

TECHNICAL SPECIFICATION

PRESSURE VESSELS
(AMENDMENTS/SUPPLEMENTS TO PD 5500)

DEP 31.22.10.32-Gen.

March 2001
(DEP Circular 22/04 has been incorporated)

DESIGN AND ENGINEERING PRACTICE



This document is restricted. Neither the whole nor any part of this document may be disclosed to any third party without the prior written consent of Shell Global Solutions International B.V. and Shell International Exploration and Production B.V., The Netherlands. The copyright of this document is vested in these companies. All rights reserved. Neither the whole nor any part of this document may be reproduced, stored in any retrieval system or transmitted in any form or by any means (electronic, mechanical, reprographic, recording or otherwise) without the prior written consent of the copyright owners.

PREFACE

DEPs (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell Global Solutions International B.V. (Shell GSI)
and
Shell International Exploration and Production B.V. (SIEP)
and
Shell International Chemicals B.V. (SIC)
and
other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, international, regional, national and industry standards.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use DEPs is granted by Shell GSI, SIEP or SIC, in most cases under Service Agreements primarily with companies of the Royal Dutch/Shell Group and other companies receiving technical advice and services from Shell GSI, SIEP, SIC or another Group Service Company. Consequently, three categories of users of DEPs can be distinguished:

- 1) Operating companies having a Service Agreement with Shell GSI, SIEP, SIC or other Service Company. The use of DEPs by these operating companies is subject in all respects to the terms and conditions of the relevant Service Agreement.
- 2) Other parties who are authorized to use DEPs subject to appropriate contractual arrangements (whether as part of a Service Agreement or otherwise).
- 3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

Subject to any particular terms and conditions as may be set forth in specific agreements with users, Shell GSI, SIEP and SIC disclaim any liability of whatsoever nature for any damage (including injury or death) suffered by any company or person whomsoever as a result of or in connection with the use, application or implementation of any DEP, combination of DEPs or any part thereof, even if it is wholly or partly caused by negligence on the part of Shell GSI, SIEP or other Service Company. The benefit of this disclaimer shall inure in all respects to Shell GSI, SIEP, SIC and/or any company affiliated to these companies that may issue DEPs or require the use of DEPs.

Without prejudice to any specific terms in respect of confidentiality under relevant contractual arrangements, DEPs shall not, without the prior written consent of Shell GSI and SIEP, be disclosed by users to any company or person whomsoever and the DEPs shall be used exclusively for the purpose for which they have been provided to the user. They shall be returned after use, including any copies which shall only be made by users with the express prior written consent of Shell GSI, SIEP or SIC. The copyright of DEPs vests in Shell GSI and SIEP. Users shall arrange for DEPs to be held in safe custody and Shell GSI, SIEP or SIC may at any time require information satisfactory to them in order to ascertain how users implement this requirement.

All administrative queries should be directed to the DEP Administrator in Shell GSI.

TABLE OF CONTENTS

PART I	INTRODUCTION	4
1.1	SCOPE.....	4
1.2	DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS	4
1.3	DEFINITIONS	4
1.4	CROSS-REFERENCES	4
PART II	GENERAL INFORMATION AND SHELL DESIGN REQUIREMENTS	5
1.	GENERAL	5
2.	CONSTRUCTION CATEGORIES	5
3.	SHELL DESIGN REQUIREMENTS.....	5
PART III	AMENDMENTS/SUPPLEMENTS TO PD 5500	10
SECTION 1	GENERAL	10
SECTION 2	MATERIALS	12
SECTION 3	DESIGN	13
SECTION 4	MANUFACTURE AND WORKMANSHIP	16
SECTION 5	INSPECTION AND TESTING.....	17
ANNEX E	RECOMMENDATIONS FOR WELDED CONNECTIONS OF PRESSURE VESSELS.....	19
ANNEX AA	ALUMINIUM SUPPLEMENT	20
PART IV	REFERENCES	21

APPENDICES

APPENDIX 1	REQUIREMENTS FOR WELDED PRESSURE VESSELS CONSTRUCTED OF MATERIAL WITH CORROSION RESISTANT INTEGRAL CLADDING, WELD METAL OVERLAY CLADDING OR APPLIED LININGS	26
APPENDIX 2	VESSEL TOLERANCES NOT COVERED IN PD 5500	28
APPENDIX 3	HARDNESS REQUIREMENTS FOR CARBON AND FERRITIC ALLOY STEEL PRESSURE VESSELS	31
APPENDIX 4	CARBON STEEL PRESSURE VESSELS IN WET H ₂ S SERVICE/SOUR SERVICE	32
APPENDIX 5	PREPARATION AND INSTALLATION OF TEST BLOCKS.....	41
APPENDIX 6	REQUIREMENTS FOR EQUIPMENT BUILT FROM Cr-Mo STEELS.....	42

PART I INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for unfired fusion welded pressure vessels, in the form of amendments and supplements to PD 5500 (2000 edition, plus amendment 10830 February 2000).

NOTE BSI have changed the name of the code from BS 5500 into PD 5500 since the European Pressure Equipment Directive became operative.

This DEP is a revision of the DEP with the same number dated December 1996.

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 to Contractors and Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F", as described in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply/marketing installations.

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 the 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

1.3.1 General 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.

1.3.2 Specific definitions

hydrogen service	service in which the hydrogen partial pressure is greater than 7 bar (abs).
very toxic substance	See DEP 01.00.01.30-Gen.

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 in this DEP are listed in (Part IV).

PART II GENERAL INFORMATION AND SHELL DESIGN REQUIREMENTS

1. GENERAL

This DEP is written in four parts. Part III is written in the form of amendments and supplements to PD 5500.

In the event of conflict between documents relating to the enquiry or order, the following hierarchy of documents shall apply:

- | | |
|---------------|---|
| first level: | purchase order and variations thereto; |
| second level: | data/requisition sheets and drawings referred to where explicit deviations from this DEP are indicated. In all other cases any discrepancy between the data/requisition sheets and this DEP shall be brought to the attention of the Principal; |
| | NOTE: The data/requisition sheet(s) for pressure vessels is DEP 31.22.00.94-Gen. |
| third level: | this DEP. |

For easy reference, the clause numbering of PD 5500 has been used in Part III of this DEP. PD 5500 clauses not mentioned in this DEP shall apply as written.

2. CONSTRUCTION CATEGORIES

In addition to the definition of the construction categories in PD 5500, Section 3, chapter 3.4.1, the following additional requirements determine the appropriate category (see also amendment to 3.4.1):

Construction category 1 shall be selected if one or more of the following conditions apply:

- hydrogen service (Part I, 1.3.2);
- very toxic substances (Part I, 1.3.2);
- liquefied gas;
- Cr-Mo steels and other ferritic alloy steels, and carbon steels having a tensile strength greater than 485 N/mm²;
- vessels operating in cyclic service;
- vessels which operate in the creep range of the materials of construction;

Construction category 3 shall be selected for:

- utilities (e.g. low pressure steam, air, water, inert gas).

Construction category 2 shall be selected for conditions not covered by category 1 or 3.

3. SHELL DESIGN REQUIREMENTS

The requirements and choices made from this section shall normally be specified by the Contractor (or Principal) on the data/requisition sheets.

The Manufacturer can then refer to Part III for the detailed technical specification.

3.1 Materials

Materials shall be in accordance with DEP 30.10.02.11-Gen., including the additional requirements specified in the Notes therein. The selected materials standard (and the afore-mentioned Notes) shall be indicated on the data/requisition sheets.

For low temperature services DEP 30.10.02.31-Gen shall apply, to prevent brittle fracture.

A materials/corrosion engineer shall judge whether additional requirements shall be specified for the metallic materials of equipment containing process streams with hydrogen

sulphide (H₂S) in concentrations which could cause any of the wet H₂S cracking mechanisms described in Appendix 4 of this DEP.

Materials selection for hydrogen service (Part 1, 1.3.2) above 230 °C shall be in accordance with API RP 941. The maximum operating conditions (temperature and hydrogen partial pressure) shall be at least 15 °C and 1.5 bar below the applicable material line of API RP 941 Figure 1. This requirement also applies to the carbon and low alloy pressure boundary material of vessels built with a stainless steel corrosion resistant cladding or overlay.

Bolting materials shall be selected from DEP 30.10.02.11-Gen. or DEP 30.10.02.31-Gen. (as applicable), otherwise the approval of the Principal is required.

3.2 Design pressure and temperature

For the definition and determination of temperature and pressure levels, including design pressure and design temperature, see DEP 01.00.01.30-Gen.

For flanges and bolts, the design temperature shall be as in the following table:

Design temperature	% of vessel design temperature	
Flanges	Uninsulated	Insulated
• Lap-joint flanges	85	100
• Other type flanges	90	100
Bolts for Flanges	80	100

3.3 Wind load

Wind loads shall be determined in accordance with Appendix 1 of DEP 34.00.01.30-Gen., unless deviation is necessary to comply with national and/or local regulations. The wind pressure either at the top of the equipment or, for equipment with an overall height over 30 metres and/or having a length to diameter ratio larger than 10, at different specific elevations shall be stated on the data/requisition sheets. The calculation of the stated wind pressure shall take into account the applicable correction factor for the aspect ratio (K) of the equipment.

Equipment having an overall height to diameter ratio larger than 10 may be prone to vortex shedding, and the following shall be considered:

- piping and platforms shall be distributed around the circumference of the equipment, especially within the top third part of the equipment, to prevent vortices being formed;
- if the above is not possible (e.g. only one overhead line and only rest platforms every 6 metres), and if the eddy shedding frequency is within 70% of the natural frequency of the equipment, three wind deflectors shall be installed with a width of $\frac{1}{10}$ of the equipment diameter, evenly spaced in circumference and having a pitch of 5 times the diameter of the equipment, within the top third part of the equipment.

Alternatively, dynamic damping devices may be considered.

3.4 Fatigue analysis

The Principal shall specify on the data/requisition sheets whether a detailed fatigue analysis is required, to be performed by the Manufacturer. (To decide whether such an analysis is required, the Principal may use PD 5500, Annex C, Section C.2).

If a detailed fatigue analysis is specified, the Principal shall specify the required fatigue service lifetime and all operating data necessary for the Manufacturer to perform the analysis. If a vessel is intended to be used in a service where more than one set of operating parameters (pressure and temperature) is envisaged (e.g. catalyst regeneration,

batch processes, etc.), the data shall include this information and shall state the duration of each envisaged operating mode.

3.5 Creep analysis

If the vessel is operating in the creep range of the intended construction material, usually above 500 °C, a creep analysis shall be performed.

The Principal shall specify the required service lifetime and all operating data, necessary to perform the analysis. If a vessel is intended to be used in a service where more than one set of operating parameters (pressure and temperature) is envisaged, the data shall include this information and shall state the duration of each envisaged operating mode.

3.6 Corrosion allowance and cladding/lining

3.6.1 Corrosion allowance

The corrosion allowance for vessels shall be as follows, unless otherwise specified by the Principal:

Service	Material	Corrosion allowance
general process	carbon steel and low-alloy steel	3 mm
non-corrosive or very mildly corrosive (e.g. steam, dry compressed air, LPG, LNG and dry natural gas)	carbon steel and fine grain carbon steel	1 mm
Service in which the operating temperature is always below 0 °C	fine grain carbon steel, 3.5% Ni steel and 9% Ni steel	1 mm
	aluminium and stainless steel	none

The corrosion allowance for removable internals shall be as follows:

Item	Corrosion allowance
Stainless steel internals	none
Heavily-loaded components (catalyst grids, etc.) in non-clad equipment made from carbon or low-alloy steel	50% of the corrosion allowance specified for the vessel shall be applied to each surface of the internal

3.6.2 Cladding/lining

The effective thickness of a cladding/lining will depend on the corrosion rate expected, and shall be subject to the approval of the Principal. Generally, no additional corrosion allowance is needed unless specified. See also Appendix 1 of this DEP.

Loose linings shall not be applied.

For the requirements for process equipment with internal chemical-resistant brick lining, see DEP 30.48.60.13-Gen. For dense refractory concrete linings, see DEP 64.24.32.30-Gen. For the requirements for glass-lined process equipment, see DEP 30.48.70.30-Gen.

3.7 Nozzles, openings and branch connections

Continuous liquid outlets on columns and vessels shall each be provided with a vortex breaker, see Standard Drawing S 10.010, and in the following cases internally extended vortex breakers shall be used:

- in fouling service;
- for the hydrocarbon liquid outlets of separators where the liquid is separated from water or aqueous solutions, except where this would give rise to corrosion problems in the bottom.

External nozzle loadings shall be specified on the data/requisition sheets.

3.8 Vessel supports

Supports shall be designed so that the metal temperature of the part of the support resting on concrete will not exceed 100 °C. For vessels with operating temperatures below ambient, this temperature shall be such that no condensation will occur under normal operating conditions. The mechanical design shall provide for insulation sealing, adequate surface protection and prevention of condensate collecting areas.

If full skirts are specified they shall be constructed in accordance with Standard Drawing S 20.001. There shall not be any flanged connection inside full skirts.

If half skirts are specified they shall be constructed in accordance with Standard Drawing S 22.005. Half skirts shall not be used for vessels with fire proofing or for vessels connected to piping that is prone to vibration.

Legs may be used as supporting structures in proven applications.

If saddles are specified they shall be constructed in accordance with Standard Drawings S 22.001 or S 22.002.

All vessel supports shall be provided with at least 2 earthing bosses in accordance with Standard Drawing S 68.004.

3.9 Lifting trunnions and other attachments

All vertical vessels shall be provided with lifting trunnions, attached by full penetration welds, or lifting lugs as specified on the data/requisition sheets. The tail end of vertical vessels that have a mass greater than 20 tonnes shall be provided with a tailing lug (or lugs).

Lifting lugs and trunnions shall be designed for a total load of 1.5 times the lifted weight of the equipment to allow for dynamic effects, etc., except lifting lugs and trunnions on vessels liable to be lifted from an offshore barge, etc., which shall be designed for a total load of 3 times the lifted weight. If vessels are dressed up, all lifting attachments shall be designed for the dressed weight. When tail lugs are fitted, the base ring and internal strengthening members shall be designed for the most severe lifting condition.

See for lifting trunnions for vertical vessels Standard Drawing S 10.115. To avoid corrosion, heat loss and thermal stress, lifting trunnions shall be removed after erection.

Cleats for ladders and platforms, insulation support rings and clips for steamtracing shall be fabricated in trapezium form to avoid corrosion under insulation. See Standard Drawings S 20.003, S 28.012, S 28.013 and S 28.014.

3.10 Bolted flanged connections

The Principal may specify the use of standard flanges other than ASME B16.5 or ASME B16.47, e.g. if the site is standardised on these other types, in which case the ratings and design requirements shall be checked against code requirements.

Spiral wound gaskets are the preferred type of gaskets for flange sizes up to DN 600 (24"), preferably graphite filled and provided with a compression stop via inner and outer rings. These rings shall be specified for this purpose, except in cases where the flange geometry provides such a compression stop (e.g. confined gaskets for heat exchangers). Tongue and groove jointing shall not be used. For larger flange sizes metal grooved ring (cam-profile) gaskets have proven to be reliable, especially with heat exchangers.

Bolting and threads shall comply with ISO metric standards if this is standard practice for the location (which shall be stated on the data/requisition sheets). See also Standard Drawings S 10.035 and S 10.116.

For bolt tensioning applications see DEP 31.38.01.11-Gen. and for bolt tensioning equipment see DEP 70.08.10.11-Gen. Bolt pitch and flange hub details shall allow for the use of bolt tensioning equipment where specified.

3.11 Manholes and inspection openings

Manholes shall have a minimum clear inside diameter of 460 mm; however, nominal pipe sizes DN 500 (20"), DN 600 (24") and DN 750 (30") are preferred. The nominal minimum diameter for inspection openings (hand holes) is DN 150 (6").

For the required sizes of access openings in columns with removable trays, see DEP 31.20.20.31-Gen.

Davits shall be provided for all openings DN 300 (12") nominal up to and including DN 750 (30"). Typical details are shown in Standard Drawing S 10.070, except for vessels in low-temperature service, for which the covers shall be hinged.

Hand hole covers shall be provided with a grip, see Standard Drawings S 10.039, S 10.053 and S 10.054.

If davits are to be provided for servicing components having a mass greater than 25 kg, mounted at the top or attached to the sides of columns taller than 20 m, this shall be specified on the data/requisition sheets. If required, davits shall be provided in accordance with Standard Drawing S 28.015.

3.12 Surface protection

The external surface of pressure vessels shall be prepared and painted in accordance with DEP 30.48.00.31-Gen. Internal surfaces shall not be painted unless so specified by the Principal, in which case a paint system selected from DEP 30.48.00.31-Gen shall be indicated on the data/requisition sheets.

PART III AMENDMENTS/SUPPLEMENTS TO PD 5500

SECTION 1 GENERAL

1.1.1 Add to this clause:

The following types of pressure vessels and components are not allowed for construction categories 1 and 2 vessels:

- pressure vessels constructed by brazing;
- pressure vessels or parts fabricated by casting;
- layered pressure vessels, unless authorised by the Principal;
- forged pressure vessels, unless authorised by the Principal;
- threaded, expanded and flued openings;
- screwed connections/constructions are not allowed on the primary pressure boundary.

NOTE: The above amendment is applicable to all further clauses in PD 5500 related to these subjects.

1.5.1 Add to this clause:

- g) The year of issue of any additional standards or codes being used and, where applicable, the published amendments thereto.

1.5.2.2 Add to this clause:

- h) Items 1, 2, 7 and 9 from Annex S.
- i) The contents of the manufacturing report shall be in accordance with DEP 31.22.10.35-Gen. The format of the manufacturing report shall be in accordance with the Manufacturer's standard or DEP 31.22.10.35-Gen.

Table 1.5 Add to this table:

Purchaser option or feature requiring approval by purchaser (Part, Section)	Classification (see 1.5.2.2 (e))
Any departure from this DEP to meet national and/or local regulations (Part I, 1.2)	Basic requirement
Use of grade M1 steel above 485 N/mm ² (Part III, 2.1.1.1)	Basic requirement
Corrective actions for hardness (Part III, 2.3.2.12)	Basic requirement
Flanges other than raised-face, WN (Part III, 3.8.1)	Variation
Accepted gasket suppliers (Part III, 3.8.1)	Basic requirement
Sheet gasket thickness if not 1.5 mm (Part III, 3.8.1)	Variation
Accepted weld details (Part III, 3.10.1)	Basic requirement
Use of Contractor's own despatch forms (Part III, 4.1.1)	Variation
Alternative joint details (Annex E)	Variation
Ultrasonic examination (Annex AA, 5.6.5.1)	Basic requirement
Alternative lining methods (Appendix 1, item 1)	Basic requirement
Calibration of ferrite scope (Appendix 1, item 7-2)	Basic requirement
Use of single-layer overlay (Appendix 1, item 9)	Basic requirement
Crack detection method and testing intensity for weld overlay deposits (Appendix 1, item 17)	Basic requirement
Alternative portable hardness tester (Appendix 3, 2.1) (Appendix 4, 3.7.2)	Variation
Use of hot-finished material (Appendix 4, 3.2)	Variation
Intentional addition of micro-alloying elements (Appendix 4, 3.2) (Appendix 4, 4.2.3)	Variation
Alternative heat treatments (Appendix 4, 4.1)	Variation
Use of ASTM 841 TMCP steel (Appendix 4, 4.2.1)	Variation
Alternative methods of inclusion shape control (Appendix 4, 4.2.2)	Variation
Witnessing party for inspection certificates type 3.1.C (Appendix 4, 5.1.1)	Basic requirement

SECTION 2 MATERIALS

2.1.1.1 Add to this clause:

Materials of Grade M1 with specified minimum tensile strength (R_m) exceeding 485 N/mm^2 may be used if the Manufacturer can prove that satisfactory welding results have been achieved (with either test plates or previous vessels); this shall be subject to the approval of the Principal.

Plates for equipment in hydrogen service shall be ultrasonically examined in accordance with EN 10160, grade S₂E₂. For clad materials in this service, see Appendix 1 of this DEP.

Add new clause:

2.1.1.1.1 Cr-Mo equipment

For equipment built from 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo and 3Cr-1Mo steels, the requirements of Appendix 6 of this DEP shall apply.

2.1.1.2 Add to this clause:

Material inspection certificates shall be in accordance with ISO 10474 type 3.1.B for construction category 1 and 2 vessels. Material test reports shall be in accordance with ISO 10474 type 2.2 for construction category 3 vessels.

2.1.2.4 Add to this clause:

Bolts coated with zinc or cadmium shall not be used. Aluminium coatings or suitable non-metallic coatings are permitted.

2.3.2.12 Add new clause:

If hardness results exceed the maximum specified values, appropriate corrective actions shall be proposed for the approval of the Principal. For hardness requirements and extent of hardness checks, see Appendix 3 of this DEP.

SECTION 3 DESIGN

3.1.1 Add to this clause:

Unless other precautions are taken to prevent deformation or damage during transport and handling, no vessel shall have a wall thickness less than:

- 3 mm for high-alloy steel vessels;
- $t_{\min}$ (including the corrosion allowance) for carbon and low-alloy steel vessels transported as one unit or in cylindrical parts. $t_{\min}$ shall be derived from the following equation, with a minimum of 6 mm:

$$t_{\min} = \frac{D}{650} + 1.8 \quad (\text{mm})$$

where D = mean vessel diameter in mm.

3.2.7 Add to this clause:

The Manufacturer shall check the static deflection and stresses induced by wind pressure during operation and the stress during shutdown. The deflection at the top of the equipment is restricted to $\frac{1}{500}$ of the overall height for brick-lined equipment and to $\frac{1}{200}$ for all other equipment. The calculation of the deflection during operational conditions shall take into account insulation, steel structures and piping that are guided or supported by the equipment.

The shape factors (Cf) shall be as follows:

ITEM		SHAPE FACTOR, Cf
Equipment (if cylindrical)		0.7
Steel structures (platforms, ladders etc)		1.0
Piping supported or Guided by the equipment	if the distance between the pipe and the equipment is more than 20 percent of the average diameter*	0.7
	if the distance between the pipe and the equipment is not more than 20 percent of the average diameter*	1.5

NOTE Average diameter = (diameter of equipment + diameter of pipe) / 2

The area to be taken into account for steel structures shall be:

ITEM	DETAIL	AREA (m ²)
Circular platform	full circumference	1.1
Square platform	full circumference	1.7
Cage ladder	per metre length	0.33
Flush ladder	per metre length	0.11

The above shall be used for calculations in accordance with Annex B of PD 5500.

3.3.3 Add to this clause:

Pressure vessels constructed of material with corrosion resistant integral cladding, weld metal overlay cladding or applied linings shall comply with the requirements as specified in Appendix 1 of this DEP.

3.4.1 Add to this clause:

The selection of the construction category is subject to review by the Principal, but unless otherwise specified, the additional requirements of Part II, Section 2, of this DEP shall apply.

3.5.4.1 Add to this clause:

For nozzles, Standard Drawing S 10.101 shall apply.

Nozzle types shall be as follows:

Type of service	vessel wall thickness, t (mm)		Nozzle type
All	$t < 50$		set-in
Non-cyclic	$50 \leq t < 100$	nozzle thickness $\geq t/2$	set-in
		nozzle thickness $< t/2$	set-on (Notes 1 and 2) or set-in
All	$t \geq 100$		forged saddle type
Cyclic	$t \geq 50$		forged saddle type

NOTES 1. For set-on nozzles, the following conditions shall apply to the plate material of the shell:

- The plate material shall meet ASTM A 770 S3 (with a minimum area reduction of 35%) or EN 10164 (Quality Class Z35); and
- 100% ultrasonic examination shall be performed on a 100 mm wide band around the nozzle opening before attachment of the nozzle. Acceptance criteria shall be EN 10160, grade S2E2.

2. Set-on nozzles shall not be used in hydrogen service above 230 °C (Part I, 1.3.2). However, they may be used on the header boxes of air-cooled heat exchangers in all services.

For both set-in and set-on nozzles, the attachment weld shall blend smoothly with both vessel and nozzle wall without any notch, sharp corner or undercut.

All inside edges of nozzles and connections, whether flush or extended, shall be rounded off to a radius of at least 3 mm.

3.5.4.5 Add to this clause:

Reinforcing pads shall not be used in hydrogen service above 230 °C (Part I, 1.3.2) or in other services above 400 °C.

Reinforcing pads shall have one hole, tapped $1/4$ " NPT, per closed compartment. See also amendment to 5.8.3.4.

3.5.4.8 Add to this clause:

Refer to amendment 3.10.1.

3.8.1 Add to this clause:

Standard flanges should conform to ASME B16.5, as per PD 5500 enquiry case 5500/58, or ASME B16.47.

Welding neck flanges shall be used for vessels, except that lap-joint flanges may be used for austenitic stainless steel and non-ferrous vessels if approved by the Principal.

Unless otherwise approved by the Principal, only raised-face (narrow-faced) flanges shall be used.

Flange facing finish shall be in accordance with ASME B16.5.

Gasket, jointing and packing materials shall be purchased only from suppliers accepted by the Principal.

Sheet gaskets shall be 1.5 mm thick unless otherwise approved by the Principal.

3.8.1.4 Add to this clause:

Bolting of less than 16 mm diameter ($\frac{5}{8}$ ") shall not be used for flanged connections. The height of the nut shall be equal to the bolt diameter.

Bolting up to 24 mm (1") shall have UNC standard thread and bolting 30 mm ($1\frac{1}{8}$ ") and larger shall have UN threading (8-thread series).

All boltholes shall straddle the normal centre lines of the vessel.

Sulphur-containing thread compounds shall not be used.

3.10.1 Add to this clause:

For construction categories 1 and 2 vessels the following weld details shall be adhered to, unless otherwise authorized by the Principal.

- Only full penetration welds are allowed. Double sided welds with crevice in between are not allowed in the primary pressure boundary or for nozzle attachments to the shell.
- Backing strips should normally not be used. If used nonetheless, all backing strips shall be carefully removed.
- Double fillet weld constructions are only permitted in secondary pressure boundaries (e.g. slip-on flanges), but not in hydrogen sulphide service or hydrogen service.
- Socket welds are not allowed.
- Continuous fillet welds shall be used for all internal structures, supports and fittings to be welded to the vessel shell.

NOTE: The above amendment is applicable to all further clauses in PD 5500 in which weld details are listed or referenced.

3.12 Add to this clause:

Flanges shall comply with section (3.8.1) of this DEP.

SECTION 4 MANUFACTURE AND WORKMANSHIP

4.1.1 Add to this clause:

To prevent deformation of thin-walled vessels, suitable handling and transport precautions shall be observed, (see also Section 3.1.1).

For the despatch of drawings and documents, approval drawing specification form DEP 05.00.54.81-Gen. and final drawing specification form DEP 05.00.54.82-Gen. shall be used, except that the Contractor's own despatch standard forms may be used if approved by the Principal.

The Manufacturer shall submit approved drawings and calculations to the Inspecting Authority.

NOTE: Certified drawings shall be understood to mean drawing(s) bearing an approval stamp of the approval office and, where applicable, an official stamp of the authorities concerned, signed and dated.

4.2.1.2 Add to this clause:

For Cr-Mo equipment the requirements of Appendix 6 of this DEP shall apply.

4.2.4 Add to this clause:

For tolerances not covered by code requirements see Appendix 2 of this DEP.

4.4.1.1 Add to this clause:

If steels of grade M1 are used with a specified minimum tensile strength (R_m) exceeding 485 N/mm², the need to employ preheat for all thicknesses shall be ascertained in view of the required hardness of the end product.

4.4.2.1 Add to this clause:

Normalizing of carbon steel components and base materials shall be performed separately, and not as part of the hot-forming operation, unless the finishing hot-forming temperature is in the normalizing temperature range of 850 °C to 960 °C. In either case the temperature shall be recorded and documented by a temperature recording chart.

4.4.3.2 Add to this clause:

For Cr-Mo equipment the requirements of Appendix 6 of this DEP shall apply.

4.4.5.2 Add to this clause:

PWHT is also a method to reduce the hardness of the end product so that the required maximum values are no longer exceeded.

4.5 Add to this clause:

Machined parts shall be treated with an easily removable anti-corrosion compound, e.g. Shell Ensis Fluid. All flanges not connected to a mating flange shall have their gasket contact surfaces treated similarly and shall be protected with wooden blanks. These blanks shall be securely attached to the flanges with at least four bolts.

Location mark 0° shall be indicated on the vessel, preferably by painting.

SECTION 5 INSPECTION AND TESTING

5.1 Add to this clause:

The Principal shall specify whether he (or his nominee) will perform shop surveillance and if so he shall specify the scope.

The Principal should tailor the scope of the Principal's inspection to avoid duplication with that of the Inspecting Authority.

A pre-manufacturing meeting shall be held if considered necessary by the Manufacturer or Purchaser.

5.4 Replace this clause by:

Production control test plates are not required for material groups M0 and M1, except for materials of group M1 which have a specified minimum tensile strength (R_m) greater than 485 N/mm². In all other cases, production control test plates shall be provided at the rate of two test plates per 100 m of butt weld or part thereof (circumferential plus longitudinal) and shall represent the welding on the vessel or on a group of similar vessels made of the same material, ordered to the same specification and with the same welding procedure/welder/welding operator qualification. Production control test plates are also required if the chemical composition of the weld deposit of welds in alloy materials has to be checked, i.e. where a minimum alloy content is required to meet the service conditions (creep, corrosion, hydrogen service). Production control test plates are also required for weld-deposited cladding.

The test plates shall be made at an early stage of production welding with a thickness equal to the thickness of the shell.

In the case of spherical vessels, the test plates shall be welded separately and they shall represent each type of seam and welding position. For site-constructed vessels, the test plates shall be welded at the construction site.

Half the total number of plates (minimum one plate) shall be selected and tested at an early stage. If the vessel will be post-weld heat treated, then these test plates shall be given a simulated heat treatment before testing, and a time/temperature record shall be retained by the Manufacturer. The test plates results shall be considered valid if the eventual vessel post-weld heat treatment is performed within the specified time/temperature range. The other test plates shall be placed inside the vessel during its post-weld heat treatment, and shall be retained in case later testing may be required.

A post-weld heat treatment certificate stating actual temperature/time parameters shall be included in the Manufacturer's report. The original temperature/time indicator recorder charts shall be retained by the Manufacturer.

For Cr-Mo equipment the requirements of Appendix 6 of this DEP shall apply.

5.6.4 Add to this clause:

Full penetration tee and corner joints (Type B welds) shall be non-destructively examined by either radiography (preferred) or ultrasonics to the extent required by the construction category.

For hardness testing requirements on carbon steel equipment see Appendix 3 of this DEP.

5.6.4.1.2 Add to this clause:

For construction category 1 vessels, the full length of Type A welds shall be examined for surface flaws.

5.6.4.3 Add to this clause:

A minimum amount of 2% radiography shall be applied.

5.6.5.1 Add to this clause:

Ultrasonic examination shall be employed instead of radiography wherever the plate thickness exceeds 50 mm (or 25 mm if the double-wall technique is being used).

For wall thicknesses greater than 100 mm, or if the angle of the fusion edge preparation is no more than 10°, a supplementary examination shall be performed by a mechanised tandem technique with an angle of refraction of 45°.

5.8.2.12 Add new clause:

Gaskets shall not be reused after breaking the joints.

5.8.3.2 Add to this clause:

For test water quality see DEP 61.10.08.11-Gen.

5.8.3.4 Add new clause:

Tell-tale holes shall not be plugged, but shall be filled with a non-corrosive compound (e.g. Shell Ensic) or grease to prevent ingress of water.

5.8.9 Add to this clause:

Standard Drawing S 10.114 shall apply to nameplates. On stainless steel equipment, a stainless steel name plate shall be used. For vessels required for low-temperature service (0 °C or lower) and for equipment containing liquefied gas or very toxic substances, the nameplates shall include the lower design temperature.

The nameplate bracket should be attached to a non-insulated, non-removable part of the pressure vessel (e.g. skirt).

ANNEX E RECOMMENDATIONS FOR WELDED CONNECTIONS OF PRESSURE VESSELS

Add to this Annex:

The following figures of joint details shall not be used for construction category 1 and 2 vessels: (for general welding statement refer to amendment 3.10.1)

E.1 d)	
E.2 e), g), h)	
E.4 b), d), e)	(See Note 1)
E.5 a), b), c)	
E.7 1 st , 2 nd , 5 th) options	
E.8 2 nd , 4 th) options	(See Note 1)
E.9 B4, J4	
E.11 a), b), e), f)	
E.13 a), b)	
E.18 b), c)	
E.19 a), b)	
E.20 a), b)	
E.28 b)	
E.29 a), b)	
E.30 a), b)	
E.31 b)	
E.32 e), f), g)	(See Note 2)
E.33 b(i) b(ii) c)	(See Note 2)
E.37 a), b)	
E.38 a), b), c), d), f)	
E.39 b), c), d)	
E.40 a) righthand side, b)	
E.41 d), g), h) j) k), l), m)	
E.42 a) lefthand side	
E.43 a)	
E.45	
E.46 a) 3)	
E.47 a)	

- NOTES
1. Backing strips shall be carefully removed after welding. Where the back of the joint cannot be dressed after welding, an adequate inert gas backing shall be applied.
 2. Socket weld and screwed connections, only if approved by the Principal.

ANNEX AA ALUMINIUM SUPPLEMENT

SECTION 2 MATERIALS

2.1 Add to this Clause:

Carbon steel and low-alloy steel bolting for aluminium vessels shall be aluminized or the bolting shall be made from stainless steel, selected from DEP 30.10.02.11-Gen.

2.3 Add to this Clause:

The aluminium grades to be used shall be as indicated in DEP 30.10.02.11-Gen. for the application concerned.

2.3.3 Replace this Clause by:

Aluminium grades having a magnesium content of 3% or higher shall not be used for design temperatures above 65 °C.

SECTION 5 INSPECTION AND TESTING

5.4 Replace this clause by:

The requirements of 5.4 of Part III of this DEP shall apply.

5.6.5.1 Add to this clause:

Ultrasonic examination shall not be used unless approved by the Principal.

5.8.3.2 Add to this clause:

For water quality see DEP 61.10.08.11-Gen.

PART IV REFERENCES

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

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

SHELL STANDARDS

DEPs

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Index to Standard Drawings	DEP 00.00.06.06-Gen.
Definition and determination of temperature, pressure and toxicity levels	DEP 01.00.01.30-Gen
Metallic materials - Selected standards	DEP 30.10.02.11-Gen.
Metallic materials - Prevention of brittle fracture	DEP 30.10.02.31-Gen.
Painting and coating of new equipment	DEP 30.48.00.31-Gen.
Design and installation of chemical-resistant brick lining for process equipment	DEP 30.48.60.13-Gen.
Glass lined steel equipment and piping	DEP 30.48.70.30-Gen
Trays for columns	DEP 31.20.20.31-Gen.
Manufacturing report for pressure vessels	DEP 31.22.10.35-Gen.
Piping – General requirements	DEP 31.38.01.11-Gen.
Minimum requirements for structural design and engineering	DEP 34.00.01.30-Gen.
Field inspection prior to commissioning of mechanical equipment	DEP 61.10.08.11-Gen.
Insulating and dense refractory concrete linings	DEP 64.24.32.30-Gen
Equipment and tools for maintenance and inspection. Part 2: Mechanical maintenance - Equipment, tools and bolt tensioning	DEP 70.08.10.11-Gen.

STANDARD FORMS

Approval drawing specification	DEP 05.00.54.81-Gen.
Final drawing specification	DEP 05.00.54.82-Gen.

Note: Standard Forms are contained in a binder,
DEP 00.00.10.05-Gen.

REQUISITIONS

Data/requisition sheet(s) for pressure vessels	DEP 31.22.00.94-Gen.
--	----------------------

Note: Data/requisition sheets are contained in a binder,
DEP 30.10.01.10-Gen.

STANDARD DRAWINGS

NOTE: The latest issue of standard drawings is identified in DEP 00.00.06.06-Gen.

Vortex breakers	S 10.010
Bolting non-standard flanges with unified inch screw threads	S 10.035

Pad-type hand holes with cover flange ANS class 150 and 300 for unfired carbon steel, low alloy steel and stainless steel pressure vessels	S 10.039
Pad-type hand holes - carbon steel	S 10.053
Pad-type hand holes - carbon steel with lining	S 10.054
Davit for ANS or BS blind flanges nom. size 12 – 24 inch incl., classes 150-600 incl.	S 10.070
Nozzles to apparatus	S 10.101
Typical details of bush-lined, overlay welded and clad steel nozzles	S 10.103
Nameplate with bracket for vessels and heat-exchange equipment	S 10.114
Typical details of lifting trunnion for vertical vessels	S 10.115
Bolting for non-standard flanges with metric screw threads	S 10.116
Skirts, cylindrical and conical	S 20.001
Support rings for insulation	S 20.003
Saddles for horizontal vessels - shell dia. nom. 150 up to and incl. 1000 mm OD	S 22.001
Saddles for horizontal vessels - shell dia. 1050 mm OD up to and incl. 3600 mm OD	S 22.002
Supports for vertical vessels shell dia. 350 mm OD up to and incl. 1500 mm OD (half skirts)	S 22.005
Ladder – typical details of sliding/fixed connections	S 28.012
Platforms - cleats and brackets to columns (design load max 300 kg)	S 28.013
Platforms - cleats and brackets to columns (design load over 300 kg)	S 28.014
Davit general arrangement and typical details	S 28.015
Earthing boss for steel structures, tanks, vessels, etc.	S 68.004

AMERICAN STANDARDS

Materials and Fabrication requirements for 2-1/4Cr-1Mo & 3Cr-1Mo Steel Heavy Wall Pressure Vessels for High temperature, High pressure Hydrogen service

API RP 934

Steels for hydrogen service at elevated temperatures and pressures in petroleum refineries and petrochemical plants.

API RP 941

Issued by:
American Petroleum Institute
Publications and Distribution Section
1220 L Street Northwest
Washington, DC 20005
USA

ASME Boiler and Pressure Vessel Code: Alternative rules for construction of pressure vessels

ASME VIII, Div. 2

Qualification standard for welding and brazing procedures, welders, brazers, and welding and brazing operators	ASME IX
Pipe flanges and flanged fittings NPS ½ through NPS 24	ASME B16.5
Large diameter steel flanges NPS 26 through NPS 60	ASME B16.47
<i>Issued by:</i> <i>American Society of Mechanical Engineers</i> <i>345 East 47th Street</i> <i>New York, NY 10017</i> <i>USA</i>	
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 piping fittings of wrought carbon steel and alloy steel for moderate and elevated temperatures	ASTM A 234
Standard specification for corrosion-resisting chromium steel-clad plate, sheet, and strip	ASTM A 263
Standard specification for nickel and nickel base alloy-clad steel plate	ASTM A 265
Standard specification for stainless chromium-nickel steel-clad plate, sheet, and strip	ASTM A 264
Standard specification for seamless and welded steel pipe for low temperature service	ASTM A 333
Standard specification for forgings, carbon and low alloy steel, requiring notch toughness testing for piping components	ASTM A 350
Standard specification for pressure vessel plates, carbon steel, for moderate and lower temperature service	ASTM A 516
Straight-beam ultrasonic examination of plain and clad steel plates for special applications	ASTM A 578
Through-thickness tension testing of steel plates for special applications	ASTM A 770
Standard specification for steel plates for pressure vessels, produced by Thermo-Mechanical Control Process (TMCP)	ASTM A 841
Standard test method for indentation hardness of metallic materials by portable hardness testers	ASTM E 110
Standard practice for assessing the degree of banding or orientation of microstructures	ASTM E 1268

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

**Amended per
Circular 22/04**

Materials resistant to sulfide stress cracking in corrosive
petroleum refining environments NACE MR0103

Petroleum and natural gas industries — Materials for
use in H₂S-containing environments in oil and gas
production NACE MR0175

Laboratory test procedures for evaluation of SOHIC resistance
of plate steels used in wet H₂S service NACE TM0103

Evaluation of pipeline and pressure vessel steels for
resistance to hydrogen-induced cracking NACE TM0284

*Issued by:
NACE International
1440 South Creek Dr.
Houston, TX 77084-4906,
USA*

BRITISH STANDARDS

Unfired fusion welded pressure vessels PD 5500
(2000 edition,
plus amendment:
10830 January 2000).

NOTE: BSI have changed the number of the code from BS 5500 into PD
5500 since the European Pressure Equipment Directive became
operative

*Issued by:
British Standards Institution
389 Chiswick High Road
London W4 4AL
United Kingdom.*

EUROPEAN STANDARDS

Destructive tests on welds in metallic materials. Hardness
testing. Hardness test on arc welded joints EN 1043-1

Flat products made of steels for pressure purposes - Part 3:
Weldable fine grain steels, normalized EN 10028-3

Ultrasonic testing of steel flat product of thickness equal or
greater than 6 mm (reflection method) EN 10160

Steel products with improved deformation properties
perpendicular to the surface of the product; technical delivery
conditions EN 10164

*Issued by:
CEN
Rue de Stassart 36
B-1050 Brussels
Belgium*

Copies can also be obtained from national standards organizations

INTERNATIONAL STANDARDS

Steel and steel products, inspection documents ISO 10474

**Amended per
Circular 22/04**

Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production ISO 15156

*Issued by:
International Organization for Standardization
3, Rue de Varembé
CH-1211 Genève 20
Switzerland*

Copies can also be obtained from national standards organizations

NOTE: Most referenced external standards are available for Shell users on the SWW (Shell Wide Web) at address <http://sww.shell.com/standards>

APPENDIX 1 REQUIREMENTS FOR WELDED PRESSURE VESSELS CONSTRUCTED OF MATERIAL WITH CORROSION RESISTANT INTEGRAL CLADDING, WELD METAL OVERLAY CLADDING OR APPLIED LININGS

Pressure vessels or vessel parts constructed of base material with corrosion-resistant integral or weld-metal overlay cladding, and vessels and vessel parts that are fully or partially lined inside or outside with corrosion-resistant plate, sheet, or strip that is attached by welding either to the base plate before or after forming or to the shell, heads, and other parts during or after assembly into the completed vessel, shall satisfy the requirements of ASME VIII, Div. 2, Article F-5, except as modified in this Appendix.

MODIFICATIONS TO ARTICLE F-5 OF ASME VIII, DIV. 2.

1. Linings other than those obtained by using integrally clad plate or overlay weld deposits shall not be used without the approval of the Principal. For linings in hydroprocessing equipment, only weld overlay deposits shall be used; the use of integrally clad plate shall be subject to the approval of the Principal.
2. Integrally clad plate shall be of the homogeneously clad type as obtained by roll cladding or explosive cladding. The clad plates shall conform to ASTM A 263, A 264 or A 265, as applicable, irrespective of the design calculation method used.
3. Integrally clad plate and linings applied by overlay weld depositing, and products formed from these materials, shall be ultrasonically examined to check the quality of the bond in accordance with the requirements of ASTM A 578, acceptance level S6.

In addition the following requirements shall be fulfilled:

- any unbonded area shall be smaller than 10 cm²;
- the total of the unbonded areas shall not exceed 100 cm² per 1 m² area of plate (areas less than 1.0 cm² shall be ignored).

This also applies to clad restoring of welds in clad plate where a band of 50 mm wide on each side of the weld shall be examined.

4. Only overlay-welded nozzles or nozzles made of integrally clad plate shall be used.
5. The design of nozzles shall be in accordance with Standard Drawing S 10.103.
6. The thickness of the material used for cladding or lining shall not be included in the computation of the required wall thickness.
7. The welding procedure shall be qualified in accordance with ASME IX, QW-217, which is referred to in ASME VIII, Div. 2, Article F-5.

1. The weld overlay of the production welds at a depth of 2 mm shall be chemically analysed to the following extent:
 - one analysis per course;
 - one analysis per head;
 - one analysis per nozzle.

The material composition shall comply with the specification of chemical requirements for the original clad material.

2. The ferrite content of the weld overlay of the production welds at a depth of 2 mm shall be determined to the following extent:
 - one analysis per course;
 - one analysis per head;
 - one analysis per nozzle.

The ferrite content shall be between 3% and 8%.

3. Liquid penetrant examination shall be performed over the entire clad surface. The acceptance criterion shall be zero indications of cracks.

8. The grade and thickness of stainless steel overlay shall be as specified by the Principal on the data/requisition sheets.
9. The Manufacturer shall demonstrate that he is able to control the chemical composition of the weld overlay within agreed values, either by using a normal two-layer technique in which the first layer is applied with a low heat input, or by a proven single-layer mechanised welding process. The latter is subject to the approval of the Principal.
10. Welds in the base materials shall be non-destructively examined in accordance with the construction category before any overlay weld is deposited. Ultrasonic examination for final acceptance purposes shall be on finished welds (including weld overlay, clad restoring and PWHT).

APPENDIX 2 VESSEL TOLERANCES NOT COVERED IN PD 5500

1. VESSELS WITH INTERNALS

If vessels are to be fitted with special screens or filters which require a more precise fitting, the tolerances shall be in accordance with the screen/filter Manufacturer's recommendation, and be specified on the data/requisition sheets.

2. LENGTH

Tolerance on overall length measured between the tangent lines shall be in accordance with the following table:

Length L (mm)	Tolerance (mm)
$L \leq 1\,000$	± 2.0
$1\,000 < L \leq 4\,000$	± 4.0
$4\,000 < L \leq 10\,000$	± 8.0
$L > 10\,000$ and all vessels having a wall thickness > 70 mm	± 13.0

NOTE Tangent lines shall be punch-marked on the dished heads, both externally and internally at the intersection of the knuckle with the cylindrical section.

3. ATTACHMENTS

Tolerances for attachments are given below. The alphabetic coding is given in Figure 1 at the end of this Appendix.

3.1 Nozzles in shells and domed ends (except for nozzles for level instruments, inspection openings/manholes)

- Position measured from tangent line: ± 6 mm
- Projection for nozzles on shell measured from shell curvature, and for nozzles on domes measured from tangent line: ± 6 mm
- Alignment of nozzle flange face with the indicated plane: maximum 0.5° in any direction.
- Radial orientation, measured from reference centre line to centre line of nozzle: $\pm 1^\circ$, with a maximum circumferential tolerance of 15 mm.
- Bolt hole orientation: maximum rotation 1.5 mm measured at bolt circle.

NOTE Bolt holes to straddle centre lines, unless otherwise indicated.

- Deviation of nozzle centre line in head not to exceed 3 mm

NOTE Nozzles and supports for stacked heat exchangers shall be checked for correct alignment during fabrication, and due allowance shall be made for the gaskets specified.

3.2 Nozzles for level instruments

- Distance measured from centre to centre: ± 1.5 mm
- Projection difference for each pair of flanges, measured from shell curvature: 1.0 mm.
- Alignment of nozzle flange face with the indicated plane: maximum 0.25° in any direction.

Further tolerances for level instrument nozzles shall be in accordance with 3.1 a, b and e.

3.3 Inspection openings/manholes

- j. Position measured from bottom tangent line: ± 12 mm. Further tolerances for manholes shall be in accordance with 3.1 d and e.
- k. Height measured from shell curvature: ± 12 mm.
- l. Alignment of flange face: maximum 1° in any direction.

3.4 Vessel supports

- m. Support height

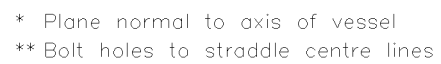
Distance H from lower tangent line to base or support (mm)				Tolerance (mm)
	H	$\leq$	1 000	± 2.0
1 000	<	H	$\leq$ 4 000	± 4.0
4 000	<	H	$\leq$ 10 000	± 8.0

- n. Base ring or support out of levelness: 0.2% of nominal diameter with a maximum of 12 mm.
- p. Foundation bolt pitch circle
for vessel with ID ≤ 2100 mm: ± 3 mm.
for vessel with ID > 2100 mm: ± 6 mm.
- q. Distance between legs (horizontal vessel): ± 3 mm.
- r. Height of leg (horizontal vessel): ± 5 mm.

3.5 Tray supports

- s. Tray support ring levelness, measured as greatest difference all around: $\pm 0.15\%$ of the outside tray diameter, with a maximum of 4 mm.
- t. Tray support ring position - distance of tray support ring from lower tangent line: ± 6 mm.
- u. Distance between two adjacent tray support rings (and from tray support ring to centre of adjacent nozzle or instrument connection): ± 3 mm, except for the distance of a draw-off tray support ring to the centre of the corresponding nozzle, for which the tolerance is ± 2 mm.
- v. Distance of vertical downcomer plate to vessel axis: ± 3 mm
- w. Height of fixed weir above tray support ring: ± 3 mm.
- y. Distance from downcomer bottom to tray support: ± 3 mm.

Alphabetic coding



APPENDIX 3 HARDNESS REQUIREMENTS FOR CARBON AND FERRITIC ALLOY STEEL PRESSURE VESSELS

1. WELDING PROCEDURE QUALIFICATION

In addition to the standard mechanical tests, each welding procedure qualification test (WPQT) shall include a macro section and hardness traverses in accordance with EN 1043-1. The series of readings shall extend from unaffected base material on one side, across the weld to unaffected base metal on the other side. Three traverses shall be made: one 2 mm below the outer surface, one 2 mm below the inner surface and one across the centre. The distance between measurements across the weld shall not exceed 2 mm. No part of the weld, HAZ or base metal shall exceed 248 HV 10.

WPQT hardness testing shall be performed by the Vickers method.

2. PRODUCTION WELDS

2.1 TEST PROCEDURE

Transverse weld hardness testing of production welds shall be carried out using a portable Vickers or Rockwell tester in accordance with ASTM E 110 or by another method capable of detecting a hard HAZ in a reliable and repeatable manner (e.g., Equotip, Microdur or other equivalent if approved by the Principal).

Whenever possible, tests shall be made on the inside (process-contacted side) of the vessel.

Tests shall be made on properly ground surfaces.

On heat-treated vessels, hardness measurements shall be carried out after PWHT.

2.2 GENERAL AND UTILITY SERVICE

Spot checks shall be carried out on the production welds with at least one set of hardness measurements carried out for each welding procedure applied.

For each set of hardness measurements required, the average of three measurements on the weld and on each HAZ shall be reported.

No part of the weld, HAZ or base metal shall exceed 248 HV 10.

2.3 HYDROGEN, HF AND VERY TOXIC SERVICES

One set of hardness measurements shall be carried out for each welding procedure qualification applied and for each 10 m of finished weld (with a minimum of one test).

For each set of hardness measurements required, the average of three measurements on the weld and on each HAZ shall be reported.

No part of the weld, HAZ or base metal shall exceed 248 HV 10.

3. WET H₂S SERVICE/SOUR SERVICE

See Appendix 4, Section 3.7.

APPENDIX 4 CARBON STEEL PRESSURE VESSELS IN WET H₂S SERVICE/SOUR SERVICE

1. INTRODUCTION

This Appendix shall be applied to the specification and fabrication of carbon steel pressure vessels in order to mitigate or avoid the effects of aqueous hydrogen charging in "Wet H₂S" or "Sour" process environments (see their definitions below). Types of material damage that can occur as a result of aqueous hydrogen charging include sulphide stress corrosion (SSC) cracking of hard weldments and microstructures, hydrogen blistering, hydrogen induced cracking (HIC) and stress-oriented hydrogen induced cracking (SOHIC).

SSC is the occurrence of brittle fracture under the combined action of stress and H₂S dissolved in water. Hydrogen blistering, HIC and SOHIC are lamellar cracking phenomena, often connected or (in the case of HIC and SOHIC) propagating in a stepwise manner. Hydrogen blistering, HIC and SOHIC are most commonly associated with plate or strip product forms and are much less common in seamless pipe or wrought products (although HIC has been experienced in seamless products which have a poor microstructure due to incorrect chemistry or heat treatment). Furthermore, in some high pH refinery process streams a form of alkaline stress corrosion cracking (ASCC) is a concern. ASCC is normally mitigated by applying PWHT to welds and cold formed products.

2. DEFINITION OF WET H₂S/SOUR SERVICE

"Wet H₂S" service is the term commonly used for refinery and gas plant (Shell GSI) environments containing water and H₂S (plus other corrosives or contaminants), whereas "Sour" service is the term traditionally used for similar environments in exploration and production (SIEP) services.

However, the chemical composition of the environments is often quite different, and these differences are described in this Section.

Although the definitions of these services differ between Shell GSI and SIEP, the approach to materials selection and testing has been standardised and is described in Sections 3, 4 and 5 of this Appendix.

2.1 SIEP - "SOUR" SERVICE

General requirements (Section 3) shall apply to prevent the occurrence of SSC if:

Amended per
Circular 22/04

- sour conditions, as defined in ISO 15156, prevail; **and**
- the temperature at any time during operation is between 0 °C and 65 °C.

NOTE: NACE MR0175 is equivalent to ISO 15156.

Additionally, special requirements (Sections 4 and 5) shall apply to prevent the occurrence of hydrogen blistering, HIC and SOHIC if:

- in gas-containing systems, the partial pressure of H₂S exceeds 0.0035 bar (abs); **or**
- in liquid-containing systems, the concentration of H₂S is higher than that occurring in a liquid equilibrium with a gas containing H₂S at a partial pressure of 0.0035 bar (abs).

and:

- the temperature has to be between 0 °C and 65 °C; **and**
- the pH of the liquid has to be lower than 7; **and**
- an electrolyte (typically an aqueous phase) is normally in contact with the steel.

2.2 Shell GSI - "WET H₂S" SERVICE

All carbon steel vessels in refineries exposed to process streams shall be designed and manufactured to resist the potential cracking mechanisms caused by the generation of free hydrogen in an aqueous corrosion reaction in Wet H₂S process environments.

In refinery streams containing free water and H₂S, the pH is often around 6 or higher due to the presence of ammonia. Trace quantities of contaminants such as chloride or fluoride may also be present, which form ammonium salts (ammonium chloride and ammonium fluoride). Cyanides can also play an important role in refinery streams as they affect iron sulphide scale persistence and possibly hydrogen pick-up. In high pH streams containing significant levels of sulphide and carbonate ions, measures shall be taken to prevent carbonate cracking, which is a form of alkaline stress corrosion cracking (ASCC).

The materials selection, testing and PWHT requirements should be based upon on the potential damage mechanism(s) anticipated or experienced in the service and the severity of the process environment (potential level of hydrogen flux and/or ASCC).

Tables 1A, 1B and 1C should be used to assess the severity of the process environment as applicable to the type of damage mechanism being considered

NOTE When using Tables 1A, 1B and 1C the environment being considered should be present during normal operations. Short term upsets should only be considered if the damage mechanism anticipated or experienced is also likely to occur in the short term. If in doubt, the materials engineer of the Principal shall be consulted.

Table 2 summarises these materials selection and PWHT requirements for the potential damage mechanisms in the different severity categories.

TABLE 1A SUSCEPTIBILITY TO SSC

If there is no free water likely to be present then the material is **not** considered susceptible to SSC.

If water is likely to be present, the pH is greater than 4.0 and the cyanide level is low, then the Table 1A should be used to estimate the severity category for SSC. The process conditions covered by Table 1A are considered to have a low severity with respect to blistering, HIC or SOHIC. Process conditions outside these ranges should be further assessed for the effects of more severe hydrogen charging using Table 1B.

		H ₂ S CONTENT OF WATER (mg/kg)		
pH of water	Cyanide content (mg/kg) (Note 1)	< 50	50 to 1000	> 1000
		SEVERITY CATEGORY		
4.0 to 5.4	(Note 2)	Low	Moderate	High
5.5 to 7.5	(Note 2)	Low	Low	Moderate
7.6 to 7.9	< 50	Low	Moderate	High
≥ 8.0	< 20	Low	Moderate	High

NOTES 1. If the cyanide level cannot be established during design or from experience, the materials engineer of the Principal shall be consulted for an assessment based upon the type of process unit, feed, water wash practices, etc.

2. The level of cyanide has no significance at pH 7.5 and below.

TABLE 1B SUSCEPTIBILITY TO HYDROGEN BLISTERING, HIC AND SOHIC

If there is no free water likely to be present then the material is **not** considered susceptible to hydrogen blistering, HIC or SOHIC. If water is likely to be present and conditions are more severe than the range of Table 1A with respect to pH or cyanide, the following table should be used to determine the severity category for hydrogen blistering, HIC and SOHIC. Note that under Table 1B conditions the severity category for SSC is High.

		H ₂ S CONTENT OF WATER (mg/kg)		
pH of water	Cyanide content (mg/kg) (Note 1)	< 50	50 to 1000	> 1000
		SEVERITY CATEGORY		
< 4.0	(Note 2)	Moderate	Moderate	Moderate
7.6 to 7.9	≥ 50	Moderate	Moderate	High
≥ 8.0	≥ 20	Moderate	High	High

NOTES 1. If the level of cyanide cannot be established during design or from experience, the materials engineer of the Principal shall be consulted for an assessment based upon the type of process unit, feed, water wash practices etc.

2. The level of cyanide has no significance at pH 7.5 and below.

TABLE 1C SUSCEPTIBILITY TO CARBONATE CRACKING (as experienced in sour water)

If there is no free water likely to be present or the water phase contains less than 50 mg/kg H₂S then the material is **not** considered susceptible to carbonate cracking. If there is free water likely to be present with more than 50 mg/kg H₂S at a pH of 7.6 or greater, then the following table should be used to determine the severity category for carbonate stress corrosion cracking.

PH of Water	CO ₃ ²⁻ CONTENT (mg/kg) of WATER			
	< 100	100 to 500	501 to 1000	> 1000
SEVERITY CATEGORY				
7.6 to 8.3	Low	Low	Low	Moderate
8.4 to 8.9	Low	Low	Moderate	High
≥ 9.0	Low	Moderate	High	High

TABLE 2 SUMMARY OF "WET H₂S" MATERIALS AND PWHT REQUIREMENTS

Amended per
Circular 22/04

POTENTIAL MECHANISM(S) (Note 1)	SEVERITY CATEGORY		
	LOW	MODERATE	HIGH
MATERIALS AND PWHT REQUIREMENTS			
SSC (Table 1A)	No special requirements	Section 3	Section 3 + PWHT (Note 4)
Hydrogen blistering, HIC and SOHIC (Table 1B) (Note 2)	Not Applicable	Sections 3, 4 and 5	Clad, or Sections 3, 4, 5 and 6 (Note 3)
Carbonate cracking (Table 1C)	Section 3	Section 3 + PWHT (Note 4)	Section 3 + PWHT (Note 4)

- NOTES
1. Potential mechanisms are not exclusive, i.e. if there is more than one mechanism active, the materials and PWHT requirements may have to be combined to address the severity of more than one environment. For example, the fractionator overheads in a Fluidised Catalytic Cracking Unit (FCCU) may have a high severity for hydrogen blistering, HIC, SOHIC and carbonate cracking and in such a case the requirements for materials and PWHT shall be combined.
 2. Any in-service vessel (or vessel in a directly comparable service) that requires replacement because it has been damaged by significant hydrogen blistering and/or HIC should be assessed as a "Moderate Severity" environment. A vessel that has experienced SOHIC should be assessed as a "High Severity" environment. In such cases the materials engineer of the Principal shall be consulted.
 3. For carbon steel vessels, additional mitigation measures, such as injection of polysulphide or inhibitors may be required; the materials engineer of the Principal shall be consulted.
 4. PWHT indicates a requirement for postweld heat treatment of all shop and field welds.

3. GENERAL MATERIALS, WELDING AND HARDNESS REQUIREMENTS FOR VESSELS IN WET H₂S/SOUR SERVICE

3.1 GENERAL

Amended per
Circular 22/04

All materials shall be in accordance with the materials property and heat treatment requirements of ISO 15156 or NACE MR0103, as applicable, as supplemented or modified by this Appendix. Certification to these standards is only required if specified by the Principal.

- NOTES:
1. ISO 15156 shall apply to oil and gas production facilities and natural gas sweetening plants. NACE MR0175 is equivalent to ISO 15156.
 2. NACE MR0103 shall apply to other applications (e.g. oil refineries, LNG plants and chemical plants).

3.2 HEAT TREATMENT CONDITION

All materials shall be supplied in the normalised condition. Normalising shall be carried out as a separate heat treatment. The acceptability of hot-finished material shall be subject to the approval of the Principal.

3.3 PLATE

Plate shall comply with ASTM A 516 or EN 10028-3, as modified below.

3.3.1 Chemical composition

In order to ensure effective resistance to SSC in the as-welded condition, the chemical composition (product analysis) shall be restricted as follows, except where the standard material specification is more restrictive:

Single Elements	Maximum wt.%
Carbon (C)	0.20
Sulphur (S)	0.01
Multiple Elements	
Vanadium (V) + Niobium (Nb)	0.02
Carbon Equivalent (Note 1)	0.43

NOTES 1. Carbon Equivalent (CE) shall be calculated by the following formula:

$$CE = C + \frac{Mn}{6} + \frac{(Ni+Cu)}{15} + \frac{(Cr+Mo+V)}{5}$$

2. The micro-alloying elements boron (B), titanium (Ti), niobium (Nb) and vanadium (V) shall not be intentionally added to the steel unless the Principal has given prior approval.

3.3.2 Through-thickness testing

All plates shall meet the through-thickness testing requirements of ASTM A 770 S3 (with a minimum area reduction of 35%). HIC-tested plate in accordance with Sections 4 and 5 of this Appendix is an acceptable alternative.

3.4 FORGINGS (Flanges, etc.)

Forgings shall be in accordance with ASTM A 105N or ASTM A 350-LF2, with the following restrictions:

Carbon: 0.25 wt.% max.
CE: 0.43 max.

3.5 SEAMLESS PIPE (e.g. for nozzles)

Seamless pipe shall be in accordance with ASTM A 106 Grade B or ASTM A 333 Grade 6, with the following restrictions:

Carbon: 0.23 wt.% max.
CE: 0.43 max.

3.6 WELDED PIPE AND FITTINGS

Fittings shall be in accordance with ASTM A 234 WPB or WPC. Generally, only seamless pipe and fittings should be used for vessel nozzles. Base materials shall be in accordance with the above specifications for forging or pipe, as applicable. Where this is impractical, welded pipe and fittings may be used and shall be manufactured from plate complying with Section 3.3 of this Appendix. Such fittings shall be welded by means of welding procedures qualified in accordance with Section 3.7 of this Appendix.

3.7 WELDING AND HARDNESS REQUIREMENTS

3.7.1 Welding Procedure Qualification

Material purchased for the contract, or equivalent material (i.e., specification, grade, CE and chemistry controls), shall be used for all welding procedure qualification tests (WPQTs).

In addition to the standard mechanical tests, each WPQT shall include a macro section and hardness traverses in accordance with EN 1043-1. The series of readings shall extend from unaffected base material on one side, across the weld to unaffected base metal on the other side. Three traverses shall be made: one 2 mm below the outer surface, one 2 mm below the inner surface and one across the centre. The distance between measurements across the weld shall not exceed 2 mm. No part of the weld, HAZ or base metal shall exceed 248 HV 10.

WPQT hardness testing shall be performed by the Vickers method.

NOTE The weld metal deposit shall not contain more than 1.00% nickel.

3.7.2 Production Welds

Transverse weld hardness testing of production welds shall be carried out using a portable Vickers or Rockwell tester in accordance with ASTM E 110 or by another method capable of detecting a hard HAZ in a reliable and repeatable manner (e.g., Equotip, Microdur or other equivalent if approved by the Principal).

Whenever possible, hardness tests shall be made on the inside (process-contacted side) of the vessel.

Hardness tests shall be made on properly ground surfaces.

On heat-treated vessels, hardness testing shall be carried out after PWHT.

One set of hardness measurements shall be carried out for each welding procedure qualification applied and for each 10 m of finished weld (with a minimum of one test).

For each set of hardness measurements required, the average of three measurements on the weld and on each HAZ shall be reported.

No part of the weld, HAZ or base metal shall exceed 248 HV 10.

4. HIC RESISTANT MATERIALS REQUIREMENTS

The requirements of this Section are additional to the general requirements of Section 3 of this Appendix.

4.1 HEAT TREATMENT CONDITION

Heat treatments other than normalising (such as quench and tempering (Q+T) or thermal/mechanical controlled process (TMCP)), used to improve microstructure homogeneity and enhance HIC resistance, may be applied only with the approval of the Principal.

Vessels shall be given PWHT unless otherwise specified by the Principal. The minimum PWHT time and temperature shall be 1 hour at 610 °C. The maximum PWHT time and temperature shall be governed by the design code requirements and the material properties as guaranteed by the material Supplier.

4.2 PLATE

4.2.1 General

Plate complying with ASTM A 516 or EN 10028-3, as modified below, shall be used for all pressure boundary plate components in contact with the process environment. All other

plate materials (e.g. reinforcing pads, clips, skirts) shall be made from material complying with Section 3.4 of this Appendix.

ASTM A 841 TMCP steel may be considered but shall only be used with the approval of the Principal.

Plate material shall be HIC-tested in accordance with Section 5 of this Appendix. Plate shall be tested in a simulated PWHT condition (see Section 4.1 of this Appendix).

4.2.2 Manufacturing process

The steel shall be vacuum-treated, fully deoxidised, desulphurised and dephosphorised. The manufacturing/rolling process shall be such that a homogeneous microstructure is obtained, i.e. the structure shall be free of any significant ferrite/pearlite banding (see Section 5.6 of this Appendix). Calcium treatment shall be applied for inclusion shape control, except that it need not be applied to plate with very low sulphur levels (below 0.001%). The calcium content should not exceed 3 times the sulphur content. Alternative methods of inclusion shape control shall be subject to the approval of the Principal.

4.2.3 Chemical composition

In order to ensure effective resistance to both HIC and SSC, the chemical composition (product analysis) shall be restricted as follows, except where the standard material specification is more restrictive:

Single Elements	Maximum wt.%
Carbon (C)	0.20
Manganese (Mn)	1.30
Phosphorous (P)	0.01
Sulphur	0.002
Silicon (Si)	0.40
Copper (Cu)	0.4
Nickel (Ni)	0.4
Chromium (Cr)	0.3
Molybdenum (Mo)	0.12
Vanadium (V)	0.015
Niobium (Nb)	0.015
Titanium (Ti)	0.02
Boron (B)	0.0005
Multiple Elements	
Cr + Mo	0.3
Ni + Cu + Cr + Mo	0.7
V + Nb	0.02
Carbon Equivalent (Note 1)	0.43

NOTES 1. Carbon Equivalent (CE) shall be calculated using the following formula:

$$CE = C + \frac{Mn}{6} + \frac{(Ni+Cu)}{15} + \frac{(Cr+Mo+V)}{5}$$

2. The micro-alloying elements boron (B), titanium (Ti), niobium (Nb) and vanadium (V) shall not be intentionally added to the steel unless the Principal has given prior approval.

4.2.4 Lamination check

Plate shall be subjected to an ultrasonic lamination check in accordance EN 10160, grade S₂E₂.

4.3 WELDED PIPE AND FITTINGS

Generally, only seamless pipe and fittings should be used for vessel nozzles. Where this is impractical, welded pipe and fittings manufactured from plate complying with Section 4.2 of this Appendix shall be used. Welding of such fittings shall be done using welding procedures complying with Section 3.7 of this Appendix.

5. HIC TESTING

5.1 RESPONSIBILITY

HIC testing is the responsibility of the vessel Manufacturer but the testing may be performed by the steel Manufacturer. Material inspection certificates shall be in accordance with ISO 10474, type 3.1.C (for which the vessel Manufacturer or steel Manufacturer shall appoint the witnessing party, which shall be subject to the approval of the Principal).

5.2 FREQUENCY OF TESTING

The vessel Manufacturer shall perform HIC sensitivity tests in the solution prescribed in Section 5.4 of this Appendix.

Plate materials shall be subjected to HIC testing at a frequency of one test per heat. For pressure vessel plate where more than one thickness may be rolled from the same heat, tests shall be performed on both the thickest and the thinnest plates produced from each heat.

5.3 TEST METHOD

Testing shall be performed in accordance with NACE TM0284 using Solution A.

5.4 ACCEPTANCE CRITERIA

The following acceptance criteria shall be met:

TABLE 5

	% (maximum)		
	CLR	CTR	CSR
Average	5	1.5	0.5
Single	7	2	0.7

The maximum individual crack length on any section shall not exceed 5 mm.

If any specimen fails to meet the above acceptance criteria, the heat of steel represented by the test shall be rejected.

5.5 EVALUATION OF PLATE MICROSTRUCTURE FOR BANDING

One specimen from each plate shall be polished and etched (in thicker plates, multiple specimens representing the full thickness shall be prepared) and the microstructure evaluated for the degree of banding according to ASTM E 1268. Micro-indentation hardness tests are not required. Results shall be reported, for information only, using ASTM E 1268 reporting nomenclature.

5.6 REPORTING

In addition to the reporting required by NACE TM0284 the following information shall be provided:

- a) Location and dimensions of specimens.
- b) Full chemical analysis of material tested including analysis for micro-alloying elements.
- c) Mechanical properties of materials tested after a simulated PWHT cycle.
- d) Results of cracking evaluation indicating individual CLR, CTR and CSR for each section and also averaged over 3 sections, and pass/fail.
- e) Photomicrographs of the specimens showing cracking and/or blistering, together with photomicrographs of adjacent material structures and photomicrographs of the bulk material structure (samples) used to assess microstructure banding:
 - i) unetched, showing the type of inclusions in the steel;
 - ii) etched, showing the parent material microstructure;
 - iii) assessment of microstructure banding according to ASTM E 1268.

6. TESTING FOR SOHIC

**Amended per
Circular 22/04**

In high severity SOHIC environments, HIC-resistant steels may be susceptible to SOHIC in areas of local stress concentrations such as welds.

If HIC-resistant carbon steel is specified for a high severity SOHIC environment then testing for SOHIC resistance shall be performed in addition to, and at the same frequency of, the HIC testing requirements of Section 5 of this Appendix.

The test method for SOHIC testing shall be in accordance with NACE TM0103. The acceptance criteria shall be as specified by the materials engineer of the Principal.

APPENDIX 5 PREPARATION AND INSTALLATION OF TEST BLOCKS

The test blocks shall be made by welding a block from the heat with the lowest J-factor to a block from the heat with the highest J-factor, as shown in Figure 1.

$$\text{J-factor} = (\% \text{Si} + \% \text{Mn}) \times (\% \text{P} + \% \text{Sn}) \times 10^4$$

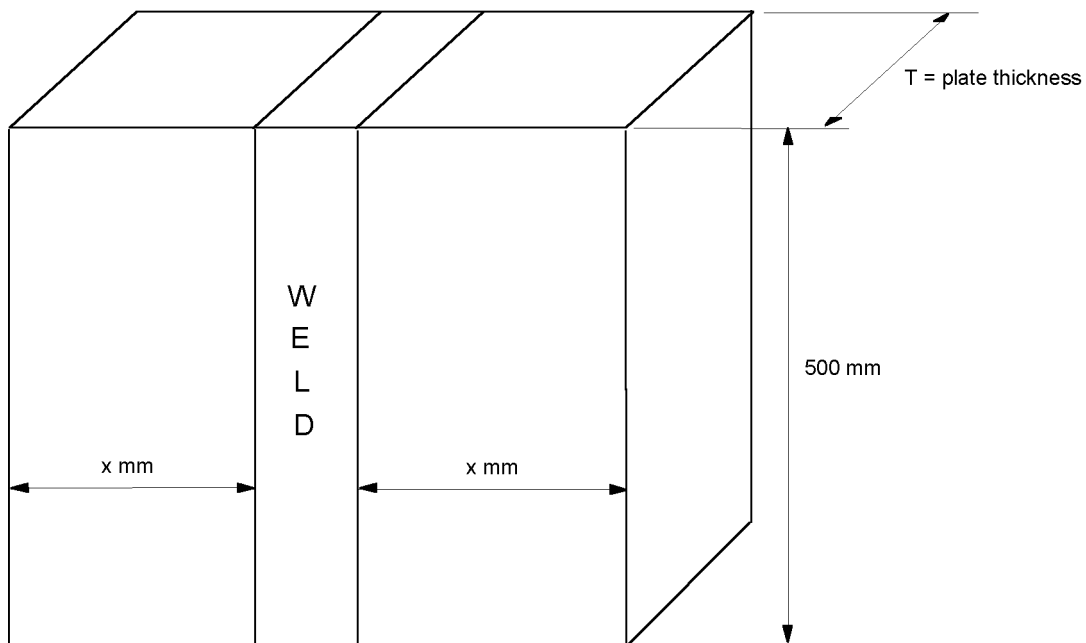
The outside surface shall be clad or weld overlayed in accordance with the same procedures used for the vessel. The heat number and J-factor shall be stamped in the cladding or weld overlay of the respective piece.

A total of four test blocks shall be installed as follows:

- 2 blocks, 180° apart, in the top of the reactor; and
- 2 blocks, 180° apart, in the bottom of the reactor.

Each block shall be installed loose, in a cage attached to supports on the vessel wall. The design of this cage shall be subject to the approval of the Principal.

Figure 1 Test block for installation in a Cr-Mo vessel



x = 100 mm if T is greater than 150 mm

x = 200 mm if T is 150 mm or less

APPENDIX 6 REQUIREMENTS FOR EQUIPMENT BUILT FROM Cr-Mo STEELS

1. SCOPE

All requirements for hydrogen service Cr-Mo vessels (regardless of grade) are intended for vessels in services having a hydrogen partial pressure less than 100 bar (abs) and/or having a thickness less than 60 mm. For heavy wall high pressure hydrogen service Cr-Mo vessels, see API RP 934.

2. HYDROGEN SERVICES

For 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo and 3Cr-1Mo steels used in equipment with a maximum operating temperature above 350 °C and with a primary membrane design stress greater than 50 MPa, the following requirements shall apply in addition to the other requirements of this DEP:

- the base material shall be vacuum degassed and aluminium killed;
- the material shall be supplied in the quenched and tempered condition and, the base material shall have a Charpy V notch energy absorption value of 55 joules average and 48 joules minimum at minus 30 °C;
- the chemical composition of the base material shall comply with DEP 30.10.02.11-Gen., including the restrictions given in the Notes therein;
- welding consumables shall produce deposited weld metal with the following restrictions on chemical composition:

$$\frac{(10 P + 5 Sb + 4 Sn + As)}{100} \leq 15$$

in which the constituents are expressed in mg/kg;

and:

$$Mn + Si \leq 1.10$$

in which the constituents are expressed in wt%.

- formed heads shall be inspected in the same way as the base plate material and shall be delivered in the quenched and tempered condition;
- in the quotation the Manufacturer shall provide complete information on temperatures and soaking periods for austenitizing, quenching and tempering and for both intermediate and final heat treatments envisaged and how he intends to guarantee the as-built properties, taking these heat treatments into account;
- two of the untested welding production control test plates shall be used to prepare four test blocks for installation in the equipment. For the details of preparation and installation of test blocks, see Appendix 5.

NOTE Equipment built according to the above requirements will provide maximum operational flexibility with respect to starting up and shutting down provided the materials' properties are monitored by the use of test blocks placed in the equipment (see Appendix 5).

3. 1.25Cr-0.5Mo USED IN HIGH TEMPERATURE CREEP SERVICE (WITH OR WITHOUT)

For 1.25Cr-0.5Mo equipment with a maximum operating temperature above 450 °C (i.e. creep design), the following requirements shall apply:

- phosphorus content shall be less than 0.005%;
- carbon content shall be less than 0.14%;
- for plate, forgings and fittings ASTM/ASME Class 1 materials, or equivalent, should be specified;
- materials should be supplied in the normalised and tempered condition;
- a minimum preheat for welding of 150 °C should be used; and
- final PWHT should be in the 700 °C to 720 °C range.

4. GENERAL FABRICATION AND INSPECTION REQUIREMENTS

- The cut edges shall be given 100% magnetic particle examination and there shall be no indications.
- the preheat temperature shall be maintained during flame cutting, welding (i.e. interpass), arc gouging, welding of temporary attachments and other thermal applications.
- For fabrication reasons, the final required heat treatment is not performed directly after welding, a post-weld soaking heat treatment shall be performed at a temperature of 350 °C for 3 hours, without cooling down below the preheat temperature, prior to cooling down to ambient temperature. However, nozzle welds shall receive an intermediate post-weld heat treatment.
- The final post-weld heat treatment temperature shall be at least 20 °C below the tempering temperature, with a minimum holding time of 1 hour per 25 mm of thickness (with a minimum of 1 hour). Soaking periods shall be based on the heaviest welded section, including the total thickness of the vessel wall.