TECHNICAL SPECIFICATION

METALLIC MATERIALS - PREVENTION OF BRITTLE FRACTURE

DEP 30.10.02.31-Gen.

October 1995
(DEP Circular 42/97 has been incorporated)

DESIGN AND ENGINEERING PRACTICE

PREFACE

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

Shell International Oil Products B.V. (SIOP)
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Shell International Exploration and Production B.V. (SIEP)
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The Hague, The Netherlands,

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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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.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 SCOPE

Amended per Circular 42/97

This DEP, which is a revision of the previous DEP of the same number dated February 1987, specifies requirements and gives recommendations for the selection and application of materials in order to prevent brittle fracture. This DEP is applicable specifically for equipment containing:

- liquefied gas,
- compressed flammable low molecular weight gas,

Guidelines are given for materials selection on the basis of the lower design temperature for:

- unfired pressure vessels,
- piping, piping components and valves (including control valves),
- rotating equipment.

This DEP is not applicable to:

- transmission pipelines,
- vertical atmospheric storage tanks,
- steel structures.

This DEP shall only be used within the context of the relevant design and construction codes (see section 2).

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 or managed by the Royal Dutch/Shell Group. It may be distributed to Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F", as defined 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, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this document 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 document as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

For the purpose of this DEP, the following definitions shall hold:

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

Amended per Circular 42/97

Adiabatic flash temperature (AFT) is the lowest temperature which the liquid reaches if a mixture is adiabatically depressurized to atmospheric pressure.

Atmospheric boiling point (ABP) is the temperature corresponding to an absolute vapour pressure of 1 bar of the product concerned.

Equipment is any unfired vessel, column, heat exchanger, pump, compressor, piping or part thereof under internal or external pressure. Steel structures, atmospheric vertical storage tanks and transmission pipelines are excluded from this definition.

Flammable low molecular weight gas shall mean butanes and lighter.

Liquefied gas shall mean a product which is gaseous at ambient temperature and atmospheric pressure, but is maintained in a liquid state by means of pressure or refrigeration, or a combination of the two.

LODMAT shall mean Lowest One Day Mean Ambient Temperature. The LODMAT should be determined on the basis of meteorological data over as long a period as possible. In this connection 'one day' is considered to cover the most unfavourable period of 24 hours. Temperature measurements should be carried out at least once per hour.

Lower design temperature is the lowest temperature at which **equipment** may be subjected to its upper design pressure. However, for the purposes of selecting materials to prevent brittle fracture, the lower design temperature may be less than this value, as is described in the text of this DEP.

LPG is liquefied petroleum gas.

LTxx is a number which indicates a steel with a guaranteed impact value at a temperature of minus xx °C, see DEP 30.10.02.11-Gen.

Membrane stress is the tensile component of the combination of **primary local membrane stress** and **primary membrane stress**

Minimum metal temperature is the lowest temperature that **equipment** may possibly attain during operation, including start-up and shutdown.

Operating temperature is the temperature which exists inside the **equipment** during the intended operation.

Post Weld Heat Treatment (PWHT) is heat treatment carried out after welding with the aim to reduce residual stresses and to restore toughness properties after degradation by welding.

Primary local membrane stress is the membrane stress produced by pressure or other mechanical loading and associated with a primary and/or a discontinuity effect producing excessive distortion in the transfer of load to other portions of the structure (refer BS 5500, Appendix A).

To establish the primary local membrane stress, all loadings shall be taken into account, such as internal and external pressures, static head, own weight and external sustained loads arising from connected piping including stresses due to thermal expansion.

Primary membrane stress is the stress, generated by mechanical loads, which is evenly distributed over the cross section. The basic characteristic of a primary stress is that it is not self-limiting (refer BS 5500, Appendix A).

Thermal stress is the self-balancing stress produced by a non-uniform distribution of temperature or by differing thermal coefficients of expansion (refer BS 5500, Appendix A).

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (8).

2. DESIGN CODES

For pressure vessels, including heat exchangers, the design codes are:

- BS 5500 and DEP 31.22.10.32-Gen.
- ASME Section VIII and DEP 31.22.20.31-Gen.

For piping systems, ANSI/ASME B31.3 and DEP 31.38.01.11-Gen.

For rotating equipment, the following DEPs and, where applicable, the associated API standards shall be considered as the design codes:

DEP 31.29.02.30-Gen.	Centrifugal pumps
DEP 31.29.06.30-Gen.	Centrifugal submerged motor pumps in refrigerated product service
DEP 31.29.12.30-Gen.	Reciprocating positive displacement pumps and metering pumps
DEP 31.29.40.30-Gen.	Centrifugal compressors
DEP 31.29.40.31-Gen.	Reciprocating compressors
DEP 31.29.40.32-Gen.	Rotary-type compressors

For equipment governed by standards and codes other than those defined above, the Contractor shall contact the Principal.

3. GENERAL SELECTION PROCEDURE

3.1 SELECTION OF DESIGN CODE

Select from section 2 the applicable design code for the equipment under consideration.

This DEP shall be used only within the context of these codes and their DEP amendments/supplements.

3.2 DETERMINATION OF LOWER DESIGN TEMPERATURE

Depressurization of equipment containing liquefied gas or compressed low molecular weight gas will normally result in a temperature drop far below the operating temperature. Under such conditions, the operating temperature cannot be used for the determination of the lower design temperature.

NOTE: Under certain conditions (e.g. sub-atmospheric operation, very low ambient temperatures, LODMAT) the operating temperature may be lower than the depressuring temperature; in that case this operating temperature becomes the lower design temperature.

The following procedure shall be followed to arrive at the lower design temperature:

(1) Determine the lowest metal temperature based on process conditions, after depressurizing.

(2) Determine the lower design temperature
The selected lower design temperature depends on an engineering threshold value for the membrane stress in combination with the minimum metal temperature in relation to operational pressures and/or other loads causing membrane stresses:

- For pressure vessels, including heat exchangers, follow sections 4 and 5.
- For process piping, including all type of valves and control valves, follow section 6.
- For rotating equipment, follow section 7.

The determination of the lower design temperature of the equipment is the responsibility of those engineers dealing with the process and mechanical design, in close co-operation with the materials/corrosion engineers.

NOTE: The metal temperature during pressure testing shall not be allowed to fall below the lower design temperature, or 5 °C, whichever is higher. Notwithstanding this requirement, it is not required to have the metal temperature above 20 °C.

4. LOWER DESIGN TEMPERATURE FOR PRESSURE VESSELS

4.1 PRESSURE VESSELS CONTAINING LIQUEFIED GAS

4.1.1 Specific design considerations for liquefied gas

In establishing the lower design temperature for pressure vessels containing liquefied gas, it should be realised that lower temperatures normally coincide with a reduced pressure, following the physical laws of the liquefied gas.

Due to the reduced pressure at the ABP/AFT, the membrane stress in the wall will drop, possibly to a negligable level. However, membrane stresses caused by other factors (e.g. wind load or nozzle forces) should also be considered.

4.1.2 Repressurizing whilst "cold"

An aspect to be considered is whether the pressure vessel can be repressurized whilst "cold". The question to be answered is whether the membrane stress in the vessel wall will be below a maximum value, related to the Robertson plateau (below this plateau initiated brittle fracture will always arrest in the low stress field present around any stress concentration area, independent of material toughness), of 50 N/mm^2 (or a different value if specified in the relevant design codes) when the metal temperature is still at or below the lower design temperature.

Repressurizing is not allowed below the lower design temperature.

In general, pressure vessels connected with another vessel containing a gas with a much lower molecular weight than its own contents whilst "cold" will result in membrane stresses staying above 50 N/mm^2, because the lighter gas will not condense and as a result the pressure and temperature will not follow the physical laws of the liquefied gas contained in the vessel.

If it cannot be excluded that the pressure of this lighter gas will cause a membrane stress above 50 N/mm^2 (see above), the lower design temperature shall be taken equal to ABP/AFT of the original vessel contents .

NOTES:
1. The desirability of installing safety devices to counteract or prevent increased pressures whilst "cold" may be taken into consideration, e.g. blocking in distillation sections during depressurization or misoperation to prevent exposure to lighter gas with a higher pressure. In this case the lower design temperature need not to be taken equal to ABP/AFT.
   This approach shall be considered if the ABP/AFT would cause expensive Ni-steels to be used even though the operating temperature is above 0 °C.
2. It should be realised that the vapour pressure is dependent on the temperature at the liquid surface and not on the bulk temperature. The safest procedure for starting up pressure vessels which have been "boiled cold" is to supply heat e.g. by the reboiler, to raise the temperature; pressure and temperature of the liquefied gas will follow closely its physical laws. If this procedure is not possible, the liquid content should be drained.

4.1.3 Process vessels

If it cannot be excluded that the pressure of another gas (from other parts of the process train) or other loads (e.g. wind load or nozzle forces) will cause a membrane stress above 50 N/mm^2 (see 4.1.2) in the temperature range of ABP/AFT+50 °C, the lower design temperature shall be taken equal to ABP/AFT. For the calculation of these stresses, reference is made to the relevant design code.

If the highest membrane stress does not exceed 50 N/mm^2, the lower design temperature may be taken as ABP/AFT+50 °C, but not above 0 °C, provided that the membrane stress remains below 50 N/mm^2.

For shell-and-tube heat exchangers, the lower design temperature of the tube plate shall be taken equal to the lower design temperature of the shell or the channel, whichever is lower.

Impact tested steels of at least LT20 quality shall be used if the vessel can contain more than 5 m^3 of liquefied gas.

4.1.4 Pressure vessels, part of a cold flare system

The lower design temperature of a pressure vessel that is a part of the cold flare system shall be taken equal to the ABP/AFT of its contents.
Impact tested steels of at least LT20 quality shall be used.

NOTE 1: For existing cold flare systems in LPG service the lower design temperature may be taken 50 °C (see 4.1.2) above the ABP/AFT of its contents, with a maximum lower design temperature of 0 °C, provided all membrane stresses are kept below 50 N/mm^2 whilst still colder than the selected lower design temperature. In these systems, thermal stresses induced by contraction may be significant.

NOTE 2: If agreed by the Principal, the larger flare lines may be designed as a pressure vessel and not as process piping. For flare lines designed as process piping, see section 6.

4.1.5 Storage pressure vessels, containing liquefied gas

The lower design temperature may be above ABP/AFT, but not above 0 °C, provided that the membrane stress at temperatures below the selected lower design temperature does not exceed 50 N/mm^2 (see 4.1.2). In general the lower design temperature can be taken as the ABP/AFT+50 °C with a maximum of 0 °C, because normally it is unlikely that re pressurization can occur whilst "cold".

However, the **minimum metal temperature** of storage vessels may also be highly influenced by climatic conditions, i.e. the LODMAT. The lower design temperature may be governed by the LODMAT.
If calculations prove that the lowest metal temperature reached due to ambient conditions is higher than the LODMAT e.g. by the effect of insulation, the calculated temperature may be taken instead of the LODMAT as the lower design temperature.

NOTE: If the vessel can contain more than 5 m^3 of liquefied gas, the lower design temperature shall never be higher than 0 °C. Impact tested steels of at least LT20 quality shall be used for these pressure vessels.

4.2 PRESSURE VESSELS CONTAINING COMPRESSED FLAMMABLE LOW MOLECULAR WEIGHT GAS

For vessels handling compressed flammable low molecular weight gas, the minimum metal temperature attained upon depressurization is usually established by calculation. If deemed necessary by the process engineer, the metal temperature before depressurization and the heat content of the equipment may be used in the calculation.
As the drop in temperature will only occur coincidentally with reduced pressure, the lower design temperature shall be established in a similar way as for the case of liquefied gas (see section 4.1).

The lower design temperature may be taken as ABP/AFT +50 °C or 50 °C above the calculated minimum metal temperature (whichever is lower), provided that the membrane stresses at this temperature do not exceed 50 N/mm^2 (see 4.1.2). For the calculation of these stresses reference is made to the relevant design code.

In selecting the lower design temperature, it shall be decided by the process engineers at which minimum metal temperature the operational pressure is required to be present. This criterion may be more stringent than the criterion based on 50 °C above the calculated lowest metal temperature upon depressurizing.

The metal temperature of plants handling compressed flammable low molecular weight gas may also be influenced significantly by climatic conditions, i.e. the LODMAT.
The lower design temperature may be governed by the LODMAT.
If calculations prove that the lowest metal temperature reached due to ambient conditions is higher than the LODMAT, e.g. by the effect of insulation, the calculated temperature may be taken instead of the LODMAT as the lower design temperature.

NOTE: Due to the reduced pressure upon depressurizing, the membrane stress in the wall will drop, possibly to a negligable level. However, membrane stresses caused by other factors (e.g. wind load or nozzle forces) should also be considered.

Amended per Circular 42/97

5. MATERIALS SELECTION FOR PRESSURE VESSELS

5.1 PRESSURE VESSELS DESIGNED AND CONSTRUCTED IN ACCORDANCE WITH BS 5500 AND DEP 31.22.10.32-GEN.

Amended per Circular 42/97

Below are given additional requirements to BS 5500, section 2.2. ("Materials for Low Temperature Applications") and Appendix D ("Requirements for ferritic steels in bands M0 to M4 inclusive for vessels required to operate below 0 °C"). These additional requirements shall be applied in conjunction with DEP 31.22.10.32-Gen.

2.2.1 Add the following:

Pressure vessels for liquefied gas with a volume greater than 5 m^3 shall have a lower design temperature of maximum 0 °C.

Pressure vessels for liquefied gas, that are site constructed or part of a process plant and located in plot, shall be constructed from impact tested steel of at least LT20 quality.

Pressure vessels for compressed flammable low molecular weight gas with a minimum metal temperature of +45 °C or below, that are part of the process plant and located in plot, shall be constructed from impact tested steel of at least LT20 quality.

Pressure vessels with a lower design temperature below -120 °C shall be made of LT196 material, i.e. 9% Ni steel, austenitic stainless steel or Al, Cu, Ni and their alloys.

In the case of 9% Ni steels, the Principal shall be contacted for additional requirements.

Pressure vessels with a lower design temperature not below -120 °C may be made of LT120 (5% Ni steel), LT100 (3.5% Ni steel) or LT80 (1.5% Ni steel).

2.2.3 Add the following:

Thermo-mechanically treated high-purity steels shall only be used after approval from the Principal.

2.2.4 Add the following:

The thickness limitation given in table 1 for LT120 (5% Ni steel), LT100 (3.5% Ni steel) or LT80 (1.5% Ni steel) shall apply.

Ni steels shall not be used for pressure vessels if the metal temperature during normal operation is above 0 °C (i.e. under conditions that internal and external corrosion can occur) unless a proper corrosion protection system is applied, for which cases approval of the Principal is required.

PWHT should not be applied because of the risk of deterioration of the impact properties. This is subject to the approval of the Principal if it violates code requirements.

TABLE 1 Limitations for Ni-steels to be used for pressure vessels designed to BS 5500 (for LT numbers see DEP 30.10.02.11-Gen.).

LT80	lower design temperature (°C) above	maximum wall thickness	
		as-welded	unwelded
	-90	8 mm	35 mm
	-80	13 mm	48 mm
	-70	18 mm	90 mm
	-60	23 mm	code limit
	-50	28 mm	code limit
	-40	34 mm	code limit
	-30	code limit	code limit
LT100	**lower design temperature (°C) above**	**maximum wall thickness**	
		as-welded	unwelded
	-100	13 mm	38 mm
	-90	19 mm	50 mm
	-80	25 mm	100 mm
	-70	32 mm	code limit
	-60	38 mm	code limit
LT120	**lower design temperature (°C) above**	**maximum wall thickness**	
		as-welded	unwelded
	-120	12 mm	30 mm
	-110	20 mm	42 mm
	-100	28 mm	code limit
	-90	36 mm	code limit
	-80	code limit	code limit

Add new clause:

2.2.8 Duplex stainless steel

1) Duplex stainless steels shall not be used outside the limitations of Table 2.

TABLE 2 Limitations for Duplex Stainless Steels to be used for pressure vessels designed to BS 5500

lower design temperature above (°C)	maximum wall thickness as welded
-70	10 mm
-60	14 mm
-50	18 mm
-40	23 mm
-30	28 mm
-20	33 mm
-10	38 mm
0	43 mm

2) Duplex stainless steels shall be impact tested at -50 °C, with three tests on each of the base metal, weld metal and heat affected zone, HAZ (fusion line, fusion line +2 mm and fusion line +5 mm). The base metal, weld metal and HAZ shall each have an average result of at least 40 J.

Applications outside the above limits shall be subject to approval by the Principal.

APPENDIX D

D.1.2 Replace by:

Where it is found difficult to meet the requirements of this standard using the criteria specified, and for reference thickness >100 mm, alternative methods of assessment, e.g. fracture mechanics as outlined in Appendix U, may be used by agreement between the Principal, the Manufacturer and, if applicable, the Inspection Authority.

D.3.2 Add:

Use for the determination of $\theta_D + \theta_S$ the guidelines given in section 4 of this DEP for the determination of the minimum design temperature (lower design temperature being the term used in this DEP).

θ_C is 0 °C for category 1 vessels; see DEP 31.22.10.32-Gen., clause 3.4.1.

θ_H is only applicable and relevant for storage vessels (of which the shells are entirely made of cylinders), spheres and large diameter straight piping, e.g. flare lines.

Figure D.3.(2):

Replace "≥ 60 mm" by "60 to 100 mm".

D.3.3 Add:

The reference thickness is limited to 100 mm maximum. (see also D.1.2).

5.2 PRESSURE VESSELS DESIGNED AND CONSTRUCTED IN ACCORDANCE WITH ASME VIII DIVISION 1 AND 2 AND DEP 31.22.20.31-GEN.

Amended per Circular 42/97

The additions/supplements to ASME VIII Division 1 and 2 given in DEP 31.22.20.31-Gen. are applicable with the following additional requirements:

Design temperature

In addition to DEP 31.22.20.31-Gen. section 3.6, the lower design temperature for liquefied gas and compressed low molecular weight gas shall be determined in accordance with Section 4 of this DEP and is to be considered as the design metal temperature in ASME VIII for the materials selection and/or impact testing temperature of ASME VIII section AM-210 and ASME VIII section UCS-65.

The following additional requirements are applicable:

- If the vessel is site-constructed and/or part of a process plant, it shall be constructed of a steel belonging to group C or D of UCS-66 (Div. 1) or group V AM-211 (Div. 2). These steels shall be in normalised condition.
- Thermo-mechanically treated high-purity steels shall only be used with the approval of the Principal.
- For shell-and-tube heat exchangers, the lower design temperature of the tube plate shall be taken equal to the lower design temperature of the shell or the channel, whichever is lower.
- Seamless heat exchanger tubes with a wall thickness below 2.6 mm and made of carbon steel with tensile strength below 450 N/mm^2 may be used down to minus 105 °C in low stress tube bundles like hairpin or spirally wound bundles without impact testing.
- The materials selection of nozzles and standard welding neck flanges that are part of a pressure vessel and which are designed to the allowable stresses of ASME B31.3, may be based on the requirements given in section 6.

Carbon and Low alloy steels

Carbon and low alloy steels shall be selected in accordance with UCS 66 (Div. 1) or AM 210 (Div. 2), and DEP 30.10.02.11-Gen.

Duplex Stainless steels

1) Further to UHA 51 (C) (2) (Div. 1) and AM 213 (b) (2) (Div. 2), duplex stainless steels shall not be used outside the limitations of Table 3:

TABLE 3 Limitations for Duplex Stainless Steels to be used for pressure vessels designed to ASME VIII Div 1 & 2

lower design temperature (°C) above	maximum wall thickness as welded
-70	10 mm
-60	14 mm
-50	18 mm
-40	23 mm
-30	28 mm
-20	33 mm
-10	38 mm
0	43 mm

2) Duplex stainless steels shall be impact tested at -50 °C, with three tests on each of the base metal, weld metal and heat affected zone HAZ (fusion line, fusion line +2 mm and fusion line +5 mm). The base metal, weld metal and HAZ shall each have an average result of at least 40 J.

Applications outside the above limits shall be subject to approval by the Principal.

Nickel Steels

Nickel steels shall be used within the limits of the code, with the following considerations:

1. PWHT should not be applied because of the risk of deterioration of the impact properties. This is subject to the approval of the Principal if it violates code requirements.
2. Ni steels shall not be used for pressure vessels if the metal temperature during normal operation is above 0 °C (i.e. under conditions that internal and external corrosion can occur) unless a proper corrosion protection system is applied, for which cases approval of the Principal is required.
3. For 9% Ni steels, the Principal shall be contacted for additional requirements.

6. PROCESS PIPING

6.1 DESIGN AND MATERIALS SELECTION

Design of piping systems shall be in accordance with ANSI/ASME B31.3 and DEP 31.38.01.11-Gen.

This section gives additional requirements for materials selection for process piping systems.

A list of material specifications permitted for process piping and piping components is included in ANSI/ASME B31.3; this list include the limitations for the upper and the lower design temperature.

Non-impact tested piping and piping components shall be normalised.

6.2 LOWER DESIGN TEMPERATURE

For liquefied gas, the lower design temperature for piping systems shall be equal to the ABP/AFT of the contents.

For compressed flammable low molecular weight gas, the lower design temperature for piping systems shall be equal to the calculated lowest metal temperature upon depressurizing of the contents.

6.3 CARBON STEEL

For non-impact tested carbon steel piping (e.g. ASTM A 106), plates, fittings, forgings and castings the lower design temperature shall not be below 0 °C. For a lower design temperature of 0 °C or higher, carbon steel shall be impact tested if specified by ANSI/ASME B31.3.

For a lower design temperature between -50 °C and 0 °C, impact tested carbon steel (e.g., for piping, ASTM A 333-gr 6) shall be used, with the impact testing having been performed at -46 °C with an average impact value of 27J.

6.4 DUPLEX STAINLESS STEEL

Duplex stainless steels (as covered by ANSI/ASME B31.3 Table A-1, under A 789 and A 790) shall not be used outside the limitations of Table 4:

TABLE 4 Limitations for Duplex Stainless Steels to be used for process piping

lower design temperature (°C) above	maximum wall thickness as-welded
-50	18 mm
-40	23 mm
-30	28 mm
-20	33 mm
-10	38 mm
0	43 mm

In addition to the requirements of ANSI/ASME B31.3, and Table 323.2.2. duplex stainless steels shall be impact tested at -50 °C with three tests on each of the base metal, weld metal and heat affected zone HAZ (fusion line, fusion line +2 mm and fusion line +5 mm). The base metal, weld metal and HAZ shall each have an average result of at least 40J.

Applications outside the limits are subject to the approval of the Principal.

Amended per Circular 42/97

7. ROTATING EQUIPMENT

7.1 DESIGN AND MATERIALS SELECTION

This DEP shall be used for rotating equipment in the context of the relevant DEPs and, where applicable, the associated API Standards:

DEP 31.29.02.30-Gen.	Centrifugal pumps	(API Std 610)
DEP 31.29.06.30-Gen.	Centrifugal submerged motor pumps in refrigerated product service	
DEP 31.29.12.30-Gen.	Reciprocating positive displacement pumps and metering pumps	API Std 674 and API Std 675)
DEP 31.29.40.30-Gen.	Centrifugal compressors	(API Std 617)
DEP 31.29.40.31-Gen.	Reciprocating compressors	(API Std 618)
DEP 31.29.40.32-Gen.	Rotary-type compressors	(API Std 619)

This DEP gives only additional requirements for the materials selection of the **pressure containing parts** within the scope of this DEP (see section 1.1).

This DEP does not deal with any requirements for the materials of the **internals of rotating equipment**. The suitability of materials for the intended low temperature service should be based on proven Manufacturer's experience. Due attention should be given to the required clearances between the static and the rotating parts as a consequence of thermal expansion/contraction upon depressurizing of liquefied gas or compressed flammable low molecular weight gas.

NOTE: The design of the pressure containing parts of the rotating equipment and the process piping should be such that thermal stresses by contraction or expansion of the process piping will be mainly absorbed by the piping and not by the rotating equipment. This is feasible in case the minimum load bearing thickness of the relevant parts of the rotating equipment are designed sufficiently above the wall thickness of the piping connected to it.

7.2 LOWER DESIGN TEMPERATURE FOR LIQUEFIED GAS

The lower design temperature for rotating equipment (pumps) containing liquefied gas shall be taken equal to the ABP/AFT of the contents.

Upon depressurizing:

If the membrane stress is kept below 50 N/mm^2, the lower design temperature may be taken equal to the calculated lowest metal temperature upon depressurizing plus 50 °C, but not above 0 °C.

For the design condition:

The lower design temperature shall be established in accordance with the ASME VIII code, Fig. UCS-66.1. In case of doubt, the Principal shall be contacted for an assessment of brittle fracture initiation.
In accordance with Fig. UCS-66.1 a reduction of 33.3 °C in minimum design metal temperature is permitted without impact testing if the design stress in tension is kept below 50% of the allowable tensile stress permitted by ASME VIII.

Materials selection for the **pressure containing parts** of rotating equipment for liquefied gas shall be in accordance with tables 5, 6 or 7:

TABLE 5 Pumps for liquefied gas with operating temperature ≥ 0 °C

MATERIAL OF PRESSURE CONTAINING PARTS	LOWER DESIGN TEMPERATURE (ABP/AFT OF CONTENTS)	REMARKS
Non impact tested carbon steel	-30 °C	Design stresses in accordance with ASME code
	-50 °C	Design stresses 50% of allowable by ASME code
LT30	-50 °C	Design stresses in accordance with ASME code
	-80 °C	Design stresses 50% of allowable by ASME code

NOTES:
1. For material specifications see DEP 30.10.02.11-Gen.
2. All pump materials shall be properly heat treated, i.e. normalised, normalised and tempered, or quenched and tempered. PWHT shall be applied after welding.
3. Materials with a nominal wall thickness below 6 mm are exempted from impact testing, if permitted by the ASME code.

TABLE 6 Pumps for liquefied gas with operating temperature below 0 °C

MATERIAL OF PRESSURE CONTAINING PARTS	LOWER DESIGN TEMPERATURE (ABP/AFT OF CONTENTS)	REMARKS
LT30	-50 °C	Design stresses in accordance with ASME code
	-80 °C	Design stresses 50% of allowable by ASME code
LT80	-100 °C	Design stresses in accordance with ASME code
	-130 °C	Design stresses 50% of allowable by ASME code
LT100	-120 °C	Design stresses in accordance with ASME code
	-150 °C	Design stresses 50% of allowable by ASME code

NOTES:
1. For material specifications see DEP 30.10.02.11-Gen.
2. All pump materials shall be properly heat treated, i.e. normalised, normalised and tempered, or quenched and tempered. PWHT shall be applied after welding.
3. Materials with a nominal wall thickness below 6 mm are exempted from impact testing if permitted by the ASME code.
4. If the equipment is thick-walled and the mass of the steel is high in relation to that of the contents, the metal temperature may not reach ABP/AFT because of the heat capacity of the steel. In such cases the minimum metal temperature could be calculated taking into account the heat transfer between the equipment and its contents. In this case the calculated minimum metal temperature can be used as the lower design temperature.

TABLE 7 Pumps made of austenitic materials

MATERIAL OF PRESSURE CONTAINING PARTS	LOWER DESIGN TEMPERATURE (ABP/AFT OF CONTENTS)	REMARKS
ductile austenitic cast iron (ASTM A 571)	-150 °C	Design stresses in accordance with ASME code
	-180 °C	Design stresses 50% of allowable by ASME code
LT196	-200 °C	Design stresses in accordance with ASME code

NOTES: 1. For material specifications see DEP 30.10.02.11-Gen.

2. If the equipment is thick-walled and the mass of the steel is high in relation to that of the contents, the metal temperature may not reach ABP/AFT because of the heat capacity of the steel. In such cases the minimum metal temperature could be calculated, taking into account the heat transfer between the equipment and its contents. In this case the calculated minimum metal temperature can be used as lower design temperature.

7.3 LOWER DESIGN TEMPERATURE FOR COMPRESSED GAS

The lower design temperature for rotating equipment (compressors) containing compressed flammable low molecular weight gas shall be taken equal to the calculated lowest metal temperature upon depressurizing of its contents.

Upon depressurizing:

If the membrane stress is kept below 50 N/mm^2, the lower design temperature may be taken equal to the calculated lowest metal temperature upon depressurizing plus 50 °C.

For the design condition:

The lower design temperature shall be established in accordance with the ASME VIII code, Fig. UCS-66.1. In case of doubt, the Principal shall be contacted for an assessment of brittle fracture initiation.
In accordance with Fig. UCS-66.1 a reduction of 33.3 °C in minimum design metal temperature is permitted without impact testing if the design stress in tension is kept below 50% of the allowable tensile stress permitted by ASME VIII.

Materials selection for the **pressure containing parts** of rotating equipment for compressed gas shall be in accordance with table 8, 9 or 10.

Table 8 Compressors with minimum operating temperature ≥ 0 °C

MATERIAL OF PRESSURE CONTAINING PARTS	LOWER DESIGN TEMPERATURE (ABP/AFT OF CONTENTS)	REMARKS
carbon steel or nodular cast iron	-30 °C	Design stresses in accordance with ASME code
	-50 °C	Design stresses 50% of allowable by ASME code
LT30	-50 °C	Design stresses in accordance with ASME code
	-80 °C	Design stresses 50% of allowable by ASME code

NOTES:
1. All compressor materials shall be properly heat treated, i.e. normalised, normalised and tempered, or quenched and tempered. PWHT shall be applied after welding.
2. Materials with a nominal wall thickness below 6 mm are exempted from impact testing, if permitted by the ASME code.
3. For reciprocating compressors, grey cast iron is considered acceptable.

Table 9 Compressors with minimum operating temperature below 0 °C

MATERIAL OF PRESSURE CONTAINING PARTS	LOWER DESIGN TEMPERATURE (ABP/AFT OF CONTENTS)	REMARKS
LT0	-50 °C	Design stresses 50% of allowable by ASME code
LT30	-50 °C	Design stresses in accordance with ASME code
	-80 °C	Design stresses 50% of allowable by ASME code
LT80	-100 °C	Design stresses in accordance with ASME code
	-130 °C	Design stresses 50% of allowable by ASME code
LT100	-120 °C	Design stresses in accordance with ASME code
	-150 °C	Design stresses 50% of allowable by ASME code

NOTES:
1. For material specifications see DEP 30.10.02.11-Gen.
2. All compressor materials shall be properly heat treated, i.e. normalised, normalised and tempered, or quenched and tempered. PWHT shall be applied after welding.
3. Materials with a nominal wall thickness below 6 mm are exempted from impact testing, if permitted by the ASME code.

Table 10 Compressors made of austenitic materials

MATERIAL OF PRESSURE CONTAINING PARTS	LOWER DESIGN TEMPERATURE (ABP/AFT OF CONTENTS)	REMARKS
Ductile austenitic cast iron (ASTM A 571)	-150 °C	Design stresses in accordance with ASME code
	-180 °C	Design stresses 50% of allowable by ASME code
LT196	-200 °C	Design stresses in accordance with ASME code

NOTE: For material specifications see DEP 30.10.02.11-Gen.

Amended per Circular 42/97

8. 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.
Metallic Materials - Selected standards	DEP 30.10.02.11-Gen.
Pressure Vessels (Amendments/Supplements to BS 5500)	DEP 31.22.10.32-Gen.
Pressure Vessels (Amendments/Supplements to ASME Section VIII, Division 1 and Division 2)	DEP 31.22.20.31-Gen.
Centrifugal pumps (Amendments/Supplements to API Std 610)	DEP 31.29.02.30-Gen.
Centrifugal submerged motor pumps in refrigerated product service	DEP 31.29.06.30-Gen.
Reciprocating positive displacement pumps and metering pumps (Amendments/Supplements to API Std 674 and API Std 675)	DEP 31.29.12.30-Gen.
Centrifugal compressors (Amendments/Supplements to API Std 617)	DEP 31.29.40.30-Gen.
Reciprocating compressors (Amendments/Supplements to API Std 618)	DEP 31.29.40.31-Gen.
Rotary-type positive displacement compressors (Amendments/Supplements to API Std 619)	DEP 31.29.40.32-Gen.
Piping General Requirements	DEP 31.38.01.11-Gen.

AMERICAN STANDARDS

Chemical plant and petroleum refinery piping	ANSI/ASME B31.3
ASME Boiler and Pressure Vessel Code "Pressure vessels, Division 1"	ASME VIII - Div. 1
ASME Boiler and Pressure Vessel Code "Pressure vessels, Division 2: Alternative Rules"	ASME VIII - Div. 2

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

Standard specification for seamless carbon steel pipe for high-temperature service	ASTM A 106
Standard specification for seamless and welded steel pipe for low-temperature service	ASTM A 333

Standard specification for austenitic ductile iron castings for pressure-containing parts suitable for low- temperature service	ASTM A 571

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

BRITISH STANDARDS

Specification for unfired fusion-welded pressure vessel	BS 5500

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