weighted	
28	Heat transfer rate: W/(m <sup>2</sup> ·K)	Required:	Fouled:	Clean:		
29	ρV <sup>2</sup> : kg/(m·s <sup>2</sup> )	Inlet nozzle:	Bundle entrance:	Bundle exit:		
30	<b>Construction per shell</b>					
31	Tube number:	OD: mm	Nozzles – Number, size and rating			
32	Tube wall thickness: mm	minimum wall/average wall		Shell side	Tube side	
33	Tube pitch: mm	Tube layout:	Inlet:			
34	Tube length: m	Tube type: plain/finned/other	Outlet:			
35	Tube to tubesheet joint:			Intermediate:		
36	Shell diameter: mm (ID/OD)	/	Vent:			
37	Cross-baffle type:			Drain:		
38	Baffle spacing: c/c mm	No. of cross passes:	Pressure relief:			
39	Baffle Cut: %	vertical/horizontal	Design pressure: kPa (ga)			
40	Tube support type:		Vacuum: kPa (abs)			
41	Longitudinal baffle seal type:		Design temp. (Max/MDMT): °C	/	/	/
42	Bypass seal type:		Number of passes per shell:			
43	Impingement protection: (Y/N)	Type:	Corrosion allowance: mm			
44	<b>Materials of construction</b>					
45	Shell:	Tubes:	Gaskets			
46	Shell cover:			Shell side:		
47	Channel or bonnet:			Tube side:		
48	Channel cover:			Floating head:		
49	Floating head cover/bolts:			Spare gaskets required:		
50	Tubesheet: Stationary:	Floating:	Test ring required: (Y/N)			
51	Baffles: Cross:	Longitudinal:	Insulation – shell: mm			
52	Tube support material:		Insulation – channel: mm		inlet/outlet	
53	Expansion joint type:			Expansion joint material:		
54	Pressure design code:	Stamp:	Calculate MAWP: (Y/N)	TEMA Class:		
55	Remarks:					
56						
57						
Rev. No.	Description	Date	Prepared by	Reviewed by		

Company	<b>SHELL-AND-TUBE HEAT EXCHANGER CONNECTIONS AND MATERIALS DATA SHEET (SI UNITS)</b>	Engineering contractor
P.O. No.:	Doc. No.:	Page 2 of

1	Client:	Location:
2	Process unit:	Item No.:
3	Job No.:	Fabricator:
4	<b>Connection schedule (optional)</b>	
5	Mark	Number required
6	Size	Rating
7	Facing	Description
8		
9		
10		
11		
12		
13		
14		
15		
16		
17	<b>Materials of construction (optional)</b>	
18	Shell:	Corrosion allowance
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		
46		
47		
48		
49	<b>Gaskets (optional)</b>	<b>Mechanical data (optional)</b>
50	Shell side: Thickness: mm	MAWP (hot and corroded): kPa (ga)
51	$\gamma =$ Pa $m =$	MAP (new and cold): kPa (ga)
52	Tube side: Thickness: mm	Hydrotest pressure:
53	$\gamma =$ Pa $m =$	Field: kPa (ga) Shop: kPa (ga)
54	Floating head: Thickness: mm	Mass: Empty: kg Bundle: kg
55	$\gamma =$ Pa $m =$	Full of water: kg
56	Rev. No.	Revision
57	Date	Prepared by
58		Reviewed by

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Company	<b>SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL INFORMATION DATA SHEET (SI UNITS)</b>	Engineering contractor
P.O. No.:	Doc. No.:	Page 3 of

1	Client:	Location:
2	Process unit:	Item No.:
3	Job No.:	Fabricator:

**Additional remarks, sketches, etc. (optional)**

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Company	<b>SHELL-AND-TUBE HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (SI UNITS)</b>	Engineering contractor
P.O. No.:	Doc. No.:	Page 4 of

1 Client:	Location:
2 Process unit:	Item No.:
3 Job No.:	Fabricator:

Fluid name:	Ref. Pressure 1:	kPa (abs)
Pressure kPa (abs)	Temp. °C	Enthalpy kJ/kg
		Vapour mass fraction

Density vapour	Density liquid	Viscosity vapour	Viscosity liquid	Thermal conductivity vapour	Thermal conductivity liquid	Specific heat vapour	Specific heat liquid	Surface tension	Liquid critical pressure	Liquid critical temp.
kg/m <sup>3</sup>	kg/m <sup>3</sup>	mPa·s	mPa·s	W/m·K	W/m·K	kJ/(kg·K)	kJ/(kg·K)	N/m	kPa (abs)	°C

Fluid name:	Ref. Pressure 2:	kPa (abs)
Pressure kPa (abs)	Temp. °C	Enthalpy kJ/kg
		Vapour mass fraction

Density vapour	Density liquid	Viscosity vapour	Viscosity liquid	Thermal conductivity vapour	Thermal conductivity liquid	Specific heat vapour	Specific heat liquid	Surface tension	Liquid critical pressure	Liquid critical temp.
kg/m <sup>3</sup>	kg/m <sup>3</sup>	mPa·s	mPa·s	W/m·K	W/m·K	kJ/(kg·K)	kJ/(kg·K)	N/m	kPa (abs)	°C

Rev. No.	Revision	Date	Prepared by	Reviewed by
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