TECHNICAL SPECIFICATION

SELECTED CONSTRUCTION MATERIALS FOR SHELL AND TUBE HEAT EXCHANGERS

DEP 31.21.01.31-Gen.

December 2004

DESIGN AND ENGINEERING PRACTICE

PREFACE

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the selection of construction materials for shell and tube heat exchangers.

The general selection of construction materials should be made after careful consideration of the design and operating conditions, the corrosivity of the fluids involved and all potential degradation mechanisms. This should be done in consultation with the materials/corrosion engineering department. Once the general selection has been determined, the lists in this DEP will enable effective specification of all heat exchanger parts.

This DEP contains a matrix with generic material designations for non-fired shell and tube heat exchangers including coolers, condensers and reboilers.

The range of materials has been expanded to include other material groups including low alloy steels, low temperature steels, duplex stainless steels and titanium. The recommendations are shown in the matrix. This still leaves many materials and materials combinations un-addressed; for instance, high-alloy stainless steel tube bundles. A materials and corrosion specialist shall be consulted for materials combinations not covered by this DEP. Particular combinations and restrictions for exploration and production facilities are governed by DEP 39.01.10.11-Gen.

Shell and tube heat exchangers shall be considered to be pressure vessels. The construction materials specified in this DEP are limited to those for the tube bundle and channels (tube side). The materials for the shell are not sufficiently distinctive from other pressure vessels to justify a separate DEP. Therefore shell materials selection shall be in compliance with the selected pressure vessel standard such as DEP 31.22.10.32-Gen., DEP 31.22.11.32-Gen. or DEP 31.22.20.31-Gen.

The lower design temperature of the heat exchanger shall be determined according to DEP 30.10.02.31-Gen., and any additional requirements of that DEP shall be adhered to.

A materials specialist shall be consulted to prevent possibility of the selected bundle material having an undesired influence on the shell construction or, for instance, if galvanic effects between bundle and shell are possible.

This DEP is a revision of the DEP of the same number dated November 1989; it is impractical to summarise the differences, see (1.5).

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company and, where necessary, to Contractors and Manufacturers nominated by them.

This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and where applicable, supply/marketing installations. When DEPs are applied, a Management of Change (MOC) process should be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic, and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (4).

1.5 CHANGES FROM PREVIOUS EDITION

This DEP constitutes a complete revision of the DEP of the same number, dated November 1989. It is impractical to summarise the differences herein.

The six lists in the previous version of this DEP have been converted into a single matrix. Nomenclature has remained the same, individual item numbers are referred to in the drawings.

Materials for the shell side of the heat exchangers are no longer included (see 1.1); item numbers for the shell side have been omitted from the table but retained in the drawings.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the DEP Administrator at standards@shell.com. Shell staff may also post comments on this DEP on the Surface Global Network (SGN) under the Standards/DEP 31.21.01.31-Gen. folder. The DEP Administrator and DEP Author monitor these folders on a regular basis.

2. CLASSIFICATION OF MATERIAL DESIGNATION LISTS

(Appendix 1, Table A-1) gives a basic materials selection guide for a number of generalised service conditions. ‘General non-corrosive service’ assumes that both the shell side and tube side are exposed to non-corrosive products. ‘Non corrosive service, low temperature’ assumes that both the product side and the heating medium side are exposed to non-corrosive products. Definitions for cooling water corrosivity are given in (3.3).

Seven main groups of materials have been considered; they are given in (Appendix 1, Table A-2):

A. Carbon steel
B. Low temperature carbon steel
C. Low alloy and stainless steels
D. Copper-based alloys
E. Duplex stainless steels
F. Alloy 400 (Monel)
G. Titanium

The most common types of heat exchangers are considered in Table A-2, including fixed tube sheet, floating head and hairpin bundle designs. It is not the intention to cover all possible heat exchanger designs, although variants will generally require similar materials selection.

3. GENERAL

3.1 SPECIFICATION OF MATERIALS

The generic materials grouping listed in this DEP are in line with the materials designations given in DEP 30.10.02.11-Gen. This DEP identifies materials by reference to ASTM standards. Equivalent ISO or CEN standards are listed in DEP 30.10.02.11-Gen.; these, or other equivalent standards, may also be used with the approval of the Principal..

Materials standards identified on drawings, requisition sheets or other documents shall be specified fully in accordance with the information given in DEP 30.10.02.11-Gen., including all additional requirements.

Whenever the initial materials selection is changed of an existing exchanger is upgraded, engineering calculations shall be produced to clearly demonstrate the suitability of the change. These should be fully in line with the requirements of DEP 31.21.01.30-Gen.

3.2 BUNDLE / TUBE SHEET MATERIALS

The use of longitudinally welded tubes is subject to consultation with the Principal, who will supply additional non-destructive examination requirements to ensure integrity. For a good (roll-) expanded tube-tube sheet connection, redressing of the weld seam is required.

For large heat exchangers it is often more economic to use clad steel. Where corrosion-resistant lining or cladding is specified, it shall be applied to all exposed (wetted) surfaces including the surface of the pass partition plates and the side and bottom of gasket grooves. The cladding shall be integrally and continuously bonded to the base metal. The general cladding thickness shall be at least 3 mm. For tubesheets, all surfaces exposed to the corrosive medium, excluding the gasket seating surfaces, shall have at least 10 mm of cladding thickness if the tubes are expanded only (to allow a groove within the cladding thickness) and at least a 5 mm thickness for a strength welded connection. Brazing shall not be used to bond the cladding to the tubesheet. Integrally-clad tubesheets and tubesheets with cladding applied by overlay welding shall be ultrasonically tested to check the integrity of the bonding in accordance with ASTM A 578, with an acceptance level of S7. The full thickness of the cladding/corrosion-resistant lining shall be used as corrosion allowance, unless specified otherwise by the Principal. Where overlay welding is applied, the chemical composition of the overlay welded areas shall be verified and be in accordance with the specification of the equivalent bulk material.

The specifications for the carbon steel base material are the same as for comparable items made of solid carbon steel, except that “clean steel” or “HIC-resistant steel” are not required if stainless or high alloy steel cladding is fully applied. (Refer to DEP 31.22.20.31-Gen., DEP 31.22.10.32-Gen. and DEP 30.10.60.18-Gen. for further design details with respect to cladding of carbon steel.)

Materials selection for flanges and nozzles of heat exchangers made in whole or in part from alloyed material depends on the type of flange construction. For all constructions the metal at the sealing faces and at the internal surfaces shall be of similar chemical composition as the main alloy.

Some examples of flange constructions are:
- lap-joint flange of carbon steel with a solid alloy stub end;
- slip-on flange of carbon steel plus overlay welded facing;
- welding-neck flange with overlay welded facing.

Some heat exchangers with fixed tube sheets require bellows in the shell to compensate for thermal expansion. The materials for this special construction shall be specified separately.

3.3 COOLING WATER CORROSIVITY

It is difficult to clearly define what constitutes corrosive, non-corrosive or mildly-corrosive cooling water and a materials specialist should be consulted in case of doubt. Generally it will be necessary to have the cooling water source evaluated if no "local" references with respect to material performance are available.

The following examples of each condition are given:

Example 1: Non-corrosive cooling water.
Cooling water in a closed or open recirculating system that is fully chemically treated and controlled can generally be regarded as non-corrosive.

Example 2: Mildly corrosive cooling water.
This condition is more difficult to specify. Local circumstances and experience determine whether the material specifications for mildly corrosive cooling water can be followed. Sweet untreated aerated water, e.g. fresh water from a lake, can generally be regarded as mildly corrosive.

Example 3: Corrosive cooling water.
Seawater is considered to be corrosive. Brackish water shall be considered as corrosive as seawater if the average chloride mass fraction exceeds 0.2 %. For fouling aspects, brackish water shall be evaluated separately.

3.4 WATER-COOLED HEAT EXCHANGERS

General restrictions applied to water-cooled heat exchangers are given by DEP 31.21.01.30-Gen.

3.5 COOLERS USING CORROSIVE WATER

Minimum velocities are required to prevent deposition of suspended solids as clay or silt in the tubes and apply to design conditions and during turndown. These depositions may cause corrosion in, for instance, Cu-Ni alloys. Also, a minimum velocity ensures a narrower temperature distribution and hence less risk of fouling by overheating and precipitation.

Corrosive water velocities must be limited for some materials to prevent velocity-induced corrosion as defined in DEP 20.21.00.31-Gen. A lower limit is set to preclude fouling and under-deposit corrosion; an upper limit is set to preclude erosion corrosion. It shall be verified that the indicated limits given in DEP 20.21.00.31-Gen. are not exceeded when the exchanger is being operated at maximum throughput and some of the tubes are plugged.

In addition, uniform velocity distribution over the tubes must be achieved by ample dimensioning of the channels or water boxes. It shall be ensured that anodes placed in the channel do not obstruct the flow to some of the tubes.

When the solubility limit of $CaCO_3$ in corrosive water is exceeded the salt will precipitate. This may occur from 50°C upwards, depending on local conditions. Even when the outlet temperature is below the precipitation temperature, the velocity in any individual tube can be low enough to cause above-average temperatures and precipitation. The flow velocity shall be sufficiently high in every single tube to preclude $CaCO_3$ precipitation.

If process-side conditions allow, the materials selection for a corrosive water-based system shall be as consistent as possible across the entire site or plant (as applicable).

For corrosive water service, copper nickel tubes shall be considered to be the base case solution, provided this material is compatible with the process-side conditions. Copper nickel tubes shall be used in conjunction with copper nickel or nickel-aluminium bronze tube (C63000) tubesheets. In addition to the requirements of the standards for copper nickel tubes, an electrochemical test has to be specified to ensure that harmful oxide films which can form during fabrication are completely removed. These oxide films will cause severe

pitting as they are more noble than the bare tube material. The electrochemical test procedure and requirements are given in (Appendix 2).

Aluminium brass tubes in the fully annealed condition may only be specified as an alternative if the following additional requirements can be satisfactorily achieved:

- Aluminium brass tubes shall be used together with aluminium bronze tubesheets. Tubes shall be supplied in a suitable condition to allow correct surface passivation, and sacrificial anodes shall be used in accordance with the requirements of (3.6).

- Where the aluminium brass tubes are integrally finned, they shall only be used in the fully annealed condition (i.e. in addition to any necessary intermediate heat treatments during the manufacturing process, the tubes shall receive a final full-anneal heat treatment after the last finning and straightening operations). This requirement of supply in the annealed condition shall be carefully specified in all purchase orders and quality control procedures.

- Aluminium brass tubes (bare or low-finned) shall be capable of meeting the requirements of the stress corrosion susceptibility tests (as specified in ASTM B 154, ASTM B 858, ISO 196 or ISO 6957).

Copper nickels and aluminium bronzes should be applied either as overlay welding or as explosive cladding or used in the bulk material form. The cladding thickness for tube sheets shall be at least 10 mm as specified in (3.2) to allow a tight (roll) expanded joint connection. Chemical composition of the overlay welded areas shall be verified and in accordance with the specification for the equivalent bulk material.

Where heat exchangers are designed with titanium tubes for use with corrosive water, all surfaces in contact with the water shall be made of either solid titanium or clad/lined with titanium. Tube-to-tubesheet welded connections shall be used when the titanium tubes are used in titanium-clad tubesheets. Metals that are less noble than passive titanium and galvanically couple to titanium will more easily corrode. Copper alloy components shall not be used in conjunction with titanium in corrosive water service. Also, the coupling of titanium tubes to the carbon steel of clad tubesheets shall be taken into account if there will be a corrosive medium on the shell side - particularly so for alkaline conditions which may cause hydrogen charging (hydriding) of the titanium tubes and cause brittle failures.

Titanium tubes shall be specified with a minimum wall thickness to reduce the possibility of vibrational failures and allow the bundles to be retractable. The recommended thicknesses for bare and low-finned tubes are given in DEP 31.21.01.30-Gen.

3.6 CATHODIC PROTECTION

The requirements for the cathodic protection of heat exchangers using sacrificial anodes, impressed current systems or internal coatings are given in DEP 30.10.73.10-Gen.

Studs required for sacrificial anodes shall have the same type of screw thread as used for other bolting of the heat exchanger.

Sacrificial anodes or plates shall not obstruct the tube side flow in such a way that some of the tubes receive less water than the rest.

3.7 GASKET SELECTION

The selection of gaskets depends on the design temperature and design pressure, and the type of service to which the flange and gasket are exposed.

For gaskets of shell nozzles and channel nozzles, the piping class of the connecting piping shall be applied.

If two gasketted joints are compressed by the same bolting, gasket selection and area of gasket facing shall be such as to ensure effective sealing of both joints without crushing of the gasket under the required bolt load. This shall be demonstrated with calculations, for approval by the Principal.

Gaskets shall be selected in accordance with DEP 31.21.01.30-Gen.

4. REFERENCES

In this DEP, reference is made to the following publications:

NOTES: 1. Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

2. The DEPs and most referenced external standards are available to Shell users on the SWW (Shell Wide Web) at http://sww.shell.com/standards.

SHELL STANDARDS

Fouling resistances for heat transfer equipment	DEP 20.21.00.31-Gen.
Metallic materials - selected standards	DEP 30.10.02.11-Gen.
Metallic materials – prevention of brittle fracture	DEP 30.10.02.31-Gen.
Welding of metals (amendments/supplements to API RP 582)	DEP 30.10.60.18-Gen.
Cathodic protection	DEP 30.10.73.10-Gen.
Shell-and-tube heat exchangers (amendments/supplement to ISO 16812)	DEP 31.21.01.30-Gen.
Pressure vessels (amendments/supplements to PD 5500)	DEP 31.22.10.32-Gen.
Unfired pressure vessels (amendments/supplements to EN 13445)	DEP 31.22.11.32-Gen.
Pressure vessels (amendments/supplements to ASME Section VIII, Division 1 and Division 2)	DEP 31.22.20.31-Gen.
Selection of materials for life cycle performance (EP)	DEP 39.01.10.11-Gen.

STANDARD DRAWINGS

Sacrificial anodes for tubulars	S 21.072
Steel sacrificial plates for tubulars 350 mm nom. dia. and larger	S 21.073

AMERICAN STANDARDS

Standard specification for carbon steel forgings, for piping applications	ASTM A 105
Standard specification for seamless carbon steel pipe for high-temperature service	ASTM A 106
Standard specification for seamless cold-drawn low-carbon steel heat-exchanger and condenser tubes	ASTM A 179
Standard specification for forged or rolled alloy-steel pipe flanges, forged fittings and valves and parts for high-temperature service.	ASTM A 182
Standard specification for alloy-steel and stainless steel bolting materials for high temperature service.	ASTM A 193
Standard specification for seamless ferritic and austenitic alloy-steel boiler, superheater, and heat-exchanger tubes	ASTM A 213
Standard specification for electric-resistance-welded carbon steel heat-exchanger and condenser tubes	ASTM A 214
Standard specification for chromium and chromium-nickel stainless steel plate, sheet, and strip for pressure vessels and for general applications	ASTM A 240
Standard specification for stainless chromium steel-clad plate	ASTM A 263
Standard specification for stainless chromium-nickel steel-clad plate, sheet, and strip	ASTM A 264

Standard specification for carbon steel forgings for pressure vessel components	ASTM A 266
Standard specification for seamless and welded ferritic and martensitic stainless steel tubing for general service	ASTM A 268
Standard specification for low and intermediate tensile strength carbon steel plates	ASTM A 283
Standard specification for pressure vessel plates, carbon steel, low- and intermediate-tensile strength	ASTM A 285
Standard specification for seamless and welded steel pipe for low-temperature service.	ASTM A 333
Standard specification for seamless and welded carbon and alloy-steel tubes for low-temperature service	ASTM A 334
Standard specification for carbon and low - alloy steel forgings, requiring notch toughness testing for piping components.	ASTM A 350
Standard specification for pressure vessel plates, alloy steel, chromium-molybdenum	ASTM A 387
Standard specification for pressure vessel plates, carbon steel, for intermediate- and higher-temperature service	ASTM A 515
Standard specification for pressure vessel plates, carbon steel, for moderate- and lower-temperature service	ASTM A 516
Standard specification for straight-beam ultrasonic examination of plain and clad steel plates for special applications	ASTM A 578
Standard specification for steel bars, carbon, hot-wrought, special quality, mechanical properties	ASTM A 675
Standard specification for carbon steel and low-alloy steel pressure vessel component forgings with mandatory toughness requirements	ASTM A 765
Standard specification for through-thickness tension testing of steel plates for special applications	ASTM A 770
Standard specification for seamless and welded ferritic/austenitic, stainless steel tubing for general service	ASTM A 789
Standard specification for seamless and welded ferritic/austenitic stainless steel pipe	ASTM A 790
Standard specification for copper and copper-alloy seamless condenser tubes and ferrule stock	ASTM B 111
Standard specification for nickel-copper alloy (uns n04400) plate, sheet, and strip	ASTM B 127
Standard specification for aluminum-bronze sand castings	ASTM B 148
Standard test method for mercurous nitrate test for copper and copper alloys	ASTM B 154
Standard specification for seamless nickel and nickel alloy condenser and heat-exchanger tubes	ASTM B 163
Standard specification for copper-alloy plate and sheet for pressure vessels, condensers, and heat exchangers	ASTM B 171
Standard specification for titanium and titanium alloy strip, sheet, and plate	ASTM B 265

Standard specification for copper and copper-alloy die forgings (hot-pressed)	ASTM B 283
Standard specification for seamless and welded titanium and titanium alloy tubes for condensers and heat exchangers	ASTM B 338
Standard specification for copper and copper-alloy seamless condenser and heat exchanger tubes with integral fins	ASTM B 359
Standard specification for titanium and titanium alloy castings	ASTM B 367
Standard specification for copper-nickel alloy castings	ASTM B 369
Standard specification for titanium and titanium alloy forgings	ASTM B 381
Standard specification for nickel alloy forgings	ASTM B 564
Standard test method for ammonia vapor test for determining susceptibility to stress corrosion cracking in copper alloys	ASTM B 858
Standard specification for titanium and titanium alloy seamless pipe	ASTM B 861

Issued by:
American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken
PA 19428-2959

EUROPEAN STANDARDS

Copper and copper alloys – Seamless round tubes for heat exchangers	EN 12451
Copper and copper alloys – Rolled, finned seamless tubes for heat exchangers	EN 12452

Issued by:
CENELEC
Rue de Stassart 35
B-1050 Brussels
Belgium

Copies can also be obtained from national standards organizations

INTERNATIONAL STANDARDS

Wrought copper and copper alloys - Detection of residual stress - Mercury (I) nitrate test	ISO 196
Copper alloys - Ammonia test for stress corrosion resistance	ISO 6957

Issued by:
International Organisation for Standardisation
Case Postale 56
Geneva 20
Switzerland CH-1211

Copies can also be obtained from national standards organizations

APPENDIX 1 MATERIALS FOR USE IN SHELL-AND-TUBE HEAT EXCHANGERS AND COOLERS

TABLE A-1 MATERIALS SELECTION GUIDE FOR VARIOUS SERVICES

Service condition	Typical materials group in Table A-2
General non-corrosive service	A
Non-corrosive service at low design temperatures	B, note 1
Corrosive hydrocarbon service	note 2
Non-corrosive cooling water	A
Mildly corrosive cooling water	note 2
Corrosive cooling water	D, G
Other services	note 2

Notes:

1. The lower design temperature of the heat exchanger shall be determined according to DEP 30.10.02.31-Gen., and any additional requirements of that DEP shall be adhered to. Alternative materials shall be selected if material group B (low temperature carbon steel) does not fulfil all the requirements of DEP 30.10.02.31-Gen.
2. Materials selection shall be considered on a case-by-case basis, in discussion with the materials specialist, depending on the process conditions on both the shell and tube sides of the heat exchanger.

TABLE A-2 MATERIALS FOR USE IN SHELL AND TUBE HEAT EXCHANGERS, REBOILERS AND COOLERS

		Materials group						
		A	B	C	D	E	F	G
Item no.	Component	Carbon steel	Low temperature carbon steel [1]	Low alloy; stainless steel	Copper alloys	Duplex stainless steel [2]	Alloy 400 (Monel)	Titanium
2a	Channel – shell (plate, integral casting)	A 285-C A 515-60/65 [5] A 516-60/65 A 106-B [5,6]	A 516-60 A 333-6	A 263-410S A 264-304L/321 A 240-304L/316L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15] B 148-C95800	A 240 **[2]**	B 127-N04400 [14]	B 265-Grade 2 [14]
2b	Channel – head (plate, integral casting)	A 285-C A 515-60/65 [5] A 516-60/65	A 516-60 A 333-6	A 263-410S A 264-304L/321 A240-304L/316L/321	As for channel - shell	A 240 **[2]**	As for channel – shell	As for channel - shell
4a	Channel flange – shell side (forging, integral casting)	A 105 [7,8,9] A 266-Cl2 [7,9]	A 765-II [6]	A 182 F-304L/316L/321 or shell side material	As for channel - shell	A 182-F51/F53	As for channel - shell	As for channel - shell
4b	Channel flange – cover side (forging, integral casting)	A 105 [7,8,9] A 266-Cl2 [7,9]	A 765-II [6]	A 182 F-304L/316L/321 or shell side material	As for channel - shell	A 182-F51/F53	As for channel - shell	As for channel - shell
5a	Stationary tube sheet [3] (with u-tube or floating head) (plate, forging)	A 515-70 (not welded) A 516-70 A 266-Cl2 [7,9]	A 765-II [6] A 516-65/70 [6]	A 263-410S A 264-304L/321 A240-304L/316L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15]	A 240 **[2]**	B 127-N04400 [14]	B 265-Grade 2 [14]
5b	Fixed tube sheets [3,4] (plate, forging)	A 515-70 (not welded) A 516-70 A 266-Cl2 [7,9]	A 765-II [6] A 516-65/70 [6]	A 263-410S A 264-304L/321 A240-304L/316L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15]	A 240 **[2]**	B 127-N04400 [14]	B 265-Grade 2 [14]
6	Floating tube sheet [3] (plate, forging)	A 515-70 (not welded) A 516-70 A 266-Cl2 [7,9]	A 765-II [6] A 516-65/70 [6]	A 263-410S A 264-304L/321 A240-304L/316L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [15]	A 240 [2]	B 127-N04400 [14]	B 265-Grade 2 [14]
7	Floating head flange (forging, integral casting)	A 105 [7,8,9] A 266-Cl2 [7,9]	A 765-II [6]	A 182 F-304L/316L/321 or shell side material	B 283-C63000 B 148-C95800 B 369-C96200 B 369-C96400	A 182-F51/F53	B 564-N04400	B 381-F-2 B 367-C-2
9	Floating head (plate, integral casting)	A 285-C A 515-60/65 [5] A 516-60/65	A 516-60 A 333-6	A 263-410S A 264-304L/321 A240-304L/316L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15] B 148-C95800 B 369-C96200 B 369-C96400	A 240 [2]	B 127-N04400 [14]	B 265-Grade 2 [14] B 367-C-2

TABLE A-2, continued

		Materials group						
		A	B	C	D	E	F	G
Item no.	Component	Carbon steel	Low temperature carbon steel [1]	Low alloy; stainless steel	Copper alloys	Duplex stainless steel [2]	Alloy 400 (Monel)	Titanium
12	Channel cover (plate)	A 285-C A 515-60/65 [5] A 516-60/65	-	-	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15]	A 240 **[2]**	B 127-N04400 [14]	B 265-Grade 2 [14]
16	Tubes	A 179 A 214 [10]	A 179 A 334-6	A 268-TP405/410 A 213-TP304L/316L/321 A 213-T5	B 111-C70600 [16] B 111-C71500 [16] B 111-C71640 [16] B 111-C68700 [16,17]	A 789 **[2]**	B 163-N04400	B 338-Grade 2 [20]
17	Nozzles – tube side (pipe, integral casting)	A 106-B	A 333-6	A 213-TP304L/316L/321	As for channel - shell	A 790 **[2]**	As for channel - shell	As for channel - shell
18	Nozzle flange – tube side (forging, integral casting)	A 105 [7,8,9]	A 350-LF2 Cl1	A 182-F304L/316L/321	As for channel - shell	A 182-F51/F53	As for channel - shell	As for channel - shell
21a	Cladding/lining – channel side	-	-	A 263-410S A 264-304L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15]	-	B 127-N04400 [14]	B 265-Grade 2 [14]
21b	Cladding/lining – tube sheets	-	-	A 263-410S A 264-304L/321	B 171-C61400 [14] B 171-C71500 [14] B 171-C63000 [14,15]	-	B 127-N04400 [14]	B 265-Grade 2 [14]
21c	Cladding/lining – floating head	-	-	A 263-410S A 264-304L/321	B 171-C61400 B 171-C71500 B 171-C63000 [15]	-	B 127-N04400	B 265-Grade 2
22	Baffles and support plates (plate)	A 283-C	A 283-C	A 240-405/410S A 240-304/316	A 283-C [18] B 171-C61400 B 171-C63000	A 240-304/316	B 127-N04400	A 283-C [18]
24	Eye bolt/loosening bolts	A 193-B7	A 193-B7	A 193-B7	A 193-B7	A 193-B7	A 193-B7	A 193-B7
29	Expansion bellows (internal)	[11]	[11]	[11]	[11]	[11]	[11]	[11]
30	Bearing ring (plate)	A 283-C A 675-45/50/55	A 283-C A 675-45/50/55	A 283-C A 675-45/50/55	A 283-C A 675-45/50/55	A 283-C A 675-45/50/55	-	-
31	Internal set of screws of bearing ring	A 193-B7/B7M	A 193-B7/B7M	A 193-B7,B6X, B7M	A 193-B7/B7M	A 193-B7/B7M	A 193-B7/B7M	A 193-B7/B7M
32	Test ring/flange	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel
33	Sacrificial plates/anodes	Zn, Mg [12,13]	-	-	Soft iron [19]	-	-	-
34	Reducer construction (plate, pipe)	A 105 [7,8,9] A 106-B	-	A 387-5/9 A 240-TP405/410S	B 171-C63000	-	-	B 861

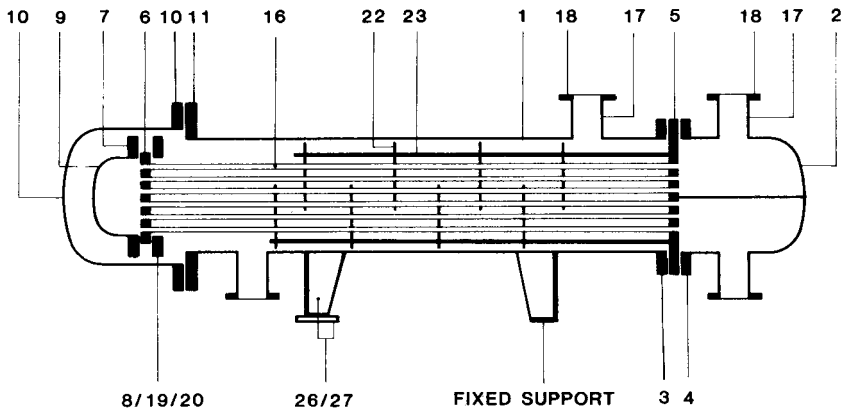
ITEM LIST AND NOTES FOR TABLE A-2

Item No.	Pressure parts	Item No.	Non-pressure parts	Item No.	Other items
1	Shell	22	Baffles and support plates	34	Reducer construction
2a	Channel - shell	23	Seal strips, bars/rods, spacers, strips	35	Stub ring
2b	Channel - head				
3	Shell flange - channel side	24	Eye bolts/loosening bolts		
4a	Channel flange - shell side	25	Weir plates		
4b	Channel - cover side	26	Saddle/brackets		
5a	Fixed tube sheet	27	Sliding plate		
5b	Stationary tube sheet	28	Reinforcing ring for floating head		
6	Floating tube sheet				
7	Floating head flange	29	Expansion bellows (internal)		
8	Clamp ring	30	Bearing ring		
9	Floating head	31	Internal set screws of bearing ring		
10	Cover - shell				
	- head	32	Test ring/flange		
	- flange	33	Sacrificial plates/anodes		
11	Shell flange - cover side				
12	Channel cover				
13	Gasket - shell side/shell cover				
	- floating head				
	- tube side/channel cover				
14	Stud bolt and nuts				
15	Stud bolt and nuts for floating head				
16	Tubes				
17	Nozzles – tube side				
18	Nozzle flange - tube side				
19	Split key ring (chem. service)				
20	Key ring flange (chem. service)				
21a	Cladding/ lining - tube side				
21b	Cladding/ lining - tube sheets				
21c	Cladding/ lining - floating head				

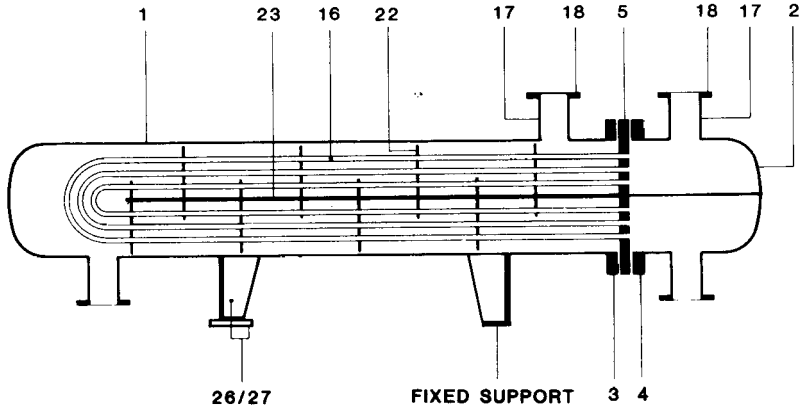
NOTES (for Table A-2)

1 Refer to DEP 30.10.02.31-Gen.
2 UNS S31803, UNS S32205, UNS S32750, UNS S32760
3 Matching tube-tubesheet compositions are preferred
4 For bundles with two fixed tubesheets, ASTM A 516-Gr70/65 may be used if, in addition, a Z-value of 35 % according to ASTM A 770+S3 or SEL 096 Cl.3 is specified and C-content is max.0.23 %.
5 C-content max. 0.23 % for carbon steel.
6 Mn < 1.3 %
7 C < 0.25 %
8 Mn < 1.2 %
9 Normalised
10 Subject to Principal's approval. Requires additional inspection. Redressing of weld seam required for expanded tube-tubesheet connections.
11 Consult a materials and corrosion specialist
12 Composition of sacrificial anodes are given in DEP 30.10.73.10-Gen.
13 For correct mounting of Mg and Zn anodes refer to drawing S 21.072.
14 Or cladded
15 Recommended grade for seawater service
16 Tubes provided with low-fins shall be ordered according to ASTM B 359 or EN 12452
17 Al brass tubes (bare or low-finned) shall only be used in the fully annealed condition and shall be capable of meeting the requirements of the stress corrosion susceptibility tests (as in ASTM B 154, B 858, ISO 196 or ISO 6957).
18 Only for non-corrosive non-aqueous service
19 Required for C68700 tubes. For correct mounting of Fe anodes refer to drawing S 21.073.
20 The wall thicknesses for titanium tubes defined in DEP 31.21.01.30-Gen. Should be complied with to reduce the possibility of vibrational failures and allow retractable bundles.

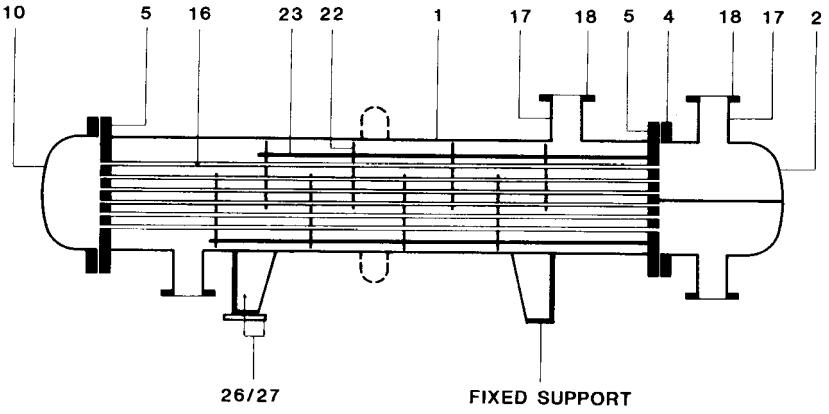
Type A:



Type B:



Type C:

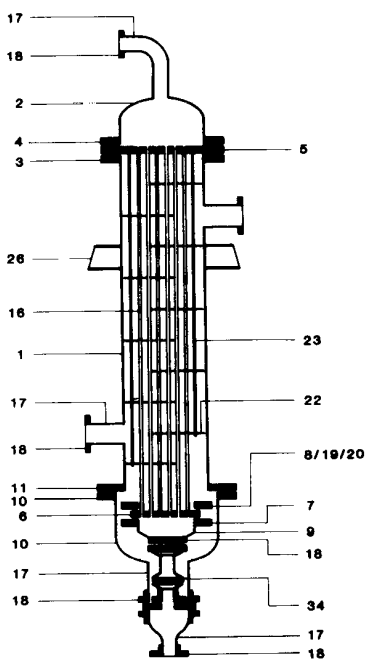


Type A, Floating head heat exchanger

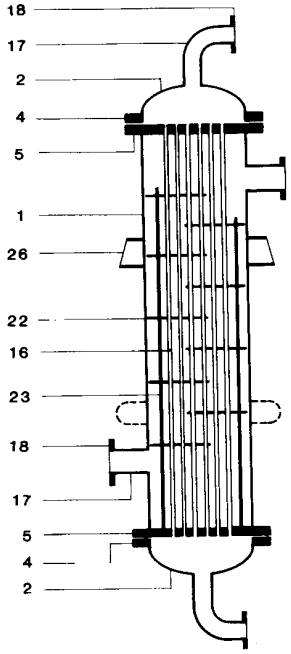
Type B, Hairpin or U-tube heat exchanger

Type C, Fixed tube sheet heat exchanger

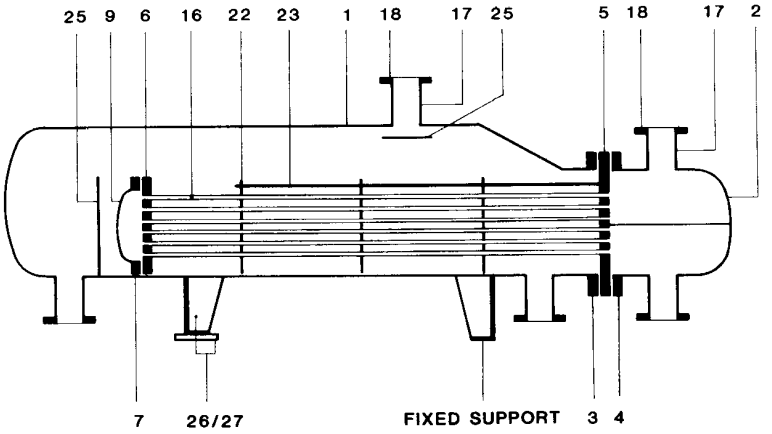
Type A:



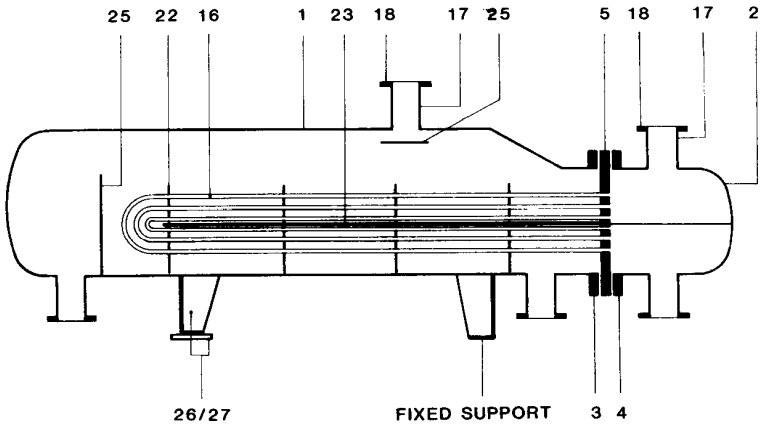
Type B:



Type C:



Type D:

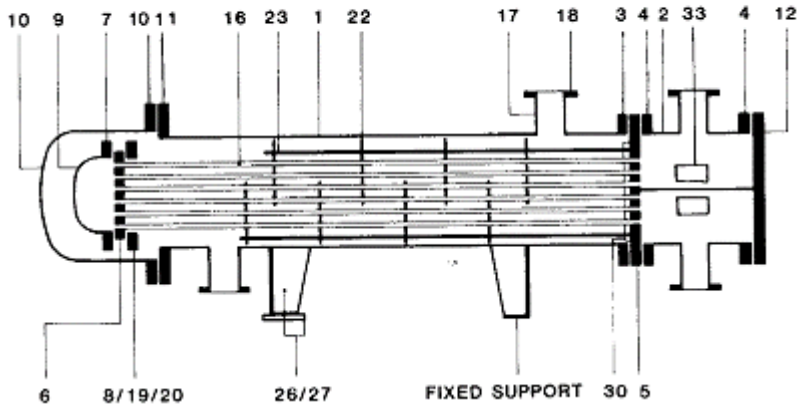


Type A, Vertical reboiler, floating head

Type B, Vertical reboiler, fixed tube sheet

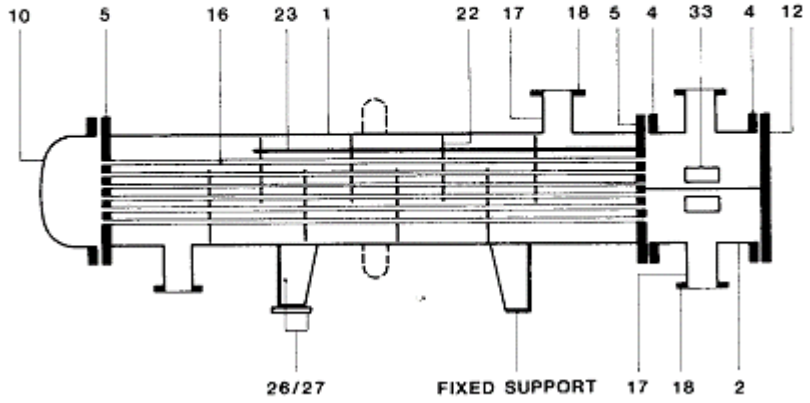
Type C, Kettle type reboiler, floating head

Type D, Kettle type reboiler, hairpin bundle



Floating tube sheet with anodes (tube side)

Fixed tube sheet with anodes (tube side)



APPENDIX 2 METHOD OF DETECTION OF HARMFUL OXIDE FILMS ON COPPER-NICKEL ALLOY TUBES

Applicable to all grades of copper nickel tubes (ASTM B 111, ASTM B 359, EN 12451 and EN 12452)

1.0 GENERAL

A Cu-Ni tube will passivate rather slowly. Generally, it will take a week before the surface is protected. In the meantime, pitting may occur under severe operating conditions. One reason may be that part of the tube is covered with cathodic oxides. To verify this, a measuring method has been developed. The principle of the method is to compare the corrosion (rest) potential E^a_{corr} of freshly abraded tube alloy with the rest potential E^t_{corr} of the tube bore in the as-received condition. The difference, ΔE, $E^t_{corr} - E^a_{corr}$, is a measure of the "nobility" of films on the tube bore surface. The larger the difference, the more cathodic is the tube. A clean, acceptable tube left in the atmosphere will develop an oxide film, which can be up to +0.070 volts cathodic compared to the bare material. Therefore, the criterion for acceptance has been taken as ΔE <+0.070 volts.

The test shall be carried out by the tube manufacturer as part of the final quality control procedure. When the tubes are ordered according to ASTM B 111 or ASTM B 359, one tube shall be tested per lot. When the tubes are ordered according to EN 12451 or EN 12452, the number of tubes to be tested shall be in accordance with the sampling rate table given in those standards.

2.0 PROCEDURE

2.1 Cleaning

Prior to testing, the tube should be degreased thoroughly by pulling a soft cloth, soaked in a petroleum spirit, through the tube and repeating this until the cloth is clean. Allow the solvent to evaporate. The potential E^t_{corr} is noted 10 minutes after inserting the reference electrode.

2.2 Filling with KCl

One end of the tube is plugged with a rubber stopper and, with the tube either vertical or inclined, it is filled with a potassium chloride solution. To enable the steady-state potential to be reached quickly a dilute solution of potassium chloride (0.02 M or approximately 1.5 g/l) shall be used to fill the tube. Potentials shall be measured against silver/silver chloride reference electrode, also in 0.02 M KCl solution, so avoiding liquid junction potentials.

2.3 Measuring potential of "as delivered condition"

Without undue delay the reference electrode, removed from its storage capsule, is carefully lowered into the tube to dip into the solution, so completing the circuit via high impedance millivolt meter, such as Fluke Model 8000 A. (The connections to the meter are: reference electrode to the ground (or black) terminal tube/crocodile clip (**kept dry**) to the positive (red) terminal.).

Note : It is important to prevent the solution wetting either the tube exterior/crocodile clip junction or a freshly cut end of the tube since either possibility will result in false readings.

2.4 Measuring potential of "bare material"

To obtain the value for the freshly abraded tube alloy a piece of tube is stoppered as before with a rubber bung and the outer surface of the tube is abraded with silicon carbide paper under clean water to obtain a bright surface. This is rinsed first with clean water and then with the potassium chloride (KCl) solution (0.02 M) before being immersed in fresh KCl solution into which the reference electrode is placed. A crocodile clip is attached to a dry portion of the tube and the potential E^a_{corr} noted after 10 minutes.

3.0 INTERPRETATION OF RESULTS

For ASTM B111-C71640 or EN 12451-CW353H alloy repeated measurements of many tubes have shown that E^a_{corr} determined by this method is -0.230 ± 0.010 volts.

An acceptable tube has the difference, ΔE, below +0.070 Volts

where $\Delta E = E^t_{corr} - (-0.230)$ volts,

e.g. for an acceptable tube E^t_{corr} may be found to be -0.180 Volts

so that $\Delta E = -0.180 - (-0.230)$

= +0.050 volts

whereas for an unacceptable tube E^t_{corr} would be more positive than -0.160 volts.

4.0 REMOVAL OF AN UNACCEPTABLE CATHODIC OXIDE FILM

Removal of an unacceptable cathodic film (ΔE > +0.07 Volts) may be done by either blast cleaning or acid cleaning. After cleaning the test shall be repeated on representative samples.

5.0 CERTIFICATION

Manufacturers shall issue certificates showing that **each (inspection) lot** of tubes supplied is free of harmful films.