

Design of Shell-and-Tube Heat Exchanger

Procedure

This Standard replaces and cancels its previous revision.

The CONTEC - Authoring Subcommittee provides guidance on the interpretation of this Standard when questions arise regarding its contents. The Department of PETROBRAS that uses this Standard is responsible for adopting and applying the sections, subsections and enumerates thereof.

Technical Requirement: A provision established as the most adequate and which shall be used strictly in accordance with this Standard. If a decision is taken not to follow the requirement ("non-conformity" to this Standard) it shall be based on well-founded economic and management reasons, and be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by imperative nature.

Recommended Practice: A provision that may be adopted under the conditions of this Standard, but which admits (and draws attention to) the possibility of there being a more adequate alternative (not written in this Standard) to the particular application. The alternative adopted shall be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by verbs of a nonmandatory nature. It is indicated by the expression: **[Recommended Practice]**.

Copies of the registered "non-conformities" to this Standard that may contribute to the improvement thereof shall be submitted to the CONTEC - Authoring Subcommittee.

Proposed revisions to this Standard shall be submitted to the CONTEC - Authoring Subcommittee, indicating the alphanumeric identification and revision of the Standard, the section, subsection and enumerate to be revised, the proposed text, and technical/economic justification for revision. The proposals are evaluated during the work for alteration of this Standard.

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Introduction

PETROBRAS Technical Standards are prepared by Working Groups - WG (consisting specialized of Technical Collaborators from Company and its Subsidiaries), are commented by Company Units and its Subsidiaries, are approved by the Authoring Subcommittees - SCs (consisting of technicians from the same specialty, representing the various Company Units and its Subsidiaries), and ratified by the Executive Nucleus (consisting of representatives of the Company Units and its Subsidiaries). A PETROBRAS Technical Standard is subject to revision at any time by its Authoring Subcommittee and shall be reviewed every 5 years to be revalidated, revised or cancelled. PETROBRAS Technical Standards are prepared in accordance with PETROBRAS Technical Standard [N-1](#). For complete information about PETROBRAS Technical Standards see PETROBRAS Technical Standards Catalog.

CONTEC

 Comissão de Normalização
Técnica

SC - 02

Boiler Room

Foreword

This Standard is the English version (issued in 07/2013) of PETROBRAS N-466 REV. J 07/2011. In case of doubt, the Portuguese version, which is the valid document for all intents and purposes, shall be used.

1 Scope

1.1 This Standard complements ISO [16812:2007](#) and establishes the requirements for the mechanical design, material selection, manufacturing, inspection and conditioning of shell-and-tube heat exchangers. This Standard also complements standard PETROBRAS [N-253](#).

1.2 For purposes of this Standard the designation "shell-and-tube heat exchanger" covers heat exchangers in general, and heaters, coolers, reboilers and other shell-and-tube heat exchanging equipment.

1.3 This Standard is not applied to vacuum-operated surface condensers and boiler feed water.

1.4 This Standard is applied to procedures beginning with its date of issuance.

1.5 This Standard contains Technical Requirements and Recommended Practices.

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 applies.

PETROBRAS [N-253](#) - Pressure Vessel Design;

ABNT [NBR 8402](#) - Execução de Caracter para Escrita em Desenho Técnico;

ABNT [NBR ISO 4287](#) - Especificações Geométricas do Produto (GPS) - Rugosidade: Método do Perfil - Termos, Definições e Parâmetros da Rugosidade;

ISO [16812:2007](#) - Petroleum, Petrochemical and Natural Gas Industries - Shell-and-Tubes Heat Exchanger;

ISO [23251](#) - Petroleum, Petrochemical and Natural Gas Industries - Pressure-Relieving and Depressuring Systems;

ASME [B1.1](#) - Unified Inch Screw Threads (UN and UNR Thread Form);

ASME [BPVC - Section II - Part A-1 - SA-263](#) - Stainless Chromium Steel-Clad Plate;

ASME [BPVC - Section II - Part A-1 - SA-264](#) - Stainless Chromium-Nickel Steel-Clad Plate;

ASME [BPVC - Section II - Part A-1 - SA-265](#) - Nickel and Nickel-Base Alloy-Clad Steel Plate;

ASME [BPVC - Section II - Part A-1 - SA-450/SA-450M](#) - General Requirements for Carbon, Ferritic Alloy, and Austenitic Alloy Steel Tubes;

ASME [BPVC - Section II - Part A-1 - SA-578/SA-578M](#) - Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications;

ASME [BPVC - Section VIII - Division 1:2009](#) - Boiler and Pressure Vessel Code - Section VIII - Pressure Vessels - Division 1 - Rules for Construction of Pressure Vessels;

ASME [BPVC - Section VIII - Division 2:2009](#) - Boiler and Pressure Vessel Code - Section VIII - Rules for Construction of Pressure Vessels - Division 2: Alternative Rules;

ASME [BPVC - Section IX](#) - Boiler and Pressure Vessel Code - Section IX - Qualification Standard For Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators Welding and Brazing Qualifications;

ASME [PCC-1:2010](#) - Guidelines for Pressure Boundary Bolted Flange Joint Assembly;

ASTM [A262](#) - Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels;

ASTM [E140](#) - Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness;

ASTM [E309](#) - Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation;

ASTM [F436](#) - Standard Specification for Hardened Steel Washers;

[TEMA](#) - Standards of Tubular Exchanger Manufacturers Association.

NOTE For documents referred in this Standard and for which only the Portuguese version is available, the PETROBRAS department that uses this Standard should be consulted for any information required for the specific application.

3 Terms and Definitions

For the purposes of this document, the terms and definitions given in ASME [BPVC - Section VIII - Division 1:2009](#), Appendix 3 and ISO [16812:2007](#) and the following.

3.1

clad

anti-corrosive metallic coating. May be obtained through processes of co-lamination, explosion or weld deposit

3.2

differential pressure

maximum difference between the pressures applied on the shell and tube side

3.3

heat treatment for stress relief

heat treatment aiming to relieve the residual stresses of welding, performed as per ASME [BPVC - Section VIII - Division 1:2009](#)

3.4

tubing

comprising tubing are tubes, tubesheets, floating head, chicanes, stems, nuts, impingement plate, skid bars and sealing bars

3.5**bimetallic tube**

tube composed of two other tubes extruded in a different material

3.6**strength-welding for tube-to-tubesheet connection**

weld which resistance is higher than that of the tube, i.e., tube must be the failure point in case of pulling-off testing

4 Symbols and Abbreviations

ASME	- American Society of Mechanical Engineers;
BFW	- Boiler Feed Water;
ISO	- International Organization for Standardization;
PMTA	- Maximum Allowable Working Pressure;
TTAS	- Heat Treatment after Welding. Includes any heat treatment after welding, such as hydrogenation, heat treatment for stress relief, among others;
TTAT	- Heat Treatment for Stress Relief;
US	- Ultra-Sound Testing.

5 General Requirements**5.1 Technical Requirements for Presentation of Proposals and Design**

The technical requirements which are considered to be the minimum necessary for presentation of proposals and design of heat exchangers shall be in accordance with ISO [16812:2007](#), items 5 and 6.

5.2 Designer's Responsibility

5.2.1 The designer's responsibilities are defined in standard PETROBRAS [N-253](#).

5.2.2 In those cases where PETROBRAS provides Data Sheets, basic drawing showing the arrangement and general dimensions, technical specification or other specific document for the heat exchanger, the thermal and mechanical designs shall fully comply with those documents that prevail over this Standard. Any discrepancies or alternatives suggested will only be accepted after being expressly approved by PETROBRAS.

5.3 Types of Heat Exchanger

5.3.1 As specified in ISO [16812:2007](#), the shell-and-tube heat exchangers shall be in accordance with the types indicated in the standard [TEMA](#). For any heat exchanger that does not precisely correspond to any of the standardized types referred to in the preceding item, a description and drawings giving complete details.

5.3.2 Use of the F-type [TEMA](#) shell shall be submitted for prior approval of PETROBRAS (shell with 2 passes) for cases in which:

- temperature change in shell side is over 190 °C for conventional exchangers or 50 °C in case of the D-type [TEMA](#) channel, with high pressure on the tube side and low pressure on the shell side;
- pressure loss at shell side exceeding 49 kPa (0,5 kgf/cm²).

NOTE In order to allow analysis, prior to any release for use of the F-type shell, the designer shall provide and submit to PETROBRAS:

- a) the physical and thermal leakage analysis via longitudinal chicane;
- b) analysis of possibility of distortion of the leaking and girth flanges due to the thermal operation gradients and to those of eventual restriction to the free expansion of the shell, such as the "banana effect" on the shell.

5.4 Mechanical Design

The mechanical design of the heat exchangers shall be done in compliance with ASME [BPVC - Section VIII - Division 1:2009](#), with standard PETROBRAS [N-253](#), as well as [TEMA](#) R-class, as applicable. The design, in accordance with [TEMA's](#) B or C classes, needs prior approval from PETROBRAS.

6 Design Criteria

6.1 Pressure

6.1.1 The design pressure shall be determined in accordance with ASME [BPVC - Section VIII - Division 1:2009](#).

6.1.2 Except as expressly accepted by PETROBRAS, no part of the exchanger may be designed for differential pressure.

6.1.2.1 Where the heat exchanger is designed for differential pressure, provision shall be made for a safety system (PSV or rupture disc) ensuring this design condition for components subject to pressure at the same time on both the shell side and the tube side.

6.1.2.2 A warning plate shall be used in heat exchangers designed for differential pressure. The design indication for differential pressure shall be recorded also in the heat exchanger's tag plate.

6.2 Temperature

6.2.1 The design temperature shall be determined as per ISO [16812:2007](#).

6.2.2 The temperature for determining the allowable stress on bolts, studs, nuts and gaskets shall be the same as that of the respective flange. For flanges used for connecting the channel to the shell (or the channel to the tubesheet and shell) the temperature for determining the allowable stress in the studs shall be the highest temperature between the shell flange and the channel flange.

6.2.3 The stud design temperature must be based on the hottest fluid temperature, except when indicated otherwise.

6.2.4 For heat exchangers with more than a single shell in series, different design temperatures shall be established for each shell, in accordance with the operating temperatures of each one.

6.2.4.1 That criterion need not be observed when the temperature differences between the various shells do not entail the use of different materials, do not entail:

- a) the use of different materials; or
- b) different allowable stresses; or
- c) the use of an expansion joint.

6.2.4.2 Special care must be taken when the difference in temperature from the shell side to the tube side leads to a material selection which cause welded gaskets in different materials. In this case, aspects which are related to equipment manufacturing, such as weldability and TTAS must be taken into account.

6.3 Other Criteria

6.3.1 The additional stresses due to the weights or resulting from differential thermal expansion shall always be taken into account for the various components, such as girth flanges, floating head and tubesheets. For these components, the distortion effect and the associated external loading must be considered in the leakage risk evaluation. The criterion required for external loading checking is of ASME [BPVC - Section VIII - Division 2:2009](#), paragraph 4.16.

6.3.2 Whenever the maximum operating temperature difference between fluid inlet and outlet exceeds 200 °C, either from tube side or from shell side, the designer must present the calculation memory, considering the distortion effect of girth flanges, floating head and tubesheets.

6.3.3 The additional stresses due to the various pressure loadings, such as own weight and/or secondary stresses induced by thermal gradient must be taken into account, mainly over supports and nozzles, in the heat exchangers' mechanical design, mainly in which have more than 1 shell directly connected between them. The manufacturer must require to PETROBRAS wind loading and loads originated from the flexibility calculation in the tubings connected to the heat exchanger's nozzles.

6.3.4 Heat exchangers that are identical or of the same type, shall contain the largest possible number of exchangeable parts. In particular, the tube bundle and test ring shall be exchangeable with other exchangers, whenever this is economically viable.

6.3.5 The designer must mechanically size the exchanger, considering the various loadings during assembly and lifting. The manufacturer must present the lifting plan and indicate the heat exchanger's gravity center.

6.3.6 As opposed to ISO [16812:2007](#), the vertical heat exchangers must be designed so that the tube bundles can be removed from the top of the equipments or that present means for horizontally removing them.

6.3.7 The over-pressure effect that arises from an eventual tube rupture must be provided in the heat exchanger sizing (see ISO [23251](#)).

6.3.8 The designer must submit to PETROBRAS approval the flow-induced vibration analysis. For the mechanical and thermal designed prepared by PETROBRAS, the designer must repeat the vibration analysis every time there is modification to any criterion which results in flow speed change in the shell side or in the tubes support, for example: modifications to the spacing between chicanes, to the passage area in the shell inlet or to the unsupported tubes length, including in the bent section of the U-shaped tubes. This new design shall be submitted again for PETROBRAS approval.

7 Materials

7.1 For all parts in contact with both fluids (e.g. tubes, tubesheets and floating head) material selection shall be based on the corrosiveness of both fluids, relative to that material, and on its tenacity (need of impact testing) relative to the lowest possible temperature, considering the unit's start-up, shutdown and operation conditions, besides the hydrostatic test.

7.2 The material of the tube bundle shall be compatible with the material of tubesheets, so as to avoid formation of a galvanic cell.

7.3 A seamless tube may be used for thermal exchange (example in carbon steel: SA 179) for services where the nozzle flange's pressure class is equal or higher than 600.

7.4 When connection tubes x tubesheet is strength-welded, the tubes must be seamless and hydrostatically tested by the tube manufacturer, as in ASME [BPVC - Section II - Part A-1 - SA-450/SA450M](#).

7.5 Seamed tubes (example in carbon steel: SA-214) when used for corrosive services or for temperatures exceeding 200 °C must be hydrostatically tested (ASME [BPVC - Section II - Part A-1 - SA-450/SA450M](#)) or tested for eddy current, as in ASTM [E309](#).

7.6 Non-metallic anti-corrosive coating, inside the shell, may only be used in exceptional circumstances, when expressly authorized by PETROBRAS.

7.7 Tubesheets may only be provided with anti-corrosive coating (including clad-plate construction) on the tube side, i.e., on the side where the tube ends are expanded or welded. The anti-corrosive coating on the shell side is only allowed when expressly authorized by PETROBRAS, as opposed to ISO [16812:2007](#).

7.8 Clad-plates, as in ASME [BPVC - Section II - Part A-1 - SA-263](#), or [SA-264](#) or [SA-265](#) are considered approved, provided they meet the shear strength test requirement as in these standards and also to the Ultra-Sound Testing as in ASME [BPVC - Section II - Part A-1 - SA-578/SA578M](#), A level.

7.9 As in ISO [16812:2007](#), "clad" (including weld deposit) must only be considered as corrosion-protection. It must not be considered as an element resistant to the mechanical efforts.

7.10 The specified corrosion allowance must be added to the female faces (male and female flanges) and to the grooves (tongue and groove flanges).

7.11 Internal bolts, studs and nuts in contact with fluid, such as the floating head's, shall be made of material assuredly resistant to corrosion by the fluid.

7.11.1 If stress corrosion is possible in the carbon steel studs, the hardness control with heat treatment, if necessary, shall be specified. For example, stud SA-193 Gr B7M.

7.11.2 In order to avoid gripping of austenitic stainless steel nuts and studs due to "galling" effect, the designer must prevent it using the appropriate lubricants in the studs, as allowed by temperature, or through selection of appropriate materials (nuts or studs) for use in higher temperatures.

7.11.3 For ¹⁾ “Breech Lock Closure”-type and/or “Screw Plug Closure”-type heat exchangers, where both sides are subject to high pressure (HH-type), the designer shall meet 6.2.4.2, where material selection may produce a dissimilar welding, which must be checked as to its weldability and heat treatments.

8 Shell and Reel

8.1 For heat exchangers which tube side fluid demands an anti-corrosive coating, it shall extend all the way around the insertion slots of the pass partitions and the entire seating area of the sealing gasket.

8.2 In order to make an easy removal of the tube bundle, the following items shall be provided:

- a) sliding trails when shell is coated;
- b) skid bars secured to the chicanes, whenever bundle weight exceeds 29,5 kN (3 000 kgf);
- c) slide bars and trails: if the tube bundle exceeds 53,6 kN (5 450 kgf).

8.3 A support welded to the coil must be provided in order to facilitate the use of **TEMA** D-type tube bundle hydraulic extractors (such as “Screw Plug” or “Breech Lock Closure[®]”) to allow fixation of the extractor device (see Figure 1).

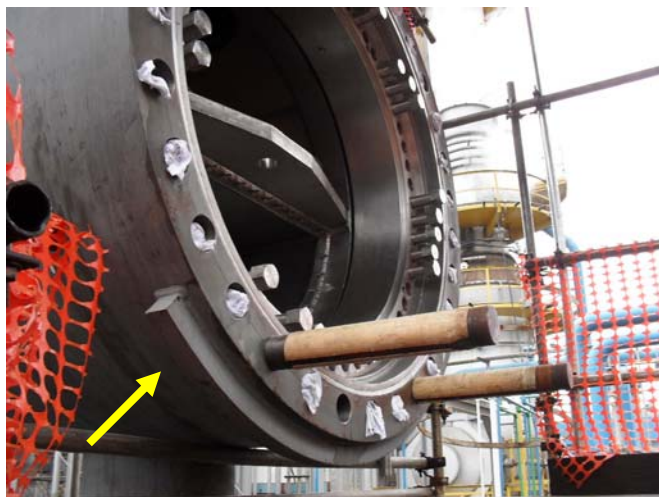


Figure 1 - Welded Support to the Breech Lock Closure[®] Coil

¹⁾ Breech Lock Closure[®] is the trade name of a product supplied by Breech Lock Closure, is an example of a suitable product available commercially. This information is given for the convenience of users of this Standard and does not constitute an endorsement by PETROBRAS of the product named. Equivalent products may be used if they can be shown to lead to the same results.