TECHNICAL SPECIFICATION

PRESSURE VESSELS
(AMENDMENTS/SUPPLEMENTS TO BS 5500)

DEP 31.22.10.32-Gen.

December 1996
(DEP Circulars 26/97, 61/97 and 53/99 have been incorporated)

DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

PREFACE

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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, national and international standards and codes of practice.

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.

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1) Operating companies having a Service Agreement with SIOP, 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.

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

NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

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APPENDICES

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 BS 5500 (1994 edition, plus amendments 8323 January 1995, 8563 March 1995, 8810 January 1996 and 9226 July 1996).

NOTE BSI are ready to issue BS 5500:1997, and it will be identical to the above edition with the amendments incorporated.

Cr-Mo vessels (regardless of grade) in services having a hydrogen partial pressure greater than 100 bar (abs), and/or having a thickness over 60 mm, are outside the scope of this DEP.

This DEP is a revision of the DEP with the same number dated July 1994.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP 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 refers to all process conditions with a hydrogen partial pressure greater than 7 bar (abs).

Very toxic substances are those which produce serious harm to health as a result of a single or short term exposure. The following shall be considered very toxic:

- Levels of $H_2S \geq 1000$ ppm mole in process streams;
- Other substances specified by the Principal to be very toxic.

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

1. GENERAL

This DEP is written in four parts. Part III is written in the form of amendments and supplements to BS 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 specification are indicated. In all other cases any discrepancy between the data/requisition sheets and this specification shall be brought to the attention of the Principal.

third level - this DEP.

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

PART III AMENDMENTS/SUPPLEMENTS TO BS 5500

Section one General

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 Appendix 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:

f Grade M1 with specified minimum tensile strength (Rm) exceeding 460 N/mm^2

Purchaser option or feature requiring approval by purchaser (Part, Section)	**Classification** (see **1.5.2.2**(e))	**Document in which option/feature should be identified**		
		Purchase order	**Approved drawing** (see **4.1.1**)	**Approved working procedure**
Any departure from this DEP to meet national and/or local regulations (Part I, 1.2)	Basic requirement	X or	X	
Use of grade M1 steel above 460 N/mm^2 (Part III, 2.1.1.1)	Basic requirement	X		
Alternative bolting materials (Part III, 2.1.2.4)	Variation	X or	X	
Use of grade M4 steel (Part III, 2.3.1)	Basic requirement	X		
Corrective actions for hardness (Part III, 2.3.2.12)	Basic requirement		N/A	repair procedure
Effective thickness of a clad liner (Part III, 3.3.2)	Basic requirement	X		
Flanges other than raised-face, WN (Part III, 3.8.1)	Variation	X or	X	
Sheet gasket thickness if not 1.5 mm (Part III, 3.8.1)	Variation	X or	X	
Use of Contractor's own despatch forms (Part III, 4.1.1)	Variation	X		
Alternative joint details (Appendix E)	Variation		X	welding procedure
Ultrasonic examination (Annex AA, 5.6.5.1)	Basic requirement	X		NDT procedure
Alternative lining methods (Appendix 1, item 1)	Basic requirement	X		
Calibration of ferrite scope (Appendix 1, item 7-2)	Basic requirement			welding procedure
Use of single-layer overlay (Appendix 1, item 9)	Basic requirement			welding procedure
Crack detection method and testing intensity for weld overlay deposits (Appendix 1, item 17)	Basic requirement			welding procedure
Alternative portable hardness tester (Appendix 3, 2.1) (Appendix 4, 3.7.2)	Variation			NDT procedure
Use of hot-finished material (Appendix 4, 3.2)	Variation	X or	X	material specification
Intentional addition of micro-alloying elements (Appendix 4, 3.2) (Appendix 4, 4.2.3)	Variation	X or	X	material specification
Alternative heat treatments (Appendix 4, 4.1)	Variation	X or	X	material specification
Use of ASTM 841 TMCP steel (Appendix 4, 4.2.1)	Variation	X or	X	material specification
Alternative methods of inclusion shape control (Appendix 4, 4.2.2)	Variation	X or	X	material specification
Witnessing party for inspection certificates type 3.1.C (Appendix 4, 5.1.1)	Basic requirement	X or	X	

Section two Materials

2.1.1.1 Add to this clause:

For the prevention of brittle fracture, DEP 30.10.02.31-Gen. shall apply for the services and conditions specified therein.

Materials of Grade M1 with specified minimum tensile strength (Rm) exceeding 460 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.

A materials/corrosion engineer shall judge whether additional requirements shall be specified for metallic materials for equipment containing process streams with hydrogen sulphide (H_2S) in concentrations which could cause sulphide stress cracking (SSC) and/or hydrogen induced cracking (HIC), see (Appendix 4).

Materials selection for hydrogen service (Part 1, 1.3.2) above 230 °C shall be in accordance with API 941. The maximum operating temperature shall be at least 20 °C below the limit of API 941.

Plates for equipment in hydrogen service shall be ultrasonically examined in accordance with BS 5996 B4E2. For clad materials in hydrogen service, see (Appendix 1).

Cr-Mo vessels (regardless of grade) in services having a hydrogen partial pressure greater than 100 bar (abs), and/or having a thickness over 60 mm, are outside the scope of this DEP.

Plates for equipment in hydrofluoric acid service shall comply with ASTM A 770 S3 (with a minimum area reduction of 35%) or with EN 10164 (Quality Class Z 35). Furthermore, these plates shall be ultrasonically examined in accordance with BS 5996 B4E2.

Add new clause:
2.1.1.1.1 Cr-Mo hydroprocessing equipment

For 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo and 3Cr-1Mo hydroprocessing 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;
- in the quenched and tempered condition, 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.

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).

For 1.25Cr-0.5Mo hydroprocessing equipment with a maximum operating temperature above 450° C and with a primary membrane design stress less than 50 MPa, 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 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 range 700-720°C.

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.

2.1.2.1 Add to this clause:

c) 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.

2.1.2.4 Add to this clause:

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.

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

2.3.1 Add to this clause:

Approval of the Principal is required for the use of Grade M4 material.

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 three Design

3.2.1 Add to this clause:

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

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:

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

where D = mean vessel diameter in mm.

3.2.3 Add to this clause:

DEP 01.00.01.30-Gen. shall apply

3.2.4 Add to this clause:

The latter shall also be incorporated in the operating manual as specified in table 1.5.

The Principal shall specify on the data/requisition sheets if a fatigue detail analysis is required to be performed by the Manufacturer. (To decide whether such an analysis is required, the Principal may use BS 5500, Appendix C, Section C.2). If a fatigue detail analysis is specified, the Principal shall specify the required fatigue service lifetime and the Principal shall provide 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.

3.2.7 Add to this clause:

Wind loads shall be determined in accordance with DEP 34.00.01.30-Gen., unless deviation is necessary to comply with national and/or local regulations. The contractor shall state the wind pressure in the data requisition sheet 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. The calculation of the stated wind pressure shall take into account the applicable correction factor for the aspect ratio (K) of the equipment and assume the shape factor (Cf) to be 1.

The Manufacturer shall check the static deflection and the stresses due to the wind pressure during operation and the stress during shutdown The deflection at the top of the equipment is restricted to $^{1}/_{500}$ of the overall height for brick-lined equipment and to $^{1}/_{200}$ 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:

1.1 m^2 for a full, round platform
1.7 m^2 for a full, square platform
0.33 m^2 per metre for a cage ladder
0.11 m^2 per metre for a flush ladder

The above shall be used for calculations in accordance with Appendix B of BS 5500. 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 frequency of shedding of eddies is within 70% of the natural frequency of the equipment, three wind deflectors shall be installed with a width of $^1/_{10}$ 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.

3.3.2 Add to this clause:

The corrosion allowance for carbon and low-alloy steel in general process service shall be 3 mm unless otherwise specified by the Principal.

For non-corrosive or very mildly corrosive conditions (e.g. steam, dry compressed air, LPG, LNG and dry natural gas service) the corrosion allowance shall be 1 mm.

Corrosion allowances shall be applied to removable internals in pressure vessels as follows:

- No corrosion allowance on stainless steel internals unless specified.
- Heavily-loaded components (catalyst grids, etc.) in non-clad equipment made from carbon or low-alloy steel shall have a corrosion allowance on each surface equal to half the required corrosion allowance for the equipment.

The effective thickness of a cladding 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.

Corrosion allowances for equipment in services where the operating temperature is always below zero °C shall be as follows:

- fine grain carbon steel, 3.5% Ni steel and 9% Ni steel: 1 mm
- aluminium and stainless steel: no corrosion allowance

3.3.3 Add to this clause:

Integrally clad steel plate and corrosion resistant lining shall also comply with ASME VIII Div. 2, Article F-5, except as modified in Appendix 1 of this DEP.

For the requirements for process equipment with internal chemical-resistant brick lining, see DEP 30.48.60.13-Gen.

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 following shall apply:

Construction category 1 shall be selected if one or more of the following conditions apply:
- Very toxic substances (Part **I**, 1.3.2);
- Liquefied gas;
- Hydrogen service (Part **I**, 1.3.2);
- A Lower Design Temperature below 0 °C;
- Vessels operating at a pressure exceeding 5 bar (ga) and with a P*V value exceeding 100 MJ (1000 bar (ga) m^3);
- Vessels operating in cyclic service;
- Nominal wall thickness > 35 mm;
- Cr-Mo steels and other ferritic alloy steels, and carbon steels having a tensile strength greater than 460 N/mm^2;
- Austenitic stainless steel and nickel alloys (design pressure > 20 bar (ga));
- Vessels which operate in the creep range of the materials of construction.

Construction category 2 shall be selected for all services which are not covered by either Construction category 1 or Construction category 3.

Construction category 3 shall be selected for:
- Utilities (low pressure steam < 10 bar (ga), air, water, inert gas)
- Atmospheric (storage) vessels.

3.4.2.1 c) Add to this clause:

Calculations for welded constructions shall assume that materials are in a soft temper condition (i.e. temper O). The material shall be selected from DEP 30.10.02.11-Gen., with a minimum elongation of 15%.

3.5.4.1 Add to this clause:

Standard Drawing S 10.101 shall apply to nozzles.

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 hydrocarbon liquid outlet of separators where the liquid is separated from water or aqueous solutions, except where this would give rise to corrosion problems in the bottom.

Nozzle types shall be as follows:

Type of service	vessel wall thickness, t (mm)		Nozzle type
all	t < 50		set-in
	t ≥ 100		forged saddle type
cyclic	t ≥ 50		forged saddle type
non-cyclic	50 ≥ t < 100	nozzle thickness ≥ t/2	set-in
		nozzle thickness < t/2	set-on (Notes 1 and 2) or set-in

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 BS 5996 B4E2.

2. Set-on nozzles shall not be used in hydrogen service above 230 °C (Part I, 1.3.2).

For both set-in and set-on nozzles, the fillet of 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.

3.5.4.3.1 Add to this clause:

External nozzle loadings shall be specified on the requisition.

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).

Reinforcing pads shall have one hole, tapped $^{1}/_{4}$ " NPT, per closed compartment.

3.5.4.8 Replace this clause by:

Single fillet-welded, expanded, brazed or screwed connections shall not be used.

3.7.1 Add to this clause:

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 higher than 20 m, this shall be specified in the data/requisition sheets. If required, davits shall be provided in accordance with Standard Drawing S 28.015.

3.7.2 Add to this clause:

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

Continuous fillet welds shall be used for all internal structures, supports and fittings to be welded to the vessel wall.

The design of supports shall be such 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 should provide for insulation sealing, adequate surface protection and prevention of condensate collecting areas.

3.7.2.2.3 Add to this clause

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

3.7.2.2.4 Add new clause:

Amended per Circular 53/99

All vertical vessels shall be provided with lifting trunnions, attached by full penetration welds, or lifting lugs as specified in the requisition. 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. See for lifting trunnions for vertical vessels over 50 tonnes Standard Drawing S 10.115. To avoid corrosion, heat loss and thermal stress, on insulated pressure vessels the protruding part of lifting trunnions should be removed after erection.

3.7.2.3 Add to this clause:

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

3.8.1 Add to this clause:

Amended per Circular 26/97

Flanges should conform to ANSI B16.5, see also BS enquiry case 5500/58. For sizes not covered by ANSI B16.5, the dimensions may be taken from ANSI B16.47 but these should be checked as for non-standard flanges for their suitability for the intended duty.

Non-standard flanges shall be designed in accordance with clause 3.8 of BS 5500.

NOTE The Principal may specify the use of DIN flanges (e.g. if the site is standardized on the use of DIN flanges), in which case the ratings and the design requirements specified by the applicable DIN standard shall apply. All further requirements stated below are applicable only to ANSI B16.5 and ANSI B16.47 flanges.

For insulated flanges the design temperature shall be equal to the design temperature of the vessel. For uninsulated flanges the design temperature may be 85% of the design temperature of the vessel for lap-joint flanges, and 90% of the design temperature of the vessel for all other types of flanges. See also clause 3.8.1.4 of this DEP.

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/ANSI B16.5.

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

Spiral wound gaskets shall be provided with a compression stop. A centering ring or centering plus inner ring 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.

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 ($^5/_8$") shall not be used for flanged connections. The height of the nut shall be equal to the bolt diameter.

Bolting up to 25 mm (1") shall have UNC standard thread and bolting 28 mm (1 $^1/_8$") and larger shall have UN threading (8-thread series). However, bolting and threads shall comply with ISO metric standards when this is standard practice for the location (which shall be stated in the data requisition sheets). See also Standard Drawings S 10.035 and S 10.116.

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

For insulated flanges, the design temperature of the bolting shall be taken as equal to the design temperature of the vessel; for uninsulated flanges, the design temperature of the bolting may be taken as equal to 80% of the design temperature of the vessel.

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.

Sulphur-containing thread compounds shall not be used.

3.12 Add to this clause:

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 DN150 (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.

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

3.13.3.2 Add to this clause:

Rupture discs are highly stressed in service. In order to avoid premature failure due to the effects of corrosion, creep and fatigue, a substantial margin (at least 30% of the nominal bursting pressure for tension-loaded discs, and at least 10% of the minimum bursting pressure for reverse-buckling discs) shall be allowed between the MOP and the design pressure of the vessel. It should be noted that the bursting pressure of rupture discs is materially influenced by temperature.

Section four Manufacture and workmanship

4.1.1 Add to this clause:

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 to the Inspecting Authority.

4.2.1.2 Add to this clause:

For Cr-Mo equipment with a maximum operating temperature above 350 °C the cut edges shall be given 100% magnetic particle examination and there shall be no indications.

4.2.4 Add to this clause:

For tolerances not covered by code requirements see Appendix 2.

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 normalising 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 with a maximum operating temperature above 350 °C the following requirements shall apply in addition to the other requirements of this DEP:

- the preheat temperature shall be maintained during flame cutting, welding (i.e. interpass), arc gouging, welding of temporary attachments and other thermal applications;
- if, 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, in the case of nozzle welds, they 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.

4.4.4.1 Add to this clause:

If steels of grade M1 are used with a specified minimum tensile strength (Rm) exceeding 460 N/mm^2, the need to employ preheat for all thicknesses shall be ascertained in view of the required hardness of the end product.

See also the amendment to (2.1.1.1).

4.4.5.2 Add to this clause:

PWHT is also a method to reduce the hardness of the end product such that the required maximum values are no longer exceeded (see 4.4.4.1 and 2.1.1.1.).

4.4.5.6 Add new clause:

Pressure vessels constructed of integrally clad steel plate or with corrosion resistant lining shall also comply with ASME VIII, Div. 2, Article F-5, except as modified in Appendix 1 of this DEP.

4.5 Add to this clause:

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 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.

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 bolts through at least four bolt holes.

Section five Inspection and testing

5.1 Add to this clause:

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

The Principal should tailor the scope of the Principal's inspection to avoid duplication with 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 (Rm) greater than 460 N/mm^2. 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 in those cases where 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.

One plate (or, if more than two plates were required, half the total number of plates) shall be selected and tested at an early stage. If the vessel will be post-weld heat treated, then this test plate(s) shall be given a simulated heat treatment before testing, and a permanent time/temperature record shall be retained by the Manufacturer. This test plate(s) result shall be considered valid if the eventual vessel post-weld heat treatment is within the specified time/temperature range. The other test plate(s) shall be placed inside the vessel during its post-weld heat treatment, and shall be retained in case later testing may be required.

NOTE As an alternative to the above, unless otherwise specified by the Principal, the Manufacturer may choose to post weld heat treat all the production control test plates inside the vessel, rather than performing a simulated post weld heat treatment.

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 with a maximum operating temperature above 350 °C and with a primary membrane design stress greater than 50 MPa, 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.

5.4.2 Add to this clause:

Appendix Q is mandatory.

5.6.4 Add to this clause:

For construction category 1 and construction category 2 vessels all tee and corner joints shall have full penetration welds.

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.

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 degrees, a supplememtary examination shall be performed by a mechanised tandem technique with an angle of refraction of 45 degrees.

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 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. Ensis) or grease to prevent ingress of water.

5.8.9 Add to this clause:

Standard Drawing S 10.114 shall apply to nameplates. Bronze nameplates shall not be used on stainless steel equipment. 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 upper design temperature and pressure and the lower design temperature.

APPENDIX E

Add to this Appendix:

Only the following figures of joint detail are acceptable for construction category 1 and construction category 2 vessels:

Amended per Circular 53/99

E.1a, b and c

E.2a, b, c, d and f

E.3a and c

E.4a, b, c (see Note 1), f, g and h

E.6

E.7- 2nd, 3rd, 4th, 6th and 7th options

E.8- 1st, 3rd and 5th options

E.9 B1, B2, B3, J1, J2 and J3

E.11c and d

E.12a and b; E.14a and b; E.15a and b (see Note 2)

E.16a and b; E.17a and b; E.18a (see Note 2)

E.21a and b; E.22a and b; E.23a and b

E.24a and b; E.25a and b; E.26a and b E.27

E.28a; E.31a (see Note 3)

E.32a, b, c and d; E33a,b(iii) only if the Principal approves the use of screwed and/or socket-welded connections

E.34a and b; E.35a, b and c

E.36a and b; E.37a, b and c; E.38e; E39a

E.41a, b, c, e, f and i

E.42b

E.43b

E.44a and b

E.46 1, 2 and b; E.47b

Other joint details shown in this Appendix may be used only with the approval of the Principal.

NOTES

1. Backing strips should not normally be used. If used, all backing strips and bars shall be carefully removed after welding (see also 4.3.6.2 and 4A.3.6.2 of BS 5500). Where the back of the joint cannot be dressed after welding, an adequate inert gas backing shall be applied and backing strips shall not be used.

2. See (3.5.4.1) of this DEP.

3. Only for full penetration welds for shell-to-branch joints.

ANNEX AA SUPPLEMENT TO BS 5500

Section two Materials

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 five 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

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 and pressure levels	DEP 01.00.01.30-Gen.
Approval drawing specification	DEP 05.00.54.81-Gen.
Final drawing specification	DEP 05.00.54.82-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.
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.
Equipment and tools for maintenance and inspection. Part 2: Mechanical maintenance - Equipment, tools and bolt tensioning	DEP 70.08.10.11-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
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
Davit general arrangement and typical details	S 28.015
Earthing boss for steel structures, tanks, vessels, etc.	S 68.004

AMERICAN STANDARDS

Pipe flanges and flanged fittings	ANSI/ASME B16.5
Large diameter steel flanges	ANSI/ASME B16.47
Surface texture	ANSI/ASME B46.1

Issued by:
American National Standards Institute, Inc.
1430 Broadway, New York
NY 10018, USA.

Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants	API 941

Issued by:
American Petroleum Institute
Publications and Distribution Section
2101 L Street Northwest
Washington, DC 20037, 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

Issued by:
American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017, USA.

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 practice for detecting susceptibility to intergranular attack in austenitic stainless steels	ASTM A 262
Standard specification for corrosion-resisting chromium steel-clad plate, sheet, and strip	ASTM A 263
Standard specification for stainless chromium-nickel steel-clad plate, sheet, and strip	ASTM A 264

Standard specification for nickel and nickel-based alloy-clad steel plate	ASTM A 265
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
Test method for hydrophobic surface films by the atomizer test	ASTM F 21

Issued by:
American Society for Testing and Materials
1916 Race Street Philadelphia
Pa 19103, USA.

Sulphide stress cracking resistant metallic materials for oilfield equipment	NACE MR0175
Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking in H_2S Environments	NACE TM0177

Issued by:
National Association of Corrosion Engineers
1440 South Creek
Houston, Texas 77084, USA.

BRITISH STANDARDS

Methods of destructive testing fusion welded joints and weld metal in steel	BS 709
Unfired fusion welded pressure vessels	BS 5500 (1994 edition, plus amendments: 8323 January 1995, 8563 March 1995, 8810 January 1996 and 9226 July 1996).

NOTE BSI are ready to issue BS 5500:1997, and it will be identical to the above edition with the amendments incorporated.

Specification for acceptance levels for internal imperfections in steel plate, strip and wide flats, based on ultrasonic testing	BS 5996

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

Issued by:
Comité Européen de Normalisation
Secrétariat Central
Rue de Stassart 36
B-1050 Brussels
Belgium.

Copies can also be obtained from national standards organizations

GERMAN STANDARDS

Clad Steel	AD Merkblatt W 8

Issued by:
Beuth Verlag GmbH
Burggrafenstrasse 4-10
D-1000 Berlin 30
Germany.

INTERNATIONAL STANDARDS

Steel and Steel Products, Inspection documents	ISO 10474

Issued by:
International Organization for Standardization
1, rue de Varembé
CH-1211 Genève 20
Switzerland.

Copies can also be obtained from national standards organizations

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, attached by welding 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. Integrally clad plate in accordance with AD Merkblatt W 8 may be 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 cm^2;
   - The total of the unbonded areas shall not exceed 100 cm^2 per 1 m^2 area of plate (areas less than 1.0 cm^2 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, which is referred to in ASME VIII, Div. 2, Article F-5.
   1. Chemical analysis of weld overlay of the production welds shall be performed at a depth of 2 mm with 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 weld overlay of the production welds shall be performed at a depth of 2 mm with the following extent:
      - one analysis per course;
      - one analysis per head;
      - one analysis per nozzle.

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

      Calibration records of the ferrite scope shall be submitted to the Principal for approval.
   3. Liquid penetrant examination shall be performed on the entire clad surface. The acceptance criterion shall be zero indications of cracks.

4. For linings in hydroprocessing equipment, the cladding shall be in a non-sensitized condition. This shall be demonstrated by passing the intergranular corrosion test in accordance with ASTM A 262, practice E.

8. The grade of stainless steel overlay shall be specified by the Principal in the data/requisition sheets.

   For a maximum operating temperature not higher than 425 °C, the weld overlay thickness shall be a minimum of 3 mm. For a maximum operating temperature higher than 425 °C, the weld overlay thickness shall be a minimum of 5 mm.

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 BS 5500

1. VESSELS WITH INTERNALS

For dimensions of tray support rings see (3.5) of this Appendix.

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 in 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 ≤ 100	± 2.0
1 000 < L ≤ 4000	± 4.0
4 000 < L ≤ 10 000	± 8.0
L > 10 000 and all vessels having a wall thickness over 70 mm	± 13.0

NOTE Tangent lines shall be punch-marked on the dished heads, both externally and internally at the intersection of 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)

a. Position
measured from tangent line: ± 6 mm

b. Projection
for nozzles on shell measured from shell curvature, and for nozzles on domes measured from tangent line: ± 6 mm

c. Alignment
of nozzle flange face with the indicated plane: maximum 0.5 degree in any direction.

d. Radial orientation
Measured from reference centre line to centre line of nozzle: ± 1 degree with a maximum circumferential tolerance of 15 mm.

e. Bolt hole orientation
Maximum rotation 1.5 mm measured at bolt circle.
NOTE Bolt holes to straddle centre lines, unless otherwise indicated

f. 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

g. Distance
measured from centre to centre: ± 1.5 mm

h. Projection difference
for each pair of flanges, measured from shell curvature: 1.0 mm.

i. Alignment
of nozzle flange face with the indicated plane: maximum 0.25 degree 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 degree in any direction.

3.4 Vessel supports

m. Support height

Distance H from lower tangent line to base or support (mm)	Tolerance (mm)
H ≤ 1000	± 2.0
1000 < H ≤ 4000	± 4.0
4000 < H ≤ 10000	± 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

Amended per Circular 61/97

s. Tray support ring levelness
measured as greatest difference all around: ± 0.15% of the outside tray diameter, with a maximum of 4 mm.

t. Tray support ring position
Distance of tray support ring to lower tangent line: ± 6 mm.

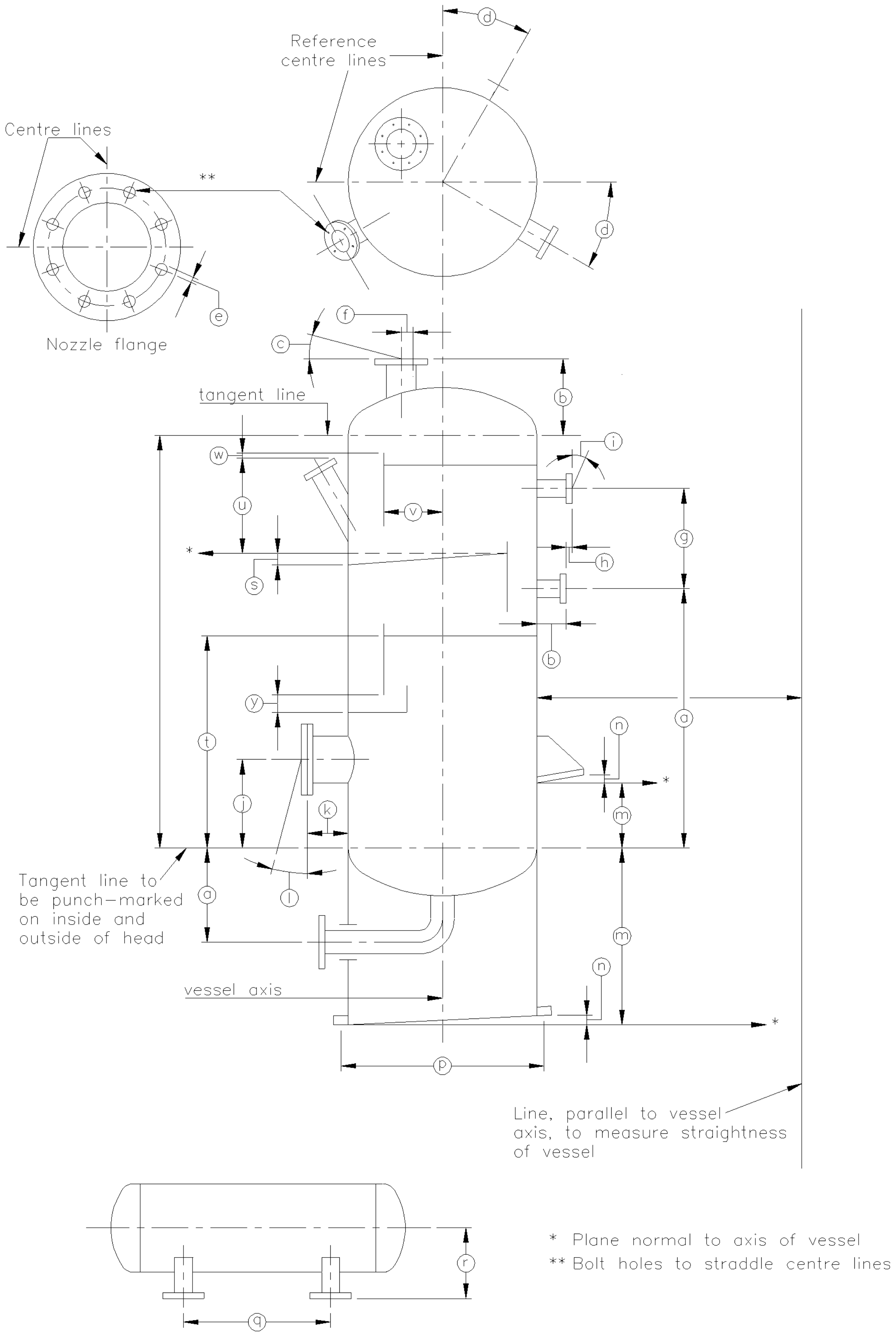
u. Distance between two adjacent tray support rings (and from tray support ring to centre of adjacent nozzle or instrument connection): ± 3 mm, except for the distance of a draw-off tray support ring to the centre of the corresponding nozzle, for which the tolerance is ± 2 mm.

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.

Figure 1 Alphabetic coding



* Plane normal to axis of vessel
** Bolt holes to straddle centre lines

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, except for utility (steam, water and air) services, for which the maximum hardness shall be 290 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 metres 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 H_2S SERVICE/SOUR SERVICE

See Appendix 4, Section 3.7.

APPENDIX 4 CARBON STEEL PRESSURE VESSELS IN WET H_2S SERVICE/SOUR SERVICE

1. INTRODUCTION

This Appendix shall be applied for the specification and fabrication of carbon steel pressure vessels in order to mitigate or avoid the effects of aqueous hydrogen charging in "Wet H_2S" 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 H_2S 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 H_2S/SOUR SERVICE

"Wet H_2S" service is the term commonly used for refinery and gas plant (SIOP) environments containing water and H_2S (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 SIOP 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:

- Sour conditions, as defined in NACE MR0175, prevail; **and**
- the temperature at any time during operation is between 0 °C and 65 °C.

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 H_2S exceeds 0.0035 bar (abs); **or**
- In liquid containing systems, the concentration of H_2S is higher than that occurring in a liquid equilibrium with a gas containing H_2S 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 SIOP - "WET H_2S" 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 H_2S process environments.

In refinery streams containing free water and H_2S, 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 following table should be used to estimate the severity category with respect to SSC. Process conditions outside these ranges should be further assessed for hydrogen blistering, HIC and SOHIC severity using Table 1B.

pH of water	**Cyanide content (mg/kg)** (Note 1)	**H_2S CONTENT OF WATER (mg/kg)**		
		< 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 is not significant 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 outside 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.

pH of water	**Cyanide content (mg/kg)** (Note 1)	**H_2S CONTENT OF WATER (mg/kg)**		
		< 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 HCN 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 HCN is not significant at pH 7.5 and below.

TABLE 1C SUSCEPTIBILITY TO CARBONATE CRACKING

If there is no free water likely to be present or the water phase contains less than 50 mg/kg H_2S 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 H_2S 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	**$CO_3^{=}$ 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 SIOP "WET H_2S" MATERIALS AND PWHT REQUIREMENTS

POTENTIAL MECHANISM(S) (Note 1)	**SEVERITY CATEGORY**		
	LOW	**MODERATE**	**HIGH**
	MATERIALS AND PWHT REQUIREMENTS		
SSC	General Refinery Service	Section 3	Section 3 + PWHT (Note 4)
Hydrogen blistering, HIC and SOHIC (Note 2)	Not Applicable	Sections 3, 4 and 5	Clad, or Sections 3, 4, 5 and 6 (Note 3)
Carbonate Cracking	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 H_2S/SOUR SERVICE

3.1 GENERAL

All materials shall be in accordance with the materials property and heat treatment requirements of NACE MR0175 as supplemented or modified by this Appendix. Certification to NACE MR0175 is only required if specified by the Principal.

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 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 this has been given the prior approval of the Principal.

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. Welding of such fittings shall be done using 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 metres 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 (TCMP)), 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 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 this has been given the prior approval of the Principal.

4.2.4 Lamination check

Plate shall be subjected to an ultrasonic lamination check in accordance with BS 5996 B4E2.

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

5.1.1 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).

5.1.2 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.

5.2 QUALIFICATION OF TEST METHOD

Before commencement of the work, the vessel Manufacturer shall provide the Purchaser with a detailed procedure for the testing, metallographic preparation and evaluation of HIC specimens. The Manufacturer shall qualify the test method using samples from a steel of known crack sensitivity. The Principal shall indicate if any of these tests are to be witnessed.

5.3 SAMPLING

5.3.1 Removal of Test Specimens

Three adjacent specimens shall be removed cold, by machining from the test plate. The dimensions shall be 100 mm x 20 mm x t, where t is the plate thickness. The long dimension of the specimen shall be parallel to the plate rolling direction. For plates or pipe greater than 20 mm in thickness but less than 50 mm, specimens shall be extracted from the middle of the plate such that the specimen thickness is not greater than 20 mm. For plate thickness equal to or greater than 50 mm, an additional set of specimens shall be removed from the surface.

5.3.2 Specimen Preparation

The specimens shall first be rough ground on a belt grinder or by surface grinding. This shall be followed by final grinding to a 320 grit finish using silicon carbide papers. They shall then be degreased in acetone. The effectiveness of degreasing shall be demonstrated by using the atomiser test of ASTM F 21. Thereafter, extreme care shall be taken not to contaminate the coupons, which should only be handled with tongs or clean gloves.

5.4 TEST SOLUTION

The test shall be performed in the NACE TM0177 (low pH) test solution, i.e. 0.5% acetic acid + 5% NaCl + H_2S in water, with a pH of 2.9 to 3.3. The test shall be performed in glass vessels only.

The solution shall be de-aerated by bubbling nitrogen through it at a rate of 100 cm^3/l/min for 1 hour. The specimens shall be immersed in the solution with the face of 100 mm x 20 mm in the vertical position and the lower face raised from the cell bottom on Teflon or glass rods. When stacked, the specimens shall also be separated by similar rods, see Figure 1.

Nitrogen bubbling shall be continued for a further 1 hour, after which the solution shall be saturated by bubbling H_2S at the rate of 2 to 5 l/min for one hour through an open-ended tube with a 5 mm internal diameter. Upon reaching saturation, the H_2S flow rate may be reduced to 100 cm^3/min. for a 10 litre solution, or pro rata, and maintained at this rate for the test period. The H_2S purity shall be 99.5 vol.% or higher, and oxygen-free.

A small positive pressure of H_2S should be maintained in the test cell by the use of an outlet trap to prevent oxygen contamination from the air. If at any time during the test a white haze clouds the solution, the test shall be stopped and repeated with new specimens and fresh solution.

Conditions for the test shall be as follows:

Temperature		25 ± 3 °C
H_2S concentration		2300 to 3500 ppm, saturated condition
pH value	initial	2.9 to 3.3
	final	3.5 to 4.0
Test period		96 hours

The pH value of the solution shall be measured at the beginning and the end of the test and the H_2S concentration in the solution shall be determined at the end by iodometric titration.

5.5 EVALUATION OF BLISTERING AND HYDROGEN INDUCED CRACKING

5.5.1 Blistering

The tendency to blistering shall be reported after visual examination, and photographs shall be taken of the two wide faces of each coupon to show any blistering.

5.5.2 Hydrogen Induced Cracking

Specimens, taken with their long axis (100 mm) parallel to the rolling direction, shall be sectioned transversely at three points as shown in Figure 2. The intention of this sectioning procedure is to examine for cracks, in each case on a plane transverse to the rolling direction.

Cracking shall be estimated by micrographic examination at magnifications of X30 and X100.

5.5.3 Evaluation

For each crack observed, the length and extent of stepwise propagation shall be measured. For each section containing cracks, one photograph shall be taken showing the complete transverse sections.

HIC is defined in terms of crack length ratio (CLR), crack thickness ratio (CTR) and crack sensitivity ratio (CSR).

These values shall be reported for each section examined, and as the average of three (3) sections per specimen. In this evaluation, cracks which have no part more than 1 mm from the surface associated with surface blistering shall be disregarded. Refer to Figure 3.

5.5.4 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.

5.6 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. Microindentation hardness tests are not required. Results shall be reported, for information only, using ASTM E 1268 reporting nomenclature.

5.7 REPORTING

a) Results of cracking evaluation indicating individual CLR, CTR and CSR for each section and also averaged over 3 sections, and pass/fail.

b) Photomicrographs of the specimens showing cracking, 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 per ASTM E 1268.

c) pH of the H_2S saturated solution at the beginning and at the end of the test, the H_2S content and confirmation of the type of solution.

d) Photographs of specimens, showing any blisters.

e) Location and dimensions of specimens.

f) Full chemical analysis of material tested including analysis for micro-alloying elements.

g) Mechanical properties of materials tested after a simulated PWHT cycle.

6. TESTING FOR SOHIC

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 the HIC testing requirements of Section 5 of this Appendix.

The materials engineer of the Principal shall be consulted for specific testing requirements and acceptance criteria. Unless otherwise specified, the testing shall be as follows:

a) A stressed Double Beam (DB) specimen shall be used. Both beams shall be from the same section of plate to be tested. Sampling shall be in accordance with the requirements for HIC testing (Section 5 of this Appendix). Sufficient specimens shall be removed from the plate(s) to be tested to cover the full plate thickness. The beam axis (i.e. the stressing orientation) shall be perpendicular to the material rolling direction and perpendicular to the intended welding direction.

b) The DB specimen(s) shall be coated on all sides except the tension surface to produce one-sided exposure conditions. A polymeric coating resistant to deterioration in the test environment should be used to mask the protected surfaces.

c) The stress concentration in the beams shall be created by machining a standard notch into the tension side of each beam.

Figure 1 Specimen arrangement in cell

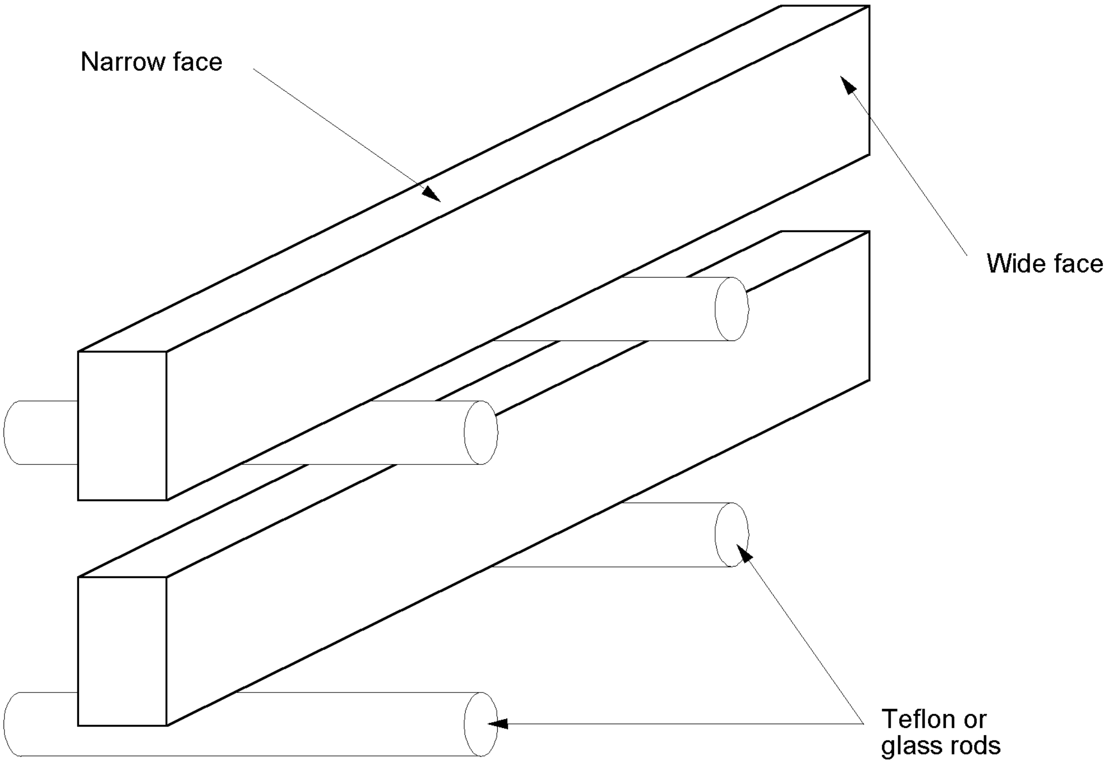


Figure 2 Sectioning of specimens

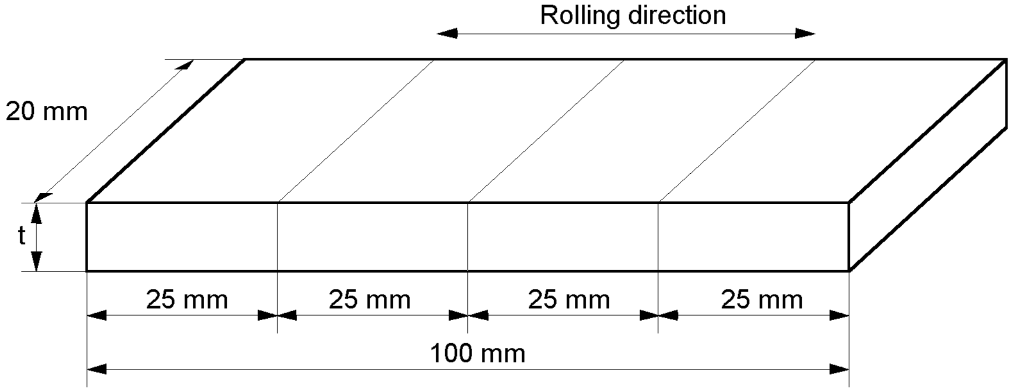
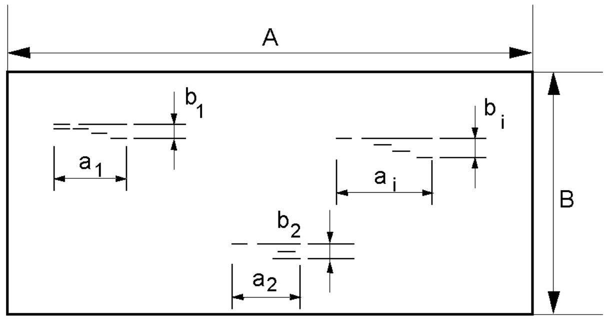


Figure 3 Evaluation of HIC

Cracks are evaluated according to crack length ratio (CLR), crack thickness ratio (CTR) or crack sensitivity ratio (CSR) by measuring the total crack length, extent of stepwise cracks or stepwise crack area respectively.

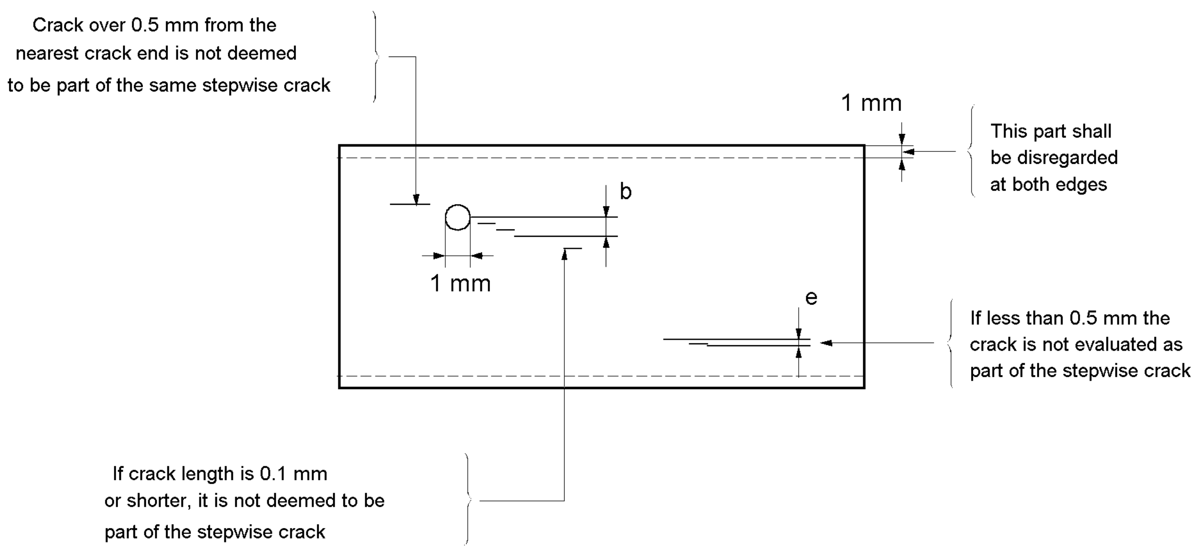


Length of stepwise crack = Σa_i

Extent of stepwise crack = Σb_i

CLR, CTR and CSR values can be calculated with the following equations.

$$CLR = \frac{\sum_{i=1}^{n} a_i}{A} \times 100\ (\%) \qquad CTR = \frac{\sum_{i=1}^{n} b_i}{B} \times 100\ (\%) \qquad CSR = \frac{\sum_{i=1}^{n} a_i \cdot b_i}{A.B} \times 100\ (\%)$$



Definition of stepwise crack

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 4.

J-factor = (%Si + %Mn) x (%P + %Sn) x 10^4

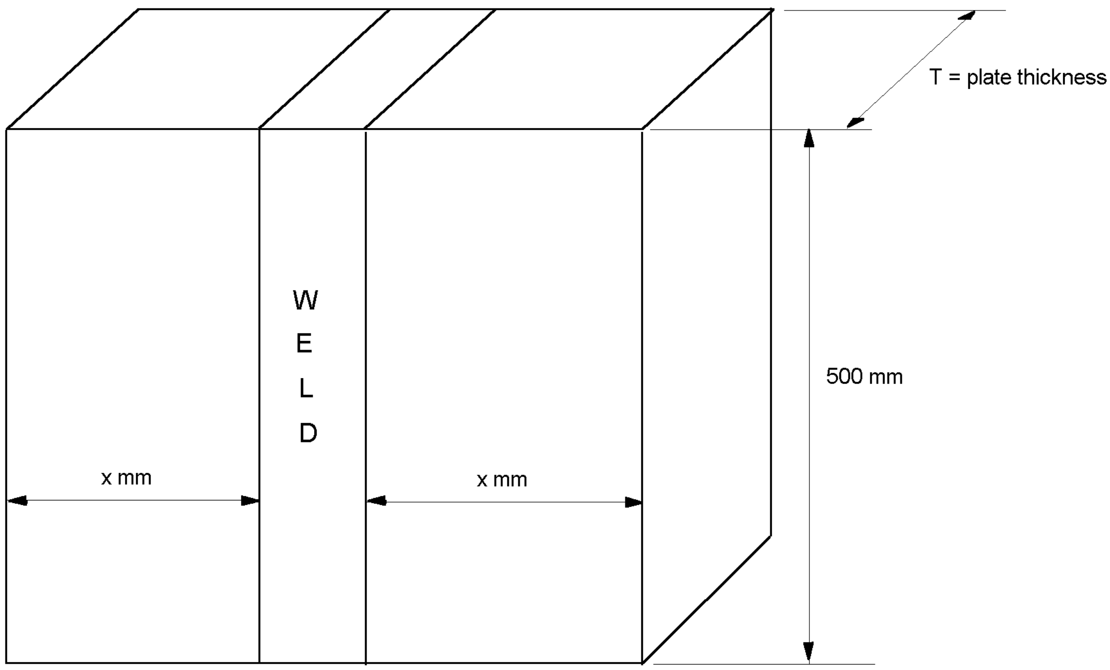
The outside surface shall be clad or weld overlayed in accordance with the same procedures used for the vessel. The heat number and J-factor shall be stamped in the cladding or weld overlay of the respective piece.

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

- 2 blocks, 180 degrees apart, in the bottom area of the catalyst bed at the top of the reactor; and
- 2 blocks, 180 degrees apart, in the bottom area of the catalyst bed at 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 4 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 not greater than 150 mm