



GS 136-1

MATERIALS FOR SOUR SERVICE

March 1997

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BP GROUP RECOMMENDED PRACTICES AND SPECIFICATIONS FOR ENGINEERING											
Doc. No. GS 136-1		Issue Date Latest Amendment Date	March 1997								
Document Title MATERIALS FOR SOUR SERVICE (Upstream Applications) (Replaces BP Engineering Std 153)											
APPLICABILITY Regional Applicability: International											
SCOPE AND PURPOSE This BP Guidance for Specification Specifies all BP general requirements for materials for sour service that are within its stated scope and is for use with a complementary Specification to adapt it for each specific application. It covers materials requirements in sour service duties applicable to upstream conditions. It makes major reference to NACE Standard MR0175 . And EFC Publications The purpose of this BP Guidance for Specification is to give appropriate recommendations on the choice of materials for sour service applications offering economical safe practice.											
AMENDMENTS <table border="0" style="width: 100%;"> <tr> <td style="width: 15%;">Amd</td> <td style="width: 25%;">Date</td> <td style="width: 25%;">Page(s)</td> <td style="width: 35%;">Description</td> </tr> <tr> <td colspan="4"> </td> </tr> </table>				Amd	Date	Page(s)	Description				
Amd	Date	Page(s)	Description								
CUSTODIAN (See above for contact) Materials Engineering											
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FOREWORD

Introduction to BP Group Recommended Practices and Specifications for Engineering

The Introductory Volume contains a series of documents that provide an introduction to the BP Group Recommended Practices and Specifications for Engineering (RPSEs). In particular, the 'General Foreword' sets out the philosophy of the RPSEs. Other documents in the Introductory Volume provide general guidance on using the RPSEs and background information to Engineering Standards in BP. There are also recommendations for specific definitions and requirements.

Value of this Guidance for Specification

This BP Specification clarifies certain requirements specified in [NACE MR0175](#) and provide guidelines for the choice of materials for sour service duty offering economy, safety and reliability of operation. The use of this Specification to its users will be significantly enhanced by their regular participation in its improvement and updating. For this reason, users are urged to inform BP of their experiences in all aspects of its application.

Application

This Guidance for Specification is intended to guide the purchaser in the use or creation of a fit-for-purpose specification for enquiry or purchasing activity.

Text in *italics* is Commentary. Commentary provides background information which supports the requirements of the Specification, and may discuss alternative options. It also gives guidance on the implementation of any 'Specification' or 'Approval' actions; specific actions are indicated by an asterisk (*) preceding a paragraph number.

This document may refer to certain local, national or international regulations but the responsibility to ensure compliance with legislation and any other statutory requirements lies with the user. The user should adapt or supplement this document to ensure compliance for the specific application.

Specification Ready for Application

A Specification (BP Spec 136-1) is available which may be suitable for enquiry or purchasing without modification. It is derived from this BP Group Guidance for Specification by retaining the technical body unaltered but omitting all commentary, omitting the data page and inserting a modified Foreword.

Principal Changes from Previous Edition

This Guidance for Specification has transpired from the general updating and conversion to the new 'Way Forward' style of BP Engineering Standard 153.



Principal Changes from June 1990 Issue:-

- (a) Document retitled to reflect the broad scope of the document, which exceeds that of [NACE MR0175-94](#).
- (b) General editorial changes made to format.
- (c) Amendment made to meet latest issue of [NACE MR0175-94](#).
- (d) Major modification of sections to reflect current understanding of sour service.
- (e) Appendices A, B, C, D, E, F, G and H amended and retitled.
- (f) Special new section and Appendix J added for downhole tubulars.

Feedback and Further Information

Users are invited to feed back any comments and to detail experiences in the application of BP RPSE's, to assist in the process of their continuous improvement.

For feedback and further information, please contact Standards Group, BP International or the Custodian. See Quarterly [Status List](#) for contacts.



1. INTRODUCTION

1.1 Scope

1.1.1 This Specification specifies BP general requirements on materials of construction for equipment handling fluids containing water and hydrogen sulphide (sour environments). It makes major reference to the [NACE Standard MR0175-94](#), (subsequently referred to in this document as the NACE Standard).

1.1.2 In-service hydrogen damage problems arising from wet hydrogen sulphide (H₂S) service fall into three main categories which are covered in this Specification. These are as follows:-

- (a) Hydrogen Embrittlement Effects - Sulphide stress cracking (SSC), a hydrogen embrittlement phenomenon, is cracking caused by hydrogen diffusing into the steel when subject to tensile stress.

Areas of high hardness are susceptible to damage and cracking is also affected by the stress level, solution chemistry and type of material.

The main method used to prevent such cracking is to control material hardness and, in some cases, stress level by heat treatment. This is described in detail in this document.

- (b) Hydrogen Internal Pressure Effects - Hydrogen diffuses into the material and collects at inclusions/other defects and produces an internal pressure which results in blistering and/or various forms of hydrogen induced cracking.

Damage can be seen in various forms depending upon type and location of the inclusions present and the stress pattern. These forms include blistering, hydrogen induced cracking (HIC), stepwise cracking (SWC) and stress oriented hydrogen induced cracking (SOHIC). These types of hydrogen damage are schematically shown in Appendix C. The differences between these forms of hydrogen pressure related cracking are described in the text (Paragraph 2.2).

The main method used to prevent this type of cracking is to select a high quality clean material and, in some cases, to reduce stresses by heat treatment. This is described in detail in the text.

- (c) Cracking in Related Environments - These include hydrogen damage in sour environments in the presence of chlorides, cyanides, alkalis and amines. This Specification modifies and extends, where necessary, the requirements of the NACE Standard, providing additional guidance for materials in sour service in the presence of these chemicals.



The NACE Standard defines sour service in gas and in multiphase systems and recommends materials which will not fail by SSC in sour environments. However, it does not cover certain sour duties nor other associated failure mechanisms in sour service.

1.1.3 This Specification introduces a new method of defining sour service limits for the use of downhole tubulars and, as such, represents a departure from the traditional NACE approach. This new approach is also described in European Federation of Corrosion Document; Guidelines on Material Requirements for Carbon and Low Alloy Steels for H₂S - Containing Oil and Gas field Service.

1.1.4 Note that this Specification does not cover all general requirements for chloride, alkali or amine services without H₂S, and should not be used for such purposes, but does provide guidance on avoiding environmental cracking.

1.1.5 This Specification defines the requirements for new sour service equipment for oil fields, transmission lines and refineries and it is applicable whenever the process design conditions are such that sour service as defined within may be encountered.

1.1.6 Reference is made in this Specification to various items of equipment, such as pressure vessels and pipework, for which specific BP Specifications exist. The requirements of such Specifications apply in all respects, except as modified by this Specification for sour service.

* 1.1.7 In some cases it may be possible to upgrade existing equipment so that the requirements of this Specification are met. Advice on this should be sought from BP.

1.2 Service Conditions

1.2.1 Definitions of Sour Service

The following apply for this Specification for all items of equipment except downhole tubulars, for which separate definitions apply (Paragraph 2.10):-

1.2.1.1 The [NACE Standard MR0175-94](#) defines sour service as process streams containing liquid water and H₂S at concentrations and pressures within the zones shown as SSC regions on the graphs in Appendix D and as described in 1.3.1.1 and 1.3.1.2 of the NACE Standard.

Sour gas Figure D1, shall be used for wet gas systems in conjunction with 1.3.1.1 (NACE Standard). Sour gas multiphase Figure D2 shall



be used for multiphase oil, gas and water systems in conjunction with 1.3.1.2 (NACE Standard).

The above definitions for sour services are accepted by BP for systems with less than 10 mol % H₂S. All systems with 10 mol % or more of H₂S are regarded as sour in this Specification.

For equipment which contains only liquid, Figure D2 shall be used, using the pressure and H₂S content of the gas at the point where it was last in equilibrium with the liquid.

1.2.1.2 Where the NACE Standard refers to total pressure, this shall be taken to mean total design pressure in the context of this Specification.

1.2.2 Associated Service Conditions

1.2.2.1 In process streams when H₂S concentrations vary, peak values shall be used in the context of this Specification.

* 1.2.2.2 This Specification specifies certain additional requirements that apply for sour service in the presence of chlorides, cyanides, alkalis and amines. BP or a process design contractor will specify when these service conditions are applicable.

1.2.2.3 For process plants, consideration shall be given to the transient conditions which arise during such operations as catalyst presulphiding and regeneration.

2. MATERIALS FOR SOUR SERVICE

All materials for sour service as defined in this Specification shall comply fully with the NACE Standard except as modified or extended below. To put the requirements into context, modifications are divided into two main categories as follows:-

(a) General Sour Service Requirements - this is further described under three sections:-

- (i) General SSC requirements (2.1)
- (ii) General HIC/SWC/SOHIC requirements (2.2)
- (iii) Special requirements for specific product forms (2.3-2.17)

(b) Related Sour Service Requirements - this is further described in two sections:-

- (i) Sour Service with Chlorides (2.18)
- (ii) Sour Service with Alkalis/Amines (2.19)



2.1 General SSC Requirements

SSC occurs as a result of diffusion of atomic hydrogen into the material from the corrosion reaction at the metal surface. For SSC to occur, a combination of tensile stress, an environment containing H₂S and a susceptible material is required.

2.1.1 The selection of materials for a particular sour duty shall take into account:-

- (a) Requirements arising from 1.2.2.1 of this Specification.
- (b) Resistance to general corrosion.

The pH value of the process stream and the presence or absence of corrosives such as oxygen, carbon dioxide, chlorides etc. are of particular importance.

- (c) Mechanical properties, including low temperature requirements where necessary, shall be given specific attention.

2.1.2 Materials shall be selected from those permitted in the NACE Standard. In addition, two other materials which have been found resistant to SSC may be employed. These are:-

- (1) Firth Vickers FV 520B in the overaged 620°C (1148°F) condition with maximum hardness 318 HV10 (RC32).

(Section 3.8 precipitation hardening stainless steel - NACE Standard).

- (2) Nimonic 90 (UNS N07090) in the following conditions:-

- (a) Solution annealed.
- (b) Solution annealed and age hardened to RC35 maximum.

Material in this condition is acceptable for general service.

- (c) Cold worked and age hardened to RC50 maximum.

Material in this condition is acceptable for springs.

(Section 4 Non-Ferrous Metals - NACE Standard).

2.1.3 All castings shall be suitably heat treated after any welding operation has been performed, and this requirement also applies to the weld

repair of defects, irrespective of size. ASTM A216 for carbon steel castings, and ASTM A217 Grade CA 15 for 11-13% chromium steel normally permits certain repairs to be made without subsequent stress relief. However, the practice of leaving 'as welded' areas in castings for sour service is unacceptable to BP. All casting repair welds shall be heat treated as follows:-

- (a) Carbon and carbon manganese steels: Thermal stress relief.
- (b) Martensitic stainless steels e.g. 11-13% chromium steel: Re-heat treat completely or double temper (see NACE Standard Section 3.7 for details of both heat treatments).
- (c) Austenitic and duplex stainless steels: Solution anneal.
- (d) Austenitic nodular iron: Welding is not permitted.

* 2.1.4 BP will impose limits on the use of austenitic, martensitic and duplex stainless steels in sour service with chlorides. These limits, and the suitability of alternative materials for specific applications, shall be sought from BP.

* 2.1.5 Where the process duty is such that a wet gas environment exists in one part of a vessel and a multiphase (oil, gas, water) system exists in another part of the same vessel, material of construction for the entire vessel shall be suitable for the more severe sour gas conditions, unless otherwise approved by BP.

2.1.6 High strength steels at high levels of stress such as internal bolting, springs, bellows and parts of reciprocating compressors require specific attention, as experience shows they are susceptible to SSC in lower concentrations of wet hydrogen sulphide than indicated by the NACE Standard definition of sour service. They shall comply with the NACE Standard when in contact with any concentration of wet hydrogen sulphide.

2.1.7 In refinery environments, it is necessary for the weld metal to comply with the hardness criteria of [NACE RP0472](#).

* 2.1.8 Nitrile (NBR) and hydrogenated nitrile (HNBR) elastomers are acceptable for low levels of H₂S. NBR has a maximum long term limit of between 10 and 100 ppm, depending on seal geometry and temperature. For HNBR these limits are between 100 and 1000 ppm.

For H₂S levels up to 5%, FKM 'Viton' type fluoroelastomers, or TFEP 'Aflas' shall be employed. Above this, FFKM perfluoroelastomers (Chemraz or Kalrez) shall be required. PTFE also has excellent H₂S



resistance; if this material is selected, account shall be taken of the fact that plastics require different seal configurations to elastomers.

In all instances, elastomer selection shall take into account the complete operating conditions to be encountered, i.e. temperature, pressure and chemical environment. All non-metallic seal materials and seal geometry shall be subject to approval by BP.

- * 2.1.9 Details of component materials and the material condition shall be subject to BP approval prior to manufacture.

2.2 General HIC/SWC Requirements

The forms of hydrogen internal pressure damage, illustrated in Figure C1 are as follows:-

(a) Hydrogen Blistering

This occurs where inclusions or voids are present in the metal. Atomic hydrogen can diffuse to these locations and convert to molecular hydrogen. Since molecular hydrogen cannot diffuse, the concentration and pressure of hydrogen gas within the voids increases and may be sufficient to cause yielding in the metal and produce a bulge. These voids or inclusions are generally associated with non-metallic inclusions.

(b) SWC or HIC

This is formed in steels by the propagation and linking up of small and moderate sized laminar cracks in a step-like manner. As more hydrogen diffuses into the steel, the areas around these laminar cracks become highly strained and this can cause linking of the adjacent cracks to form HIC/SWC in the through thickness direction between the individual planar cracks.

(c) SOHIC (Stress Oriented HIC)

In some cases, when metal is subject to stress, small laminar HIC cracks become lined up in the through-thickness direction and step cracks form between them hence the occurrence of SOHIC. Formation of this type of damage is linked to particular locations which are susceptible to laminar cracking and to the stress pattern. This is often found, though not exclusively so, in weld heat affected zones.

SOHIC is a phenomenon resulting from a combination of two independent forms of hydrogen damage; HIC and SSC. New generations of linepipe steel are becoming available offering superior metallurgy with improved strength. These materials, reported to be resistant to either HIC or SSC, have been found to suffer from SOHIC in certain environments. In these circumstances, hydrogen concentration within the lattice is not sufficient to cause conventional HIC, but adequate to cause combination of HIC/SSC in the presence of external stress, hence the occurrence of SOHIC..

* 2.2.1 In cases where hydrogen blistering, HIC/SWC or SOHIC may occur, BP may specify steel with increased resistance to these cracking mechanisms and this shall conform to the requirements of either Appendix G or H, as specified by BP. Alternatively, carbon steel internally clad with stainless steel may be specified.

2.2.2 Plate steels and pipes made from plate have a particular sensitivity to HIC/SWC damage. The mechanism of cracking involves two main aspects which need to be considered when assessing the possibility of cracking; these are described as follows:-

(a) Hydrogen diffusion

Hydrogen diffusion into the steel is affected by environmental and surface conditions.

Environment; Hydrogen diffusion will be affected by the specific chemical environment e.g. level of H₂S, pH, CO₂, cyanide. There is not an established level of H₂S in refinery environments below which cracking will not occur. However, a level of 50 ppmw H₂S in solution in the water phase has been taken by some as a level above which special emphasis should be placed. The presence of cyanides significantly increases hydrogen permeation.

(b) The material's susceptibility to hydrogen damage

The susceptibility of the metallurgical structure to hydrogen damage is defined by several parameters as follows:-

Strength; Increasing strength leads to increasing susceptibility to hydrogen damage. The maximum tensile strength for process vessel plates as supplied and tested should not exceed 586 MPa (85,000 psi.).

Microstructure/Material Cleanliness; Optimum HIC/SWC resistance is obtained by utilising a clean steel with a homogenous microstructure.

Experience in BP has shown that an improvement in performance can be achieved by specifying Z quality steel. This quality should be suitable for moderate severity environments and is specified in Appendix G.

For higher severity environments (H₂S/cyanide) a special HIC/SWC resistant grade may be specified. This involves very low sulphur, phosphorus and sometimes inclusion shape control with Ca. This is detailed in Appendix H. Some of these steels may have some susceptibility to SOHIC, so it is recommended that there should be BP specialist involvement in purchase of these steels.

Heat Treatment; Material should usually be supplied in the normalised condition. However, some of the newer steels processed by TMCP to [ASTM 841](#) can give even better performance and may be utilised at the approval of the purchaser.

- 2.3 Pressure Vessels; Carbon, Carbon Manganese and Low-Alloy Steel**
- * 2.3.1 Pressure vessels, including heat exchanger shells, channels and floating heads, shall be stress relieved. Where hydrogen sulphide contents in excess of 10 mol % are encountered, stress relief is mandatory in all cases.
 - 2.3.2 Stress-relieving heat-treatment procedures shall be as required by BP Group [GS 146-2](#) or BP Group [GS 146-3](#).
 - 2.3.3 In cases where hydrogen blistering, HIC/SWC or SOHIC may occur, requirements of Paragraph 2.2 are applicable.
 - 2.3.4 All internal bolting subject to sour environments shall be selected to be resistant to SSC (see 2.1.6 of this Specification).
- 2.4 Pressure Vessels; Austenitic/Duplex Stainless Steel and Internally Clad**
- * 2.4.1 Pressure vessels in sour service constructed from materials other than carbon, carbon manganese and low-alloy steels e.g. austenitic/duplex stainless steels and internally clad vessels or other high alloy corrosion resistant alloys shall be subject to BP specification or approval.
- 2.5 Heat-Exchanger Tube Bundles; Carbon, Carbon Manganese and Low-Alloy Steel**
- 2.5.1 Where tube end welding is specified, special fabrication procedures are necessary. For carbon steel assemblies, in order to avoid high hardnesses in the weld and heat affected zones, either PWHT shall be applied or the tube sheet shall be faced with low carbon weld metal and stress relieved prior to tube end welding. For low alloy steel assemblies, PWHT of tube end welds to achieve adequate resistance to SSC is difficult. In this case consideration should be given to overlaying the tubesheet with an austenitic alloy such as Inconel 625. Irrespective of the fabrication technique adopted, the welding procedure qualification tests shall be in accordance with this Specification and requirements of BP [Group Specification 118-8](#).
- 2.6 Heat-Exchanger Tube Bundles; Austenitic/Duplex Stainless Steel and Nickel Base Alloys**
- 2.6.1 Tube bundles made from materials other than carbon, carbon manganese and low-alloy steels, e.g. austenitic/duplex stainless steels and nickel base alloys or other high alloy corrosion resistant materials

shall be in accordance with BP [Group Specification 118-8](#) and this Specification.

2.7 Process Pipework; Carbon, Carbon Manganese and Alloy Steel

2.7.1 Fabricated pipework shall comply with the requirements of BP [Group Specification 118-5](#) and this Specification.

2.7.2 Carbon and carbon manganese steel pipework shall have a carbon content of 0.23% maximum for plate, seamless pipe and forged fittings. The CE shall be 0.43% maximum based on product analysis and shall be calculated as:-

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

2.7.3 EFW pipe shall be in the normalised heat treated condition.

2.7.4 All carbon steel pipework with a wall thickness greater than 19 mm will require PWHT unless otherwise approved by BP. At thickness below 19 mm the welding procedure should be designed with the objective of meeting the NACE Standard hardness criteria in the as-welded conditions.

Careful control of the welding parameters will generally allow multi-pass tubular butt joints to be completed in accordance with the NACE hardness criteria. However, particular attention should be paid to joints involving forged fittings since the actual CE values for these are often higher than for pipe. Welding procedures should be qualified using materials representative of the maximum supply CE value.

* 2.7.5 In cases where hydrogen blistering, HIC/SWC or SOHIC may occur, BP may specify steel with increased resistance to these cracking mechanisms and this shall conform to the requirements of either Paragraph 2.2, Appendix G or Appendix H as specified by BP. Alternatively, carbon steel internally clad with stainless steel may be specified.

2.7.6 Low alloy steel pipework in sour service shall be subject to PWHT irrespective of pipe size or wall thickness.

2.8 Process Pipework; Austenitic/Duplex Stainless Steel and Nickel Base Alloys

* 2.8.1 Fabricated pipework from austenitic/duplex stainless steel and nickel base alloys shall comply with the requirements of BP Group [GS 118-7](#) and this Specification. Hardness levels and any associated heat

treatments shall be subject to NACE standard requirements unless otherwise approved by BP.



2.9 Transmission Pipelines

- * 2.9.1 Pipelines and associated fittings will be subject to the requirements of BP Group [GS 142](#). On pipelines for sour service, all material specifications shall be subject to approval by BP.
- * 2.9.2 Production control tests using the method of [NACE Standard TM0284](#) shall be carried out on all pipeline steels specified by BP as suitable for sour service, to demonstrate that they are resistant to HIC. The hydrogen charging solution and procedures for this test and the acceptance criteria will be in accordance with Appendix H as specified by BP. Other tests may be specified by BP for manufacturing procedure qualification. Acceptance criteria for the test shall be subject to approval by BP.
- * 2.9.3 Full diameter pipe HIC/SWC/SOHIC testing may be required, details of which shall be specified by BP.
- * 2.9.4 The mill and site welding procedures shall be carried out as specified in 3.3 of this Specification.
- 2.9.5 The specific service environment which the pipeline will be subjected to will be taken into account by BP when assessing the results of hardness surveys. Requirements may vary for each particular project and will be individually specified.
- * 2.9.6 PWHT of field girth welds of pipelines is not required unless specified by BP, in which case the specific provisions shall be subject to BP approval.

2.10 Downhole Tubulars

Specific requirements for the selection of downhole tubular steels are described in Appendix J and defined in Figure J1 and Table J1, taking on board the significance of in-situ pH.

The recognition within BP that the use of NACE guidelines does not lead to optimum downhole materials choice led to the development of these specific requirements.

In some countries NACE is a legislative requirement for the selection of downhole materials for sour service duty.

2.11 Low Temperature Plant

- * 2.11.1 The use of carbon and low-alloy ferritic steels and weld metals containing more than 1% nickel are not permitted for sour service as defined by NACE Standard. However, where low temperatures are



encountered, such steels and weld metals may be used subject to BP approval, providing the formation of liquid water can be prevented at all times.

This will not be a problem during operation at temperatures below the freezing point of aqueous solutions of hydrogen sulphide, but special measures (e.g. drying the process stream) may be required during start up and shut-down if sour gas and water are present at ambient temperature.

2.12 Valves

2.12.1 For valves specified for sour service, material selection and fabrication procedures shall be in accordance with the 1994 Edition of the NACE Standard and this Specification.

2.12.2 All valve parts which can be contacted by the sour environment shall conform to this Specification. Valve parts not subjected to sour environment need not comply with this Specification. Items which are not freely vented to atmosphere such as insulated and buried equipment and bolts inside flange protectors etc., where leakage of the process stream could subject the equipment to a sour environment, shall conform fully to this Specification.

2.12.3 Where plated components are employed, the material on which the plating is deposited shall conform with this Specification. The plating employed shall be resistant to the environment. Cadmium and zinc plating are unsuitable as these metals corrode readily when in contact with hydrogen sulphide.

2.12.4 Structural welding and weld repair of any cast component in contact with the sour environment shall be followed by PWHT. Repairs to valve balls, gates, disks, plugs etc. shall always be subject to PWHT.

2.12.5 All valve springs, except as outlined in Paragraph 2.12.5, shall be made from materials resistant to SSC. Acceptable spring materials are those given in 8.3 of the NACE Standard and UNS N07090 in accordance with 2.1.2 (2c) of this Specification.

2.12.6 For large springs where the cost of resistant materials is very high, and where spring failure is not critical in terms of safety or production losses, non-resistant materials, suitably protected from the environment, may be proposed for approval. The use of the following coatings may be considered:-

- (a) Flexible 2-pack epoxy paint formulation. The maximum service temperature for this type of coating is 100°C (212°F).



- (b) Aluminium metal spray plus sealer.
- (c) Coatings of the fluorinated polymer type applied by the fluidised bed process.

Where coatings have been accepted the complete spring shall be protected and special attention shall be given to the half coils at the spring ends.

It should be recognised that protective coatings cannot provide long-term protection against failure and this must be taken into account.

- * 2.12.7 When bellows-sealed safety or relief valves discharge into a common header or piping system, springs shall comply with Paragraph 2.12.5. Where this is not the case, the springs of bellows sealed valves may be provided in accordance with Paragraph 2.12.6 subject to approval.
- 2.12.8 Internal bolting in valves shall be in accordance with Paragraph 2.15 (see 2.1.6).
- 2.12.9 The packing selected shall be compatible with the stem material. Uninhibited graphite or carbon-type packing is not acceptable.

2.13 Rotating Machinery

- 2.13.1 General
 - 2.13.1.1 Sour service for rotating machinery shall be taken as defined in 1.2.1.1, except for reciprocating compressors where the presence of any level of H₂S shall be defined as sour.
 - 2.13.1.2 The materials selected and fabrication procedures employed shall comply with this Specification.
 - * 2.13.1.2 Carbon and carbon manganese steel plate for fabricated compressor casings shall be resistant to HIC and shall conform to either Appendix G or Appendix H, as specified by BP.
 - * 2.13.1.3 All fabrication welds and repair welds shall be heat treated as follows:-
 - (a) Carbon and carbon manganese steels: PWHT at 580/620°C (1076/1148°F), other temperatures only as approved by BP.
 - (b) Low alloy steels: PWHT details shall be subject to approval by BP.



- (c) Martensitic stainless steel (11-13% chromium steel): Re-heat treat completely including double temper.

For certain welds, complete heat treatment is not possible and double tempering treatment only is acceptable.

- (d) Austenitic stainless steels do not normally require PWHT.

- (e) Duplex stainless steels: subject to approval by BP.

- * 2.13.1.4 Cast irons and ferritic ductile (nodular) iron e.g. ASTM A 395 are unacceptable for pressure-retaining parts and for impellers etc. The use of these materials for non-pressure, low-stressed components shall be subject to approval by BP. Austenitic irons are also unacceptable for pressure-retaining parts except as permitted by 2.13.2.2. None of these materials shall be weld repaired.
- 2.13.1.5 All components such as internal bolting, springs, etc. shall comply with the relevant parts of this Specification.
- 2.13.1.6 Shafts and piston rods in plain carbon, low and medium alloy and 11-13% chromium steels shall be heat treated to minimise residual stresses, and shall have a hardness not exceeding 248 HV10 (HRC22) and a yield stress not exceeding 620 N/mm² (90 000 lbf/in²).
- 2.13.1.7 Shafts in austenitic and duplex stainless steel shall be in the solution annealed condition. Where 17 Cr. - 4 Ni precipitation hardening steel is employed, it shall conform to the NACE Standard. Precipitation hardened nickel alloy shafts shall be in accordance with Section 4 of the NACE Standard.
- * 2.13.1.8 The straightening of shafts after completion of machining shall not be commenced without prior approval from BP.
- * 2.13.1.9 Approval shall be obtained from BP before any attempt is made to rectify machining errors by the application of metal coatings.
- 2.13.1.10 All associated equipment e.g. pressure vessels, pipework etc. shall comply with this Specification.
- 2.13.1.11 All components in 11-13% chromium steel shall be double tempered after either normalising or quenching, and unless stated otherwise as in 2.13.3.6 of this Specification the hardness shall be 248 HV10 (HRC22) maximum in conformity with 3.7 of the NACE Standard.

- 2.13.2 Centrifugal Pumps
 - 2.13.2.1 Centrifugal pumps shall conform to BP Group [GS 134-4](#) except as modified by this Specification.
 - * 2.13.2.2 For centrifugal pumps only, austenitic nodular iron [BS 3468](#) Grade S-Ni Cr. 20 2 or equivalent is acceptable in certain cases, subject to approval by BP. Welding of this material, including repair welding, is not permitted. All castings shall be proved sound by radiography, and they shall be stress relieved at 620/670°C (1148/1240°F).
 - 2.13.2.3 Shafts in plain carbon and low alloy steels shall be totally protected from the process stream by corrosion-resistant sleeves, cap nuts (where applicable) etc. Unprotected 11-13% chromium steel may be used only where it has adequate corrosion resistance to the process fluid.
- 2.13.3 Reciprocating Compressors
 - 2.13.3.1 For reciprocating compressors only, the service shall be regarded as sour when the gas contains any level of H₂S. In all such cases, the materials and fabrication procedures shall be in accordance with this Specification.
 - 2.13.3.2 Reciprocating compressors shall conform to BP Group [GS 134-6](#) except as modified by this Specification.
 - * 2.13.3.3 Piston rods shall be either 11-13% chromium steel or an alternative material approved by BP.
 - 2.13.3.4 The piston rods shall conform to 2.13.1.7 of this Specification. However, the rods may be hardened in the region of the packings by the surface induction hardening method.
 - * 2.13.3.5 Liners shall be resistant to the corrosive environment. Where cast iron would be corroded, a suitable grade of austenitic cast iron may be proposed for BP approval.
 - * 2.13.3.6 Valve plates, rings, channels, seats and stops shall be made from 11-13% chromium steel, unless otherwise approved by BP. The maximum hardness for these components shall be 300 HV10 (HRC30). The double tempering requirement after normalising or quenching (see 2.13.1.11) still applies.
 - * 2.13.3.7 Valves involving flexing plates are not normally permitted. Exceptions may be made as follows:-
 - (a) As stated in 2.13.3.9.



- (b) Where the valve plate stresses for the application proposed are low enough to render SSC unlikely.

In both cases, BP approval shall be obtained.

- 2.13.3.8 Valve springs shall be in accordance with 8.3 of the NACE Standard and 2.1.1 (c) of this Specification. The design stress shall not exceed 276 N/mm² (40 000 lbf/in²).
- * 2.13.3.9 Alternative materials and designs may be used for compressor valves, where proof is submitted that they have given satisfactory service. However, all changes in materials, fabrication procedures and design shall be subject to BP approval.
- 2.13.4 Centrifugal Compressors
- 2.13.4.1 Centrifugal compressors shall conform to BP Group [GS 134-5](#) except as modified by this Specification.
- * 2.13.4.2 Fabrication processes which result in cold-worked material, e.g. riveting of impellers, shall not be employed unless prior approval has been obtained from BP.
- 2.13.5 Rotary-Type Positive Displacement Compressors
- Rotary-type positive displacement compressors shall conform to BP Group [GS 134-9](#) except as modified by this Specification.
- 2.13.6 Lubrication, Shaft Sealing and Control Oil Systems
- 2.13.6.1 Lubrication, shaft sealing and control oil systems shall conform to BP Group [GS 134-3](#) except as modified in this Specification.
- 2.13.6.2 All equipment in contact either with seal oil or gas which is sour as defined in this Specification, e.g. vessels, pumps, piping, valves, etc., shall conform to this Specification as regards material selection and fabrication procedures.
- 2.14 Instrumentation**
- 2.14.1 Instrument piping shall be in accordance with the associated process line specification.
- * 2.14.2 Bellows, diaphragms, Bourdon tubes, items which cannot be heat treated after welding, and components which cannot function in the softened condition shall be fabricated from materials resistant to



cracking in the hardened or non-heat-treated conditions as defined in the NACE Standard. UNS N08825 and UNS N04400 have given satisfactory service in certain environments, and may be proposed for BP approval.

- * 2.14.3 Compression fittings in type 316L stainless steel may be used. For relatively high temperature and high chloride service BP may require the use of more corrosion resistant alloys (refer 2.14.2).

2.15 Bolting

2.15.1 Bolting shall comply with the NACE Standard requirements when in contact with any concentration of wet H₂S (see 2.1.6 of this Specification).

2.15.2 Ferritic steel bolts and nuts shall conform to Section 6 of the NACE Standard.

2.15.3 Where austenitic stainless steel bolts and nuts are required, these items shall be free from cold work; they shall be solution treated after thread forming etc. as outlined as follows:-

- (a) Bolts shall be Class 1A of ASTM A 193 e.g. B8MA (Type 316 bolts solution treated after all cold work including thread forming).
- (b) Nuts shall be of the 'A' suffix variety of ASTM A 194 e.g. Grade 8MA (Type 316) solution treated after all hot or cold working.

2.16 Bellows

2.16.1 Bellows shall comply with the NACE Standard requirement when in contact with any concentration of wet Hydrogen Sulphide (see Paragraph 2.1.6) of this Specification.

- * 2.16.2 Austenitic stainless steels shall not be used for bellows, but material selection may be made according to the process conditions from the following:-

- Alloy 825 (UNS N 08825)
- Alloy 625 (UNS N 06625)
- Alloy 400 (UNS N 04400)

Other materials may be proposed for approval by BP. The production procedure shall comply with the requirements of the NACE Standard.



2.17 Metallic Overlays

Explosively clad, roll bonded and fusion-bonded corrosion resistant overlays such as austenitic stainless steels and nickel alloys are considered to be effective barriers to the sulphide environment. Where such overlays are employed the backing material need not conform to this Specification.

2.18 Sour Service with Chlorides

Where chlorides are present in sour service, but where the chloride level and pH etc. permit the use of austenitic stainless steels, Appendix E of this Specification shall apply. Refer also to Paragraphs 2.1.3 and 2.15.3 regarding H₂S limits for stainless steel.

2.19 Sour Service with Alkalis/Amines

For sour service in association with alkalis, amines or other alkaline process fluids, the requirements of Paragraph 2.16.2 and Appendix F shall apply as appropriate.

3. FABRICATION AND REPAIR WELDING

In addition to the requirements of NACE Standard, the following shall apply to any heat treatment associated with initial fabrication or repair welding.

*** 3.1 Approval of Heat-Treatment Procedure**

For equipment which is to be post-weld heat treated, the following information shall be submitted to BP for approval:-

- (a) Details of the method of heating, e.g. furnace, electric resistance, induction, etc.
- (b) Details of the position of thermocouples.
- (c) Special requirements for heat-treatment, e.g. if it were proposed to post-weld heat treat a heat-exchanger tube bundle incorporating tube end welding.
- (d) Copies of relevant heat treatment charts on completion.

*** 3.2 Possible Avoidance of PWHT for Carbon Steel Pipework**

In order to avoid the need for PWHT on any part of a piping system, the following requirements shall be met to the satisfaction of BP:-



- (a) Standard welding procedures for all pipework shall provide for a minimum of two passes.
- (b) The use of double sided welding on larger diameter pipe, internal sealing runs to correct bore misalignment, internal root repairs or the use of fittings requiring back welding, etc. will all result in untempered weld beads on the process side. In such cases the contractor or supplier shall either submit their proposals for BP approval in accordance with 3.3, or shall PWHT the welds concerned.
- (c) Pipework with wall thicknesses greater than 19 mm (0.750 in), or on weldolets when the weld throat thickness exceeds 30 mm shall be subject to PWHT as required by BP Group [GS 118-5](#).
- (d) Where it is necessary to apply the requirements of Appendix F of this Specification the above requirements are over-ruled.

3.3 Welding Procedure Qualification Tests

- 3.3.1 Prior to the commencement of work, the fabricator or supplier shall submit to BP their proposals for qualifying the proposed welding procedures, particularly related to the control of hardness.
- * 3.3.2 In the case of 'as-welded' equipment the fabricator or supplier shall submit to BP for approval the proposed method of meeting the hardness limits of typical butt welds, internal sealing runs, branch welds and local repairs etc. The hardness limits shall be subject to a guarantee by the fabricator or supplier.
- 3.3.3 In the case of equipment which is to be post weld heat treated, the welding procedure tests shall incorporate a hardness survey as specified in 3.3.5 below.
- 3.3.4 On receipt of approval of the proposals, the contractor shall carry out the agreed test welds and hardness surveys. The hardness surveys shall be carried out on agreed samples cut from approved procedure test coupons.
- 3.3.5 Test coupons shall be ground smooth and macro etched to reveal the various zones of the weld. Hardness traverses shall be made at a distance of 2 mm from the inner and outer surfaces of the welded joint using the Vickers hardness test method with a load of 10 kg. The hardness traverse shall include the parent metals, weld and weld heat affected zones on both sides of the joint, and the positions of the indentations shall be selected to establish peak hardness values. The

maximum permitted hardness shall be in accordance with NACE Standard requirements unless otherwise approved by BP (see also paragraph 2.1.7).

- * 3.3.6 The results of the qualification tests plus welder qualifications shall be submitted to BP for approval.

4. IDENTIFICATION, STAMPING AND MARKING

4.1 Hard Stamps

Conventional sharp 'V' stamping is acceptable only on the outer circumferences of flanges. Round 'V' stamps may be used elsewhere, providing the identities are placed on the external surfaces of low stress areas. Where stamps have been inadvertently applied to high stress areas, subsequent heat treatment is required.

- * **4.2 Marking Paints, Crayons etc.**

Conventional paints, crayons and adhesive tapes frequently used for temporary marking during fabrication etc. may contain significant amounts of chloride and heavy metals. Unless approved by BP, these marking materials shall not be used on any stainless steel, and if used on carbon or low alloy steels they shall be removed before heat treatment (if applied) and before shipment if heat treatment is not required.

5. INSPECTION

In addition to normal inspection, the following shall apply:

- * 5.1 Documentation and inspection shall be provided to prove the identities of all materials of construction and to establish that the correct heat treatment has been applied so that the finished product complies fully with this Specification. All material certificates shall be in accordance with [DIN 50049 3.1B or 3.1C as specified \(BS EN 10204\)](#), or the supplier may submit alternative proposals for approval by BP.
- 5.2 Where the hardness can be checked without damaging the component, the manufacturer shall conduct hardness tests to ensure that the hardness requirements of this Specification are met, and BP inspectors will carry out random hardness checks. Where hardness values in excess of the requirements of this Specification and the NACE Standard are obtained the part shall be rejected. This requirement does not apply to austenitic alloys supplied in the solution annealed condition.

- * 5.3 For small items, e.g. small springs, pins etc. which cannot be hardness tested individually, the manufacturer shall conduct tests on a random basis by selecting components from production runs or stores batches to ensure that the product complies fully with this Specification. Procedures for doing this shall be subject to approval by BP. This requirement does not apply to austenitic alloys supplied in the solution annealed condition.
- 5.4 For welded components, hardness measurements can only realistically be taken in weld metal and parent material. Acceptability of heat affected zone hardness may be based on (i) welding procedure qualifications tests and (ii) production test plates, when these are required by the fabrication specifications.
- 5.5 For all corrosion resistant alloys, it shall be proved to the satisfaction of the inspector that the specified heat treatment has been carried out correctly.

DEFINITIONS AND ABBREVIATIONS

Definitions

Standardised definitions may be found in the BP Group RPSEs Introductory Volume.

Abbreviations

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BS	British Standard
CE	Carbon Equivalent
DEA	Di-Ethanolamine
DIN	Deutsche Institute for Normung
DIPA	Di-Iso Propanol Amine
EFC	European Federation of Corrosion
EFW	Electric Fusion Welded
FFKM	Perfluoroelastomers
HIC	Hydrogen Induced Cracking
HNBR	Hydrogenated Nitrile Butadiene Rubber
HRC	Rockwell Hardness Scale C
HV	Vickers Hardness
MEA	Mono-Ethanolamine
NACE	National Association of Corrosion Engineers
NACE Standard	NACE Standard MR0175-94
NBR	Nitrile Butadiene Rubber
NPS	Nominal Pipe Size
PTFE	Polytetrafluoroethylene
PWHT	Post Weld Heat Treatment
SOHIC	Stress Orientated Hydrogen Induced Cracking
SSC	Sulphide Stress Cracking
SCC	Stress Corrosion Cracking
SWC	Step-wise Cracking
TFEP	Tetro Flouro Ethylene Propylene
TMCP	Thermo-Mechanical Controlled Processing

LIST OF REFERENCED DOCUMENTS

A reference invokes the latest published issue or amendment unless stated otherwise.

Referenced standards may be replaced by equivalent standards that are internationally or otherwise recognised provided that it can be shown to the satisfaction of the purchaser's professional engineer that they meet or exceed the requirements of the referenced standards.

British Standards

BS 1501	Steels for Pressure Purposes : Plates, Part 1 - Specification for Carbon and Carbon Manganese Steels
BS 3468	Austenitic Cast Iron
BS 4360	Weldable Structural Steels
BS 5996	Methods for Ultrasonic Testing and Specifying Quality Grades for Ferritic Steel Plate
BS EN 10164	Steel Products with Improved Deformation Properties Perpendicular to the Surface of the Product - Technical Delivery Conditions

American Standards

NACE STD. MR0175-94	Standard Material Requirements - Sulphide Stress Cracking Resistant Metallic Materials for Oilfield Equipment
NACE STD TM0284-87	Test Method-Evaluation of Pipeline Steels for Resistance to Stepwise Cracking.
NACE STD TM0177-92	Testing of Metals for Resistance to Sulphide Stress Cracking at Ambient Temperatures.
NACE RP 0472	'Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments'
ASTM A193	Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature Service
ASTM A194	Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure and High Temperature Service
ASTM A395	Specification for Ferritic Ductile Iron Pressure - Retaining Castings for Use at Elevated Temperatures
ASTM A516	Specification for Pressure Vessel Plates, Carbon Steel for Moderate and Lower Temperature Service
ASTM A841	Specification for Steel Plates for Pressure Vessels, Produced by the Thermo-Mechanical Control Process
ASTM D1141-52	Specification for Substitute Ocean Water
ASTM E140	Standard Hardness Conversion Tables for Metals
API 614	Lubrication, Shaft-sealing and Control Oil Systems for Special Purpose Applications



API RP 945	Guidelines for Avoiding Corrosion and Cracking Problems in Amine Units
DIN 50049 or BS EN 1024; 1991	Materials Certificates or Metallic Products, Types of Inspection Documents.
+ EFC Document	European Federation of Corrosion Document; Guidelines on Material Requirements for Carbon and Low Alloy Steels for H ₂ S- Containing Oil and Gasfield Service.
+ Anticipated date of publication mid. 1995	

BP Group Documents

BP Group GS 106-2	Painting of Metal Surfaces (replaces BP Std 144)
BP Group GS 118-5	The Fabrication, Assembly, Erection and Inspection of Carbon, Carbon Manganese and Low Alloy Ferritic Steel Pipework to ANSI/ASME B31.3 (replaces BP Std 167 Part 1 and Part 2)
BP Group GS 118-7	Fabrication of Pipework to ANSI B31.3. Part 3: Austenitic and Duplex Steel Pipework, Cupro-Nickel and Nickel Base Alloy Pipework (replaces BP Std 167 Part 3)
BP Group GS 118-8	Tube End Welding of Heat Exchanger Tubes (replaces BP Std 191)
BP Group GS 134-3	Lubrication, Shaft-sealing and Control Oil Systems for Special Purpose Applications to API 614 (replaces BP Std 190)
BP Group GS 134-4	Centrifugal Pumps to API 610 (replaces BP Std 195)
BP Group GS 134-5	Centrifugal Compressors to API 617 (replaces BP Std 196)
BP Group GS 134-6	Reciprocating Compressors to API 618 (replaces BP Std 197)
BP Group GS 134-9	Rotary Type Positive Displacement Compressors to API 619 (replaces BP Std 201)
BP Group GS 142-1 to 5)	Line Pipe and Fittings (replaces BP Std 166)



BP Group GS 146-2

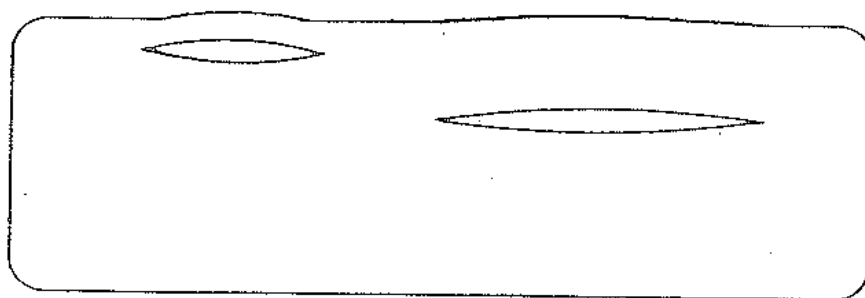
Unfired Pressure Vessels to BS 5500
(replaces BP Std 194 Part 1)

BP Group GS 152-1

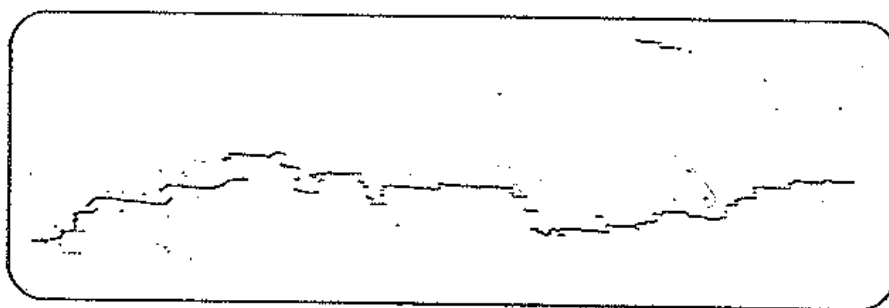
Materials for Thermal Insulation of Pipework and Equipment
(replaces BP Std 172)



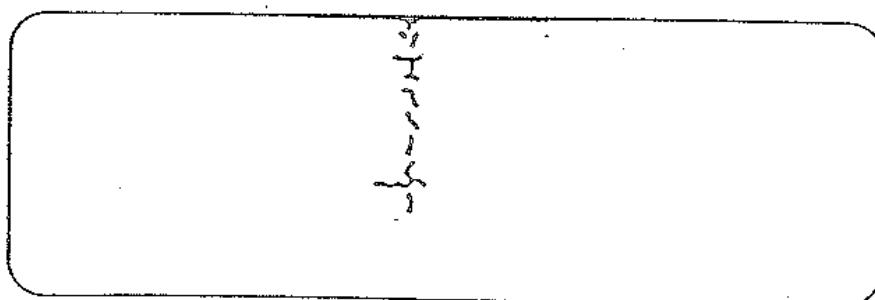
SCHEMATIC ILLUSTRATION OF HYDROGEN INTERNAL PRESSURE EFFECTS



Hydrogen Blistering



Hydrogen Induced Cracking (HIC)/Stepwise Cracking (SWC)



Stress Orientated Hydrogen Induced Cracking (SOHIC)

FIGURE C1
SCHEMATIC ILLUSTRATIONS OF ASSOCIATED FAILURE MECHANISMS

SULPHIDE STRESS CRACKING REGION GRAPHS (NACE MR0175)

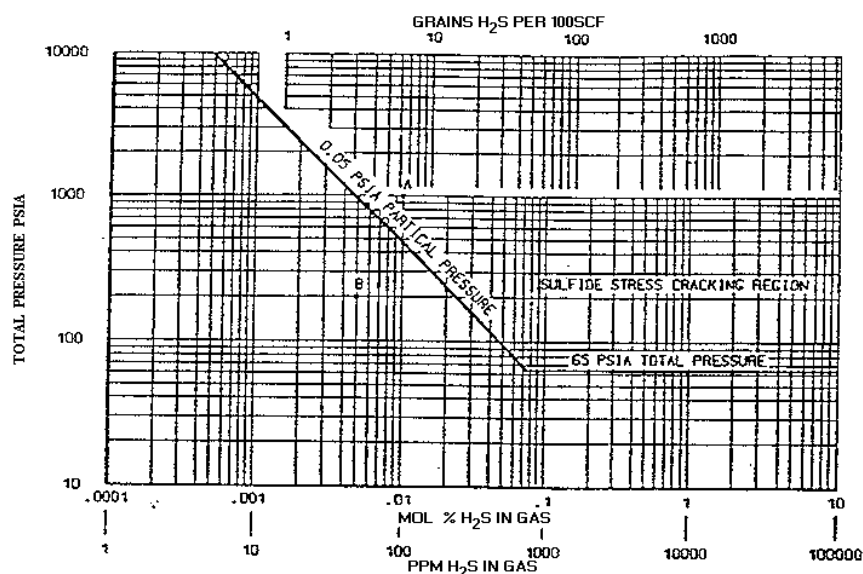


FIGURE D1
SOUR GAS SYSTEMS

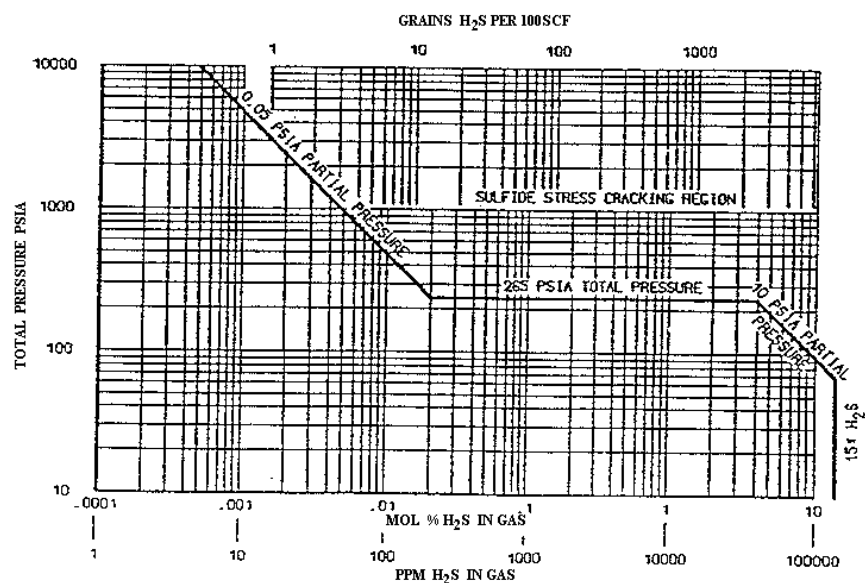


FIGURE D2
SOUR MULTIPHASE SYSTEMS
(see 1.3.1.1 NACE document)

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SOUR SERVICE WITH CHLORIDES - REQUIREMENTS FOR 300-SERIES AUSTENITIC STAINLESS STEELS

- E1. Austenitic stainless steels shall be in the solution annealed condition.
- E2. Bends in pipework and tubing and other cold formed items shall be solution annealed at 1050°C (1920°F) or stress relieved at 900/950°C (1650/1740°F) after forming.
- E3. Austenitic stainless steels are not acceptable for bellows or other components in the cold worked or highly stressed condition; note that 3.5.1 of the NACE Standard prohibits the use of cold worked austenitic stainless steels. UNS N 08825 is an acceptable material among others for this duty. (See 2.16.2 for alternatives).
- *E4. For welded equipment, stabilised or low carbon grades shall be used, and unless otherwise approved by BP, all welded items shall be either solution annealed at 1050°C (1920°F) or stress relieved at 900/950°C (1650/174°F).
- E5. Attention is drawn to the fact that stress relieving heat treatments in the range 900-950°C usually result in a reduction in the notch toughness of ferrite containing weldments. For this reason, when a PWHT is specified for pipework in low temperature service, or when the piping code includes notch toughness requirements, welding procedure tests should ensure that the PWHT does not result in unacceptable embrittlement.
- E6. Because of the significantly greater risk of crevice corrosion in sour/chloride service, the use of socket welded fittings, screwed couplings or any other weld detail which could result in a crevice on the process side is not permitted.
- E7. Fusion-bonded overlays of Stellite or Colmonoy may be applied to stabilised or low carbon grades of austenitic stainless steels, provided that the component is subsequently heated rapidly to 900/950°C (1650/1742°F), held for 1 hour per 25 mm (1 in) of thickness and cooled in still air.
- *E8. Note that marine environments can often promote external chloride attack. In such cases, the following shall apply:-
 - (a) Austenitic stainless steels shall be protected externally if they are to operate at temperatures between 40°C (104°F) and 120°C (248°F) in chloride-containing environments, i.e. areas close to the sea.
 - (b) Stainless steels for use in tropical marine areas, as specified by BP, shall be protected externally before transporting to site and the protection maintained during construction and operation at site. Protection of

welds and associated heat-affected zones is most important. Any painting specification used in the context of this Section shall be subject to BP approval.

- (c) Thermal insulation of pipework and equipment shall be as required by BP Group [GS 152-1](#) and BP Group [GS 106-2](#).



SOUR SERVICE WITH CAUSTIC OR OTHER ALKALINE PROCESS FLUIDS

F1. GENERAL REQUIREMENTS FOR CARBON STEEL EQUIPMENT

F1.1 Carbon steel is generally an acceptable material for handling certain caustic soda and other alkaline solutions. However, it has limitations at higher temperatures in that stress corrosion cracking can occur unless the equipment is stress relieved, also unacceptable general corrosion can take place.

F1.2 The stress relief requirements and upper temperature limits as given in Figure F1 shall be applied, for carbon steel vessels and pipework in caustic soda and other alkaline service. Stress relief shall be applied to the whole vessel, and to welds, cold bends etc., in the case of pipework.

F1.3 The Designer shall make due allowance for general corrosion, which is not taken into account in Figure F1.

General corrosion is significantly affected by increasing temperature.

* F1.4 Where the particular caustic soda or other alkaline solution is at a temperature in excess of that shown in Area B (Figure F1) material selection shall be subject to approval by BP.

* F1.5 Figure F1 shall apply to vessels and pipework only; material selection for other equipment, e.g. pumps, shall be subject to approval by BP.

F2. SOUR STREAMS CONTAINING POTASSIUM CARBONATE

F2.1 Some sweetening plants employ a potassium carbonate solution (normally between 20% and 30% concentration) which can cause stress corrosion cracking of welded carbon steel components. All welds in contact with such fluids, whether in vessels or pipework, shall be stress relieved. A hardness limit of 248 HV10 (HRC22) alone is not acceptable.

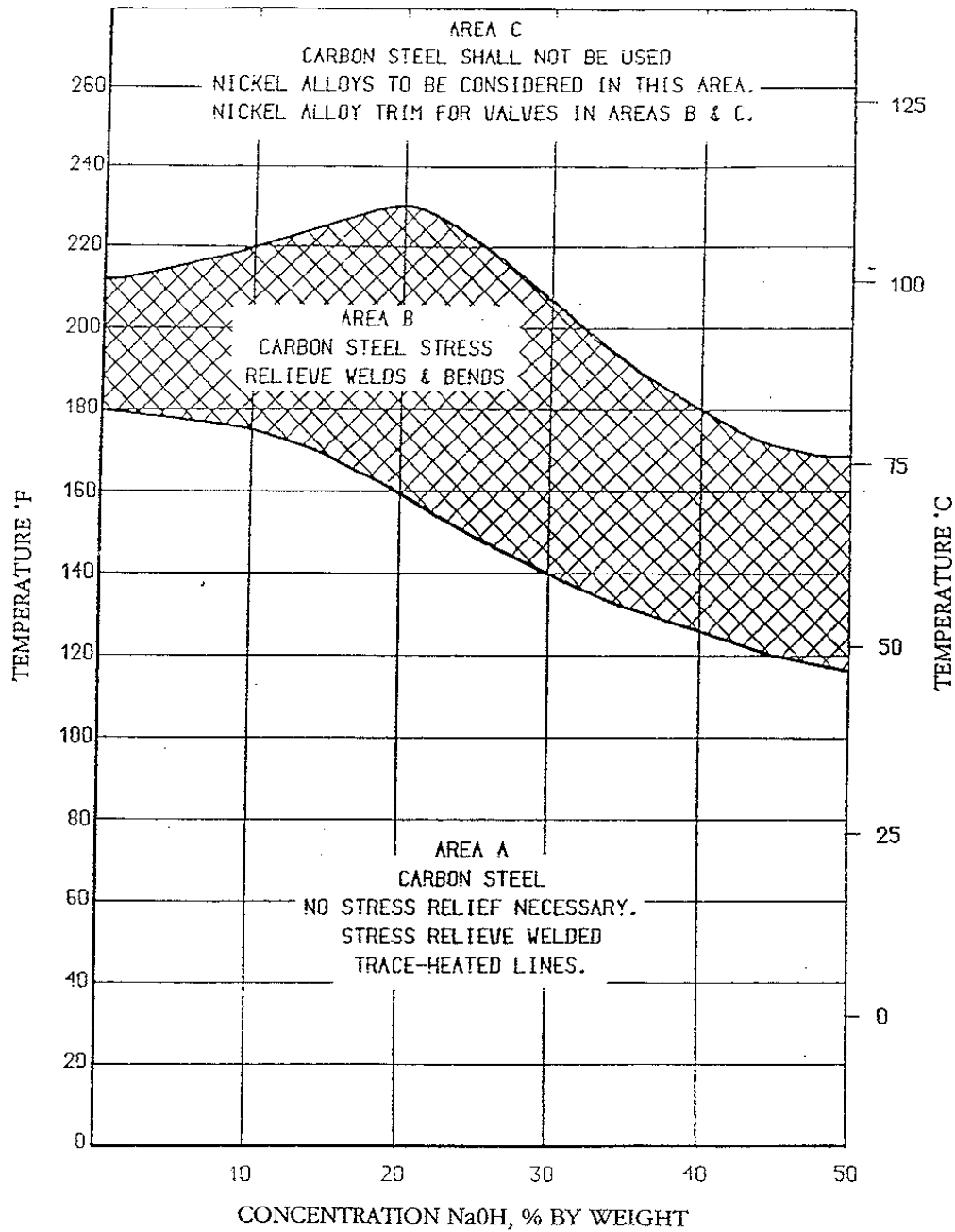
F3. SOUR STREAMS CONTAINING AMINES

* F3.1 To avoid stress corrosion cracking (SCC) of carbon steel welds exposed to various amine solutions used in acid gas sweetening plants, stress relieving of all welds is required as follows:-

MEA	Stress Relieved (SR) for all design temps.
DEA	SR above 140°F (60°C)
DIPA	SR for all design temps.
Other amine plants	SR above 82°C (180°F)



Additional guidance on the avoidance of corrosion and SCC in amine service, including licensed processes can be found in [API RP 945](#). The guidelines in [API RP 945](#) shall be followed in all cases.



THIS GRAPH IS BASED ON INFORMATION EXTRACTED FROM 'NACE CORROSION DATA SURVEY, FIFTH EDITION, 1974' BY KIND PERMISSION OF THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS, HOUSTON, TEXAS

FIGURE F1
REQUIREMENTS FOR STRESS RELIEF OF FABRICATIONS FOR USE WITH CAUSTIC SODA

SPECIFICATION FOR STEEL PLATE (Z QUALITY)

G1. SCOPE

This appendix defines the requirements to achieve enhanced resistance to wet H₂S service. It has been found by experience that steel made with enhanced through thickness properties has improved resistance to hydrogen induced cracking. This type of steel is known as 'Z' quality steel.

This type of steel was originally developed to prevent lamellar tearing in thick sections during welding under conditions of high through-thickness stresses. However, the same requirements which confer improved through-thickness properties also confer improved resistance to hydrogen induced cracking.

G2. DEFINITION

Z quality steel plate shall be designated as follows:-

BS 1501: 224 Grade 430 + EN 10164, Z35

G3. MATERIAL**G3.1 Standards**

The plate furnished by the supplier shall meet the requirements of [BS 1501](#) or equivalent steel grades together with the following supplementary requirements.

*** G3.2 Process**

Steels shall be made by a low sulphur and low phosphorus refining process, for example, in an electric furnace with double deslagging or in the basic oxygen furnace (BOF). The steel shall be vacuum degassed while molten by means of a BP approved process.

G3.3 Chemical Composition

The following supplementary requirements shall apply:-

	Check Analysis %
Carbon	0.20 max.
Sulphur	0.008 max.
Phosphorus	0.025 max.
Carbon Equivalent	0.43 max.

The carbon equivalent values used in the above Table shall be calculated by means of the formula defined in Paragraph 2.7.2 of this Specification.

The use of rare earth metals is not permitted.

G4. INSPECTION REQUIREMENTS FOR PLATE

*** G4.1 Ultrasonic Examination**

Material supplied in accordance with this specification shall be ultrasonically tested in accordance with the requirements of BS 5996-Grade LC3 or an equivalent approved by BP.

*** G4.2 Through-Thickness Tensile Test**

Each plate shall comply with acceptance class Z35 of [BS EN 10164](#) or equivalent.

BP may agree to a retest after consideration of information supplied. The through-thickness test shall be made after the completion of all heat treatments.

In addition to the above, all the necessary tests required by the relevant material specification shall be carried out.

G5. WELD REPAIR OF PLATE

- *** Weld repair of plate surface defects will not be permitted without BP approval and shall be subject to an agreed repair procedure prior to the work being carried out.

SPECIFICATION FOR HIC RESISTANT STEEL PLATE FOR SEVERE HYDROGEN CHARGING SERVICE

H1. SCOPE

This Appendix defines requirements for the manufacture and testing of steel plates with maximum resistance to HIC/SWC for pressure vessels in severe hydrogen charging environments e.g. sour water containing significant quantities of cyanides. For less severe environments, as advised by BP, 'Z' quality plate may be specified, in which case the requirements of Appendix G shall apply.

H2. MANUFACTURING REQUIREMENTS

H2.1 Standards

Plates furnished by the supplier shall meet the requirements of [BS 1501](#), [ASTM A516](#), [ASTM A841](#) or equivalent standards, together with the requirements of this Appendix.

H2.2 Process

Steels shall be made by a low sulphur and low phosphorus refining process, for example in an electric furnace with double deslagging or in the basic oxygen furnace (BOF). The steel shall be vacuum degassed while molten by means of a BP approved process.

H2.3 Heat Treatment

Plates for vessels shall be either normalised or TMCP.

* H2.4 Chemical Composition

The following requirements shall apply:-

	Check Analysis &
Carbon	0.20 max.
Sulphur	0.002 max.
Phosphorus	0.010 max.
Oxygen	0.003 max.
Carbon Equivalent	0.43 max.

The carbon equivalent values quoted in the above Table shall be calculated using the formula defined in Paragraph 2.7.2 of this Specification.

Calcium treatment may be applied, but rare earth metals are not permitted. For wet H₂S service only, copper additions up to a maximum of 0.35% are also permitted when specified by BP.

H3. TESTING REQUIREMENTS

*** 3.1 Ultrasonic Examination**

Material supplied in accordance with this specification shall meet the requirements of [BS 5996](#) Grade L4 or an equivalent approved by BP.

3.2 HIC/SWC Test

Tests shall be made in accordance with [NACE TM0284](#) in the [NACE TM0177](#) test solution. One set of 3 specimens shall be tested from each thickness of plate from each heat. After testing, acceptance values shall be 15% CLR (crack length ratio), 0.5% CTR (crack thickness ratio) and 1.5% CSR (crack sensitivity ratio) unless otherwise agreed with the purchaser. In marginal cases the supplier may request BP to consider permitting a retest.

Following exposure, the test coupons shall be ultrasonically tested for evidence of HIC/SWC in accordance with [BS 5996](#) prior to sectioning. Additional sections for microscopic examination shall be prepared through any suspect locations, as approved by BP.

H4. WELD REPAIR OF PLATE

Weld repair of plate surface defects will not be permitted.

SOUR SERVICE LIMITS FOR DOWNHOLE TUBULAR STEELS

J1 SCOPE

This Appendix defines limits of sour service specific to downhole tubular steels. These guidelines do not include downhole completion accessories for which the requirements in the main body of this document apply.

J2. BACKGROUND

The presence of H₂S, CO₂ and brine in wells not only give rise to increased corrosion rates, but also can lead to SSC associated with enhanced uptake of hydrogen atoms into the steel. Resistance to SSC is often the principal factor affecting the choice of materials for H₂S-containing environments, since the occurrence of SSC can result in a catastrophic and potentially hazardous failure.

The occurrence of SSC requires a combination of tensile stress, an environment containing H₂S and a susceptible material. It follows that control of the problem may be through manipulation of any or all of these parameters. It is apparent that factors which promote hydrogen embrittlement would in turn affect the SSC behaviour of steels. These include factors which influence hydrogen availability, entry and transport within the metal lattice. Thus solution chemistry, as defined by its acidity, can influence the performance of materials in sour environments. Solution acidity, i.e. 'in-situ pH', in the presence of sulphide ions (sour environments) increases the degree of susceptibility to SSC.

Laboratory test results and the understanding of the mechanism of SSC have led to the severity of the corrosive medium being expressed in the form of a pH - H₂S partial pressure diagram (see Figure J1)

In the context of the [NACE MR0175](#) recommendation, it has been assumed that the presence of oil favours the resistance to SSC. However, in such circumstances, there has never been a guarantee against wetting of the steel surface by water or against the presence of very aggressive formation waters. It is apparent, however, that the presence of oil in a production circuit is not sufficient to ensure better resistance to SSC and a distinction between oil and gas production systems is inappropriate. The good performance observed in the oil fields are believed to be the result of complementary effects arising from the nature of water, the wettability or to the flow characteristic and emulsion conditions. In this respect, it is important to base the definition of 'Sour Service' on the analysis of the corrosive medium itself.

J3. LIMITS OF SOUR SERVICE FOR DOWNHOLE TUBULAR STEELS

Bearing in mind the limitations of [NACE MR0175](#), new limits of sour service have been developed for a limited range of carbon and low alloy steels as well as corrosion resistant alloys.



The environmental variables used in obtaining qualitative SSC information have been restricted to pH and H₂S partial pressures, as these are believed to be the most important parameters determining the SSC resistance of materials.

J3.1 SSC Domains

The limits of sour service have been plotted in graphs correlating solution pH with H₂S partial pressure in a domain relationship of the type shown in Figure J1. The graph has been divided into three main domains, each characterising the materials' suitability for sour service applications with respect to SSC behaviour. These are as follows:-

- (a) Domain 1; Designated as 'Non-Sour Service Domain' where no special precaution is necessary when selecting the completion tubing steels within those defined in Table J1.
- (b) Domain 2; Designated the 'Transition Region' where in addition to sour service grade materials, certain non-sour grades can also be used (Table J1).
- (c) Domain 3; Designated 'Sour Service Domain' which characterise sour service conditions wherein H₂S proved steels to NACE Standard shall be utilised.

In pH/H₂S partial pressure graphs, risk of SSC increases with increasing H₂S partial pressure and decreasing pH.

- J4. To apply the guidelines presented in this Appendix, it is necessary to know certain information about the well including H₂S partial pressure in the gas phase and the 'in-situ' pH of the water associated with the produced fluid. Practical problems of determining in-situ pH can be overcome by using a software program designated CORMED.
- J5. Tendency of carbon and low alloy steels to other forms of corrosion attack have not been covered in this Appendix.
- J6. Apart from SSC, tendency of corrosion resistant alloys to other types of failure should be clarified. These include failure by chloride stress corrosion cracking (SCC), the resistance to well treating chemicals and the tendency to hydrogen embrittlement (HE), particularly for high strength duplex stainless steels.

DOMAIN	DESIGNATION	SUITABLE GRADES OF STEEL	EXAMPLES
Domain 1	Non Sour Service	Any Grades up to P110	- Carbon Steel Grade P110 - 13% Cr. Grade N80
Domain 2	Transition Region	Strictly Controlled Grades and NACE Approved Grades	- Carbon Steel Grade N80 - 13% Cr. Grade L80
Domain 3	Sour Service	Only Sour Service Proved Grades	- Carbon Steel Grade L80 - Proprietary Grades

TABLE J1
SOUR SERVICE DOMAINS

SSC PERFORMANCE DOMAIN

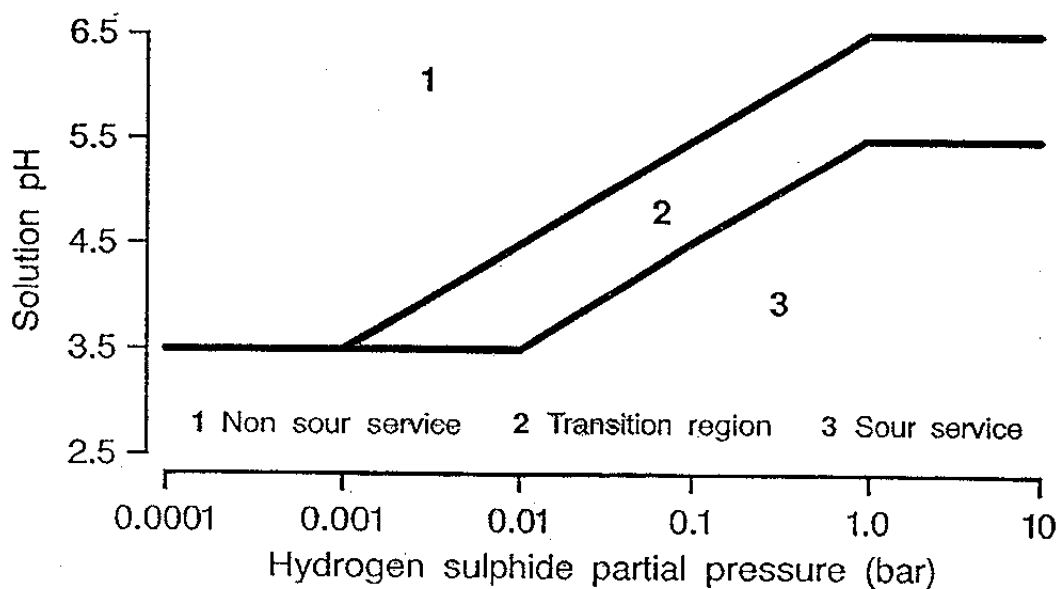


FIGURE J1
SOUR SERVICE DOMAINS FOR DESIGN OF DOWNHOLE TUBULAR STEELS AGAINST SSC