



Exploration & Production

GENERAL SPECIFICATION

CORROSION

GS COR 170

**Materials for sour service (upstream applications)
Specification for design**

03	10/04	Update and modifications of various sections
02	11/03	The requirements of the new ISO 15156 are included in the Third issue - Change of group name and logo
01	10/02	Second issue
00	03/01	First issue
Rev.	Date	Notes

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Foreword

Value of this General Specification

This COMPANY General Specification clarifies certain requirements specified in [ISO 15156](#) and provides guidelines for the choice of materials for sour service duty applicable to upstream conditions, 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 COMPANY of their experiences in all aspects of its application.

Application

Text in italics is Commentary. It is included in the main text and in Appendix 2. Commentary provides background information that supports the requirements of this 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 Section.

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.

Principal changes from previous edition

This General Specification Revision 1 was modified from the previous version to be consistent with other COMPANY General Specification requirements for use in H₂S containing environments. This was true in particular for GS PVV and PLR. In Revision 2, the requirements of the new [ISO 15156](#) have been included.

Note that the material requirements of [NACE MR0175-2003](#) Standard have been fully incorporated into the new three part [ISO 15156](#) document. Hence, in this Specification, reference is only made to [ISO 15156](#) which is also called [ISO 15156/MR0175](#) in United States.

As a consequence, in all other COMPANY General Specifications, where reference is made to [NACE MR0175](#) Standard, the new [ISO 15156](#) document automatically applies.

Feedback and further information

Users are invited to feed back any comments and to detail experiences in the application of this General Specification, to assist in the process of their continuous improvement.

1. Scope

This Specification specifies COMPANY general requirements on materials of construction for equipment handling fluids containing water and hydrogen sulphide in upstream conditions. It makes major reference to **ISO 15156 International Standard**. Other documents such as EFC **Publications No. 16** and **No. 17** and **NACE TM 0177** and **TM0284 Standards** are referenced but mostly for testing.

2. Reference documents

The reference documents listed below form an integral part of this General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the EFFECTIVE DATE of the CONTRACT.

Standards

Reference	Title
EN 10002-1	Metallic Materials - Tensile testing - Part 1: Method of test (at ambient temperature)
EN 10028	Flat Products made of Steels for Pressure Purpose
EN 10204	Metallic Products - Type of Inspection Documents
EURONORM 160	Definition of Quality - Test Methods
ASTM A 193	Alloy-Steel and Stainless Steel Bolting Materials for High - Temperature Service
ASTM A 194	Carbon and Alloy Steel Nuts for Bolts for High - Pressure and High Temperature Service
ASTM A 216	Steel castings, Carbon, Suitable for Fusion Welding, for High - Temperature Service
ASTM A 217	Steel Casting, Martensitic Stainless and Alloy, for Pressure - Containing Parts, Suitable for High - Temperature Service
ASTM A 307	Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength
ASTM A 320	Alloy Steel Bolting Materials for Low - Temperature Service
ASTM A 370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A 516	Pressure Vessel Plates, Carbon Steel, for Moderate and Lower Temperature Service
ASTM A 841	Steel Plates for Pressure Vessels, Produced by the Thermo-Mechanical Control Process (TMCP)
ASTM A 439	Austenitic Ductile Iron Castings
ASTM A 395	Ferritic Ductile Iron Pressure - Retaining Castings for Use at Elevated Temperatures
API 5 CT	Specification for Casing and Tubing

Reference	Title
API 619	Rotary - Type Positive Displacement Compressors for General Refinery Services
ISO 15156-1	Petroleum and Gas Industries-Materials for Use in H ₂ S-containing environments in oil and gas production - Part 1: General principles for selection of cracking-resistant materials
ISO 15156-2	Petroleum and Gas Industries-Materials for Use in H ₂ S-containing environments in oil and gas production - Part 2: Cracking-resistant carbon and low alloy steels, and cast irons
ISO 15156-3	Petroleum and Gas Industries-Materials for Use in H ₂ S-containing environments in oil and gas production - Part 3: Cracking-resistant CRAs (corrosion resistant alloys) and other alloys

Professional Documents

Reference	Title
EFC Publication No. 16	European Federation of Corrosion Publication No 16; Guidelines on Material Requirements for Carbon and Low Alloy Steels for H ₂ S - Containing Oil and Gas Field Service
EFC Publication No. 17	Corrosion Resistant Alloys for Oil and Gas Production: Guideline on General Requirements and Test Methods for H ₂ S Service

Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
NACE Standard TM0284	Test Method - Evaluation of Pipeline and Pressure Vessels Steels for Resistance to Hydrogen - Induced Cracking
NACE Standard TM0177	Test method - Laboratory Testing of Metals for Resistance to Sulphide Stress Cracking in H ₂ S Environments

Other documents

Reference	Title
Not applicable	

Total General Specifications

Reference	Title
GS PLR 211	Fabrication of seamless pipes for pipelines (Intermediate and Severe Sour Service)
GS PLR 212	Fabrication of longitudinally submerged arc welded pipes for pipelines (Intermediate and Severe Sour Service)
GS PLR 231	Induction bends for pipelines (Intermediate and Severe Sour Service)
GS PLR 232	Carbon steel flanges and branch outlet fittings for pipelines (Intermediate and Severe Sour Service)
GS PLR 233	Carbon steel tees for pipelines (Intermediate and Severe Sour Service)
GS PVV 171	Steel piping fabrication
GS PVV 211	Design and fabrication of pressure vessels according to ASME VIII div.1 or div.2
GS PVV 212	Design and fabrication of pressure vessels according to BS 5500
GS PVV 612	Piping and equipment subject to severe sour service. Metallurgical and welding requirements
GS PVV 613	Valve materials requirements for use in sour service
GS PVV 622	Piping and Equipment Subject to Intermediate Sour Service Metallurgical and Welding Requirements
GS MEC 271	Process centrifugal pumps - Comments to API 610
GS MEC 273	Supply of Centrifugal Pumps Class II According to ISO 5199
GS MEC 281	API Standard 614 Lubrication Shaft Sealing and Control Oil Systems for Special Purpose Applications
GS MEC 251	Supply of Centrifugal Compressors for Petroleum, Chemical and Gas Service Industries According to API Standard 617
GS MEC 261	Reciprocating Compressors

Note: in the listed COMPANY General Specifications when **NACE MR 0175** Standard is referenced, **ISO 15156** document automatically applies.

3. General

3.1 Application

All installations for fluid containing hydrogen sulphide shall meet the requirements of this Specification. These include:

- (i) All wetted parts which are in direct contact with the H₂S containing fluid.
- (ii) All attachments which are not freely ventilated to the atmosphere (insulated, buried, shielded equipment, etc.) and are liable, in case of a leak, to be exposed to H₂S.

3.2 Hydrogen-related cracking phenomena

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

a) Sulphide Stress Cracking (SSC)

This is a form of hydrogen embrittlement phenomenon, i.e. cracking is caused by the dissolution and diffusion of hydrogen atoms into the steel when subject to a tensile stress.

Hydrogen originating from corrosion reactions acts in a detrimental manner. Areas of high hardness/high strength 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 or yield strength and, in some cases, stress level by heat treatment. This is described in detail in this document.

b) Hydrogen Induced Cracking (HIC)

In a similar manner to SSC, hydrogen diffuses into the material, but precipitates as gaseous hydrogen at inclusions or other microstructural defects, where it produces an internal pressure. This results in various forms of internal cracking, or blistering if swelling of the cracked area predominates.

Damage can be seen in various forms depending upon type and location of the inclusions present and the stress pattern. These forms include blistering, stepwise cracking (SWC) and stress oriented hydrogen induced cracking (SOHIC). These types of hydrogen damage are schematically shown in Figure A2.1 of Appendix 2. The differences between these forms of hydrogen recombination related cracking are described in the text of Appendix 2.

Confusion between HIC and other types of hydrogen embrittlement sometimes also called HIC but not involving the presence of H₂S should be avoided.

The main method used to prevent this type of cracking is to select a high quality clean material and, for SOHIC, to reduce internal stresses by heat treatment; as described in this Specification.

c) Stress Corrosion Cracking (SCC)

This is a form of cracking, usually occurring on passive materials (such as stainless steel or corrosion resistant alloys) submitted to applied and/or residual tensile stresses.

This form is an extension of the "classical" SCC of stainless steels in aerated chloride containing solutions, which also **occurs in deaerated brines when sulphides are present**. The presence of H₂S exacerbates this form of damage.

The main method used to prevent such cracking is to select a material resistant to SCC under the service conditions and, in some cases, to reduce service stresses.

3.3 ISO 15156 or ISO 15156/MR0175 International Standard

This standard introduced in December 2003 is basically a combination of NACE MR 0175-2003 and EFC 16 and 17 documents. This specification is based on this standard with some modifications or additional information where necessary.

3.4 Present definition of sour service

This Specification defines sour service according to the limits of use of common downhole tubular, i.e. the most strategic petroleum equipment. For equipment other than tubing/casing, it defines classes of severity, which are not limits of use, but can be used to adjust materials requirements and testing to the actual level of corrosive constraint.

3.5 Other types of corrosion

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. Also it does not provide materials requirements due to other corrosion mechanisms than environmental cracking: e.g. general corrosion (weight loss) or localised corrosion (pitting, crevice). The materials suitability with respect to those other forms of corrosion will have to be established separately. These requirements are of special concern for stainless steels or other so called CRAs.

3.6 Requirements

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

3.7 Materials concerned

- ★ Reference is made in this Specification to various items of equipment, such as pressure vessels, process pipework, well tubing and casing, pipelines, rotating machinery and instrumentation, for which specific COMPANY Specifications exist. The requirements of such Specifications apply in all respects, except as modified by this Specification for sour service.

3.8 Upgrading of equipment

- ★ 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 COMPANY.

3.9 General HIC requirement

The various forms of hydrogen internal pressure damage are explained in Appendix 2 and illustrated in Figure A-1.

4. Service in the presence of wet H₂S

4.1 Definition of service conditions

The guidance is based on severity of corrosive medium as characterised by the in-situ pH and the H₂S partial pressure, and representing the risks connected with any equipment damage. This concept is associated with that of the severity of operating conditions, related to the type and function of the equipment concerned in terms of personnel and equipment safety (risk of damage, cost of repair or replacement, etc.).

4.2 Domains of sour service

4.2.1 Background

The presence of wet H_2S promotes and exacerbates many types of environmental cracking, involving a range of mechanisms. For SSC to occur, a combination of susceptible material (metallurgical factors), an aqueous environment containing H_2S and a tensile stress (applied or residual) are required. The service conditions within which these types of cracking may become an integrity concern and hence require metallurgical design or operational precautions are known as “sour service”. This is in contrast to “sweet service” where no metallurgical design or operational precautions are normally required in order to avoid environmental cracking.

For the purpose of materials selection and a description of metallurgical requirements for sour duties, “domains of service” are defined. These domains take account of the in-situ pH and the H_2S partial pressure, which are the two predominant parameters which influence materials performance in sour media. The concept of domains offers several advantages:

- The number of qualifying tests may be reduced
- The relevant operational information is provided and
- The approach is quantitative.

Domains also give greater freedom than the former **NACE Standard MR 0175** when selecting materials. Dependent on the material selection design parameters, they can also provide improved safety, reliability and economy, and facilitate the selection of the most suitable and cost effective materials.

4.2.2 Severity of operating conditions

The **ISO 15156-2** diagram **has been adopted in this Specification but with additional constraints** related to the unknown behaviour of some materials in specific areas, as described below.

Hence, four sour service “domains” are identified on the graphical presentation of Figure 1. Each domain characterises materials’ suitability, indicated by decreasing susceptibility to cracking with increasing severity of corrosive conditions. In the context of these domains, severity of sour service is enhanced by decreasing pH and/or increasing H_2S partial pressure.

The definition of sour service domains of in-situ pH versus H_2S partial pressure offers several advantages, e.g.:

- *It is applicable to any production system, since it is not necessary to distinguish between oil or gas environments.*
- *It is quantitative and simple to apply.*
- *The limits of H_2S service defined can deliver both increased safety and economy.*
- *It incorporates all the experience accumulated over the years by the users of **NACE Standard MR 0175**, whilst at the same time covering cases of three phase production systems, particularly formation waters with traces of H_2S in CO_2 -containing fields, or in CO_2 transport or injection systems.*
- *It reflects all aspects of the present understanding of acid gases and H_2S induced cracking.*
- *The use of the domains can be extended to defining the likelihood of damage by other types of H_2S induced cracking, such as HIC and SOHIC.*

4.2.3 Domains of sour service

Domains of sour service are defined in Figure 1, showing four Regions characterising materials suitability for sour service applications. These are:

Region 0: “Sweet Service” (only negligible traces of H₂S): the domain within which no specific metallurgical precautions are needed. This Region applies to all metallic components.

Region 1: “Mild Sour Service” The domain within which minor and inexpensive precautions are required. An example of materials which can be used within Region 1 includes carbon steel tubing and casing up to [API 5CT](#) grade P110 - this Region applies to any material of similar sensitivity to SSC.

Region 2: “Intermediate Sour Service” The domain within which increasing precautions are required. An example of materials, which can be used within Region 2, includes carbon and low alloy steel tubing and casing up to the API 5CT grade N80. This Region applies to any material of similar sensitivity to SSC.

Similarly, resistance to HIC and SOHIC can be achieved by the use of moderately low sulphur, clean and microstructurally homogeneous steels.

Region 3: “Severe Sour Service” The domain within which the most stringent precautions are necessary. Examples include materials taken from the [ISO 15156](#) reference list. Similarly, resistance to SWC requires steels with very low sulphur and other impurity contents, and/or calcium treatment, and qualified by laboratory testing in the expected service conditions.

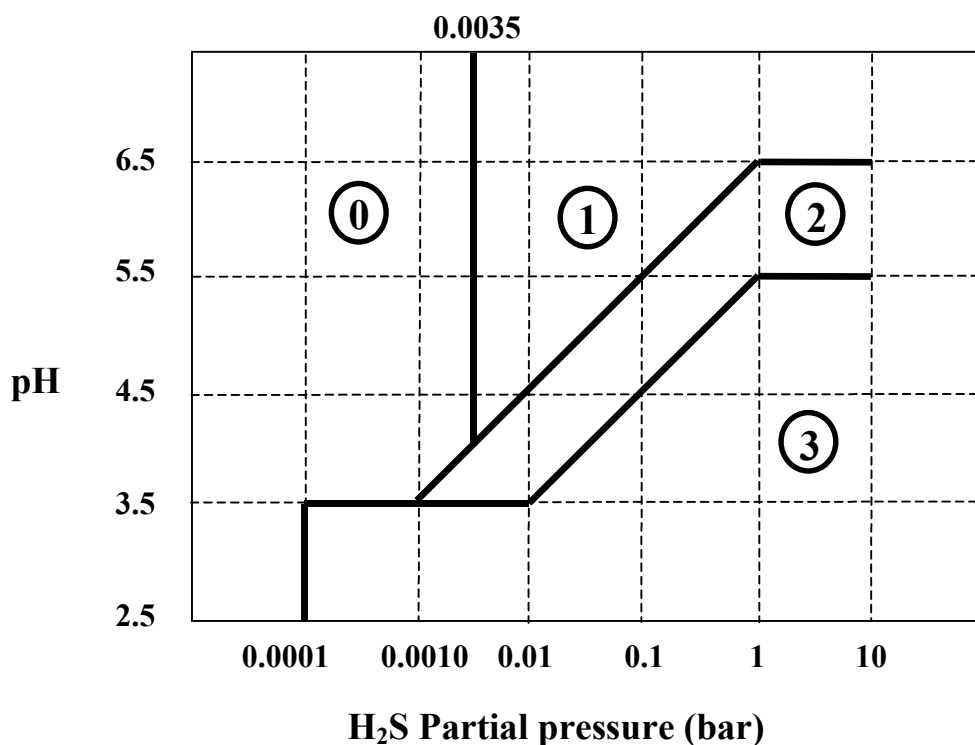


Figure 1 - Limits of sour service

Note that this diagram is slightly different from the one adopted in [ISO 15156-2](#). While the dashed lines in the ISO document have disappeared into Region 0, the following rules have been adopted in this Specification:

- The severe "sour service" region (Region 3) **includes the area below 3.5 down to 0.1 mbar of H₂S partial pressure**
- The small triangular region above pH 3.5 and below 3.5 mbar of H₂S remains in the intermediate "sour service" region (Region 2) until precise data are available.

Note that, in practice, if PH₂S is <0.1 mbar or below the detection limit regardless of pH, the conditions are considered sweet or in Region 0.

4.3 Use of the pH-P_{H₂S} partial pressure domains diagrams

4.3.1 Characterisation of the corrosive medium

4.3.1.1 H₂S partial pressure

Partial pressure of H₂S is calculated as:

$$P_{H_2S} = P_{tot} \times \% H_2S \text{ (in the gas phase)}$$

(P_{tot} is the normal maximum operating absolute pressure, though design absolute pressure could also be used for a slightly more conservative approach)

At pH < 3.5, the lack of lower limit for P_{H₂S} means that any detectable trace of H₂S leads to the restriction of Region 3.

When no gas phase is locally present, P_{H₂S} is the partial pressure of the last or next gas phase in equilibrium with the aqueous phase, e.g. the partial pressure at the last separator for any liquid circuit downstream, or the partial pressure at the bubble point for any hydrated oil upstream.

4.3.1.2 In-situ pH

The in-situ pH depends on the partial pressures of both CO₂ and H₂S and alkalinity of the water, represented by the sum of the bicarbonate (HCO₃) and disulphide (HS⁻) contents, the ionic strength of water and, to some extent, temperature. The pH value can be determined by various means:

- Direct measurement (at the in-situ pressure)
- Computer calculation, or
- Approximate assessment from published charts (see Appendix No. 1 in [EFC Publication No. 16](#) and Annex D in [ISO 15156-2](#) Standard)

For example, Figures 2 and 3 can be used to determine the value of the pH when H₂S and CO₂ partial pressures are known, as well as the alkalinity (or "bicarbonate") content of the produced water. When available, more accurate determination through computer programmes are recommended (i.e. CORMED, CORPLUS or equivalent Softwares). **In case of doubt or lack of information on the associated water chemistry, condensed water shall be taken as the safe worst case scenario.**

4.3.2 The use of a domain diagram

Domains of sour service cannot be defined without information on the partial pressure of CO_2 . For example, when $P_{\text{CO}_2} > 6$ bar, the pH of condensed water may fall below 3.5, in which case the presence of any traces of H_2S leads to the domain of Severe Sour Service. In contrast, at $P_{\text{CO}_2} < 0.6$ bar, without further acidification by H_2S , the pH remains above 4.0. In these latter conditions, the H_2S partial pressure determines the respective domain. In other conditions, where P_{CO_2} is between 0.6 and 6 bar, the corresponding pH lies between 4.0 and 3.5 and the respective domain is also determined by the H_2S partial pressure.

In summary, a safe and simplified decision tree defining domains of sour service is presented in Figure 4 and is as follows:

- Without chemical acidification: Regions 0, 1, 2 or 3 depending on $P_{\text{H}_2\text{S}}$
- With chemical acidification below pH 3.5: Region 3 for any trace of H_2S .

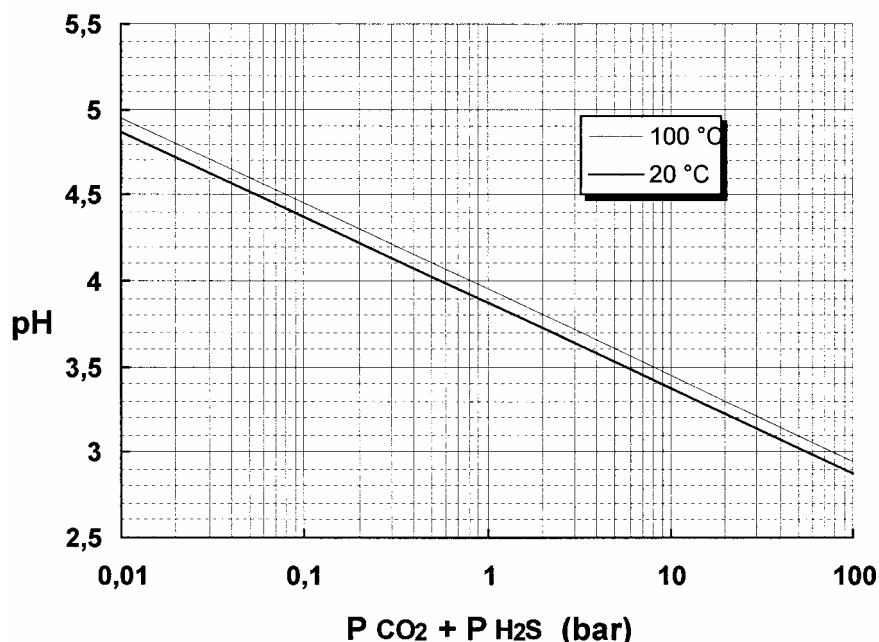


Figure 2 - pH of condensed water under CO_2 and H_2S pressure

Care must be taken that the analysis of water is restricted to dissolved species and is not biased by suspended solids such as CaCO_3 or corrosion products. In case of doubt or in the presence of precipitation effects, an accurate assessment through computer calculation is recommended.

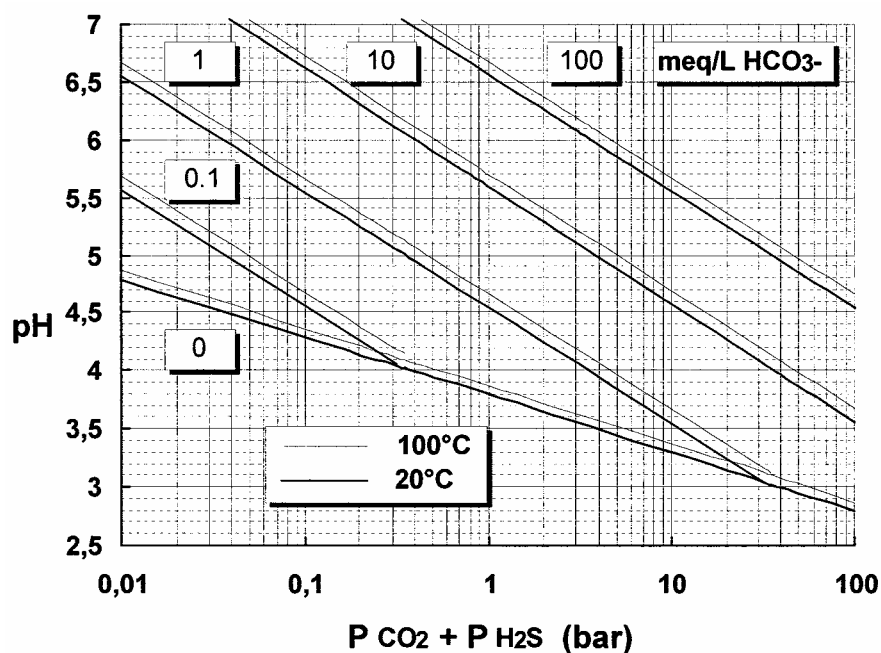


Figure 3 - pH of formation water under CO₂ and H₂S partial pressure

Note:

- For temperatures over 100°C use the 100°C line
- For temperatures below 20°C use the 20°C line
- For temperatures between 20 and 100°C, interpolate linearly between the two lines.

4.3.3 Characterisation of materials

All components and materials which have not been qualified for sour service duty can be used in Region 0 (Sweet Service) without any metallurgical precaution. Materials and components that have been qualified according to the procedures defined in this Specification over a wide range of pH and H₂S partial pressures can be used in Regions 1, 2 and 3.

4.3.3.1 Strategic materials

For the most strategic materials, such as steels for tubing, casing or linepipe, the metallurgical precautions necessary for their use in sour service are generally well known and the application domains are well established. Nevertheless, reference to the four Regions of Figure 1 conveniently simplifies the reporting of individual performance.

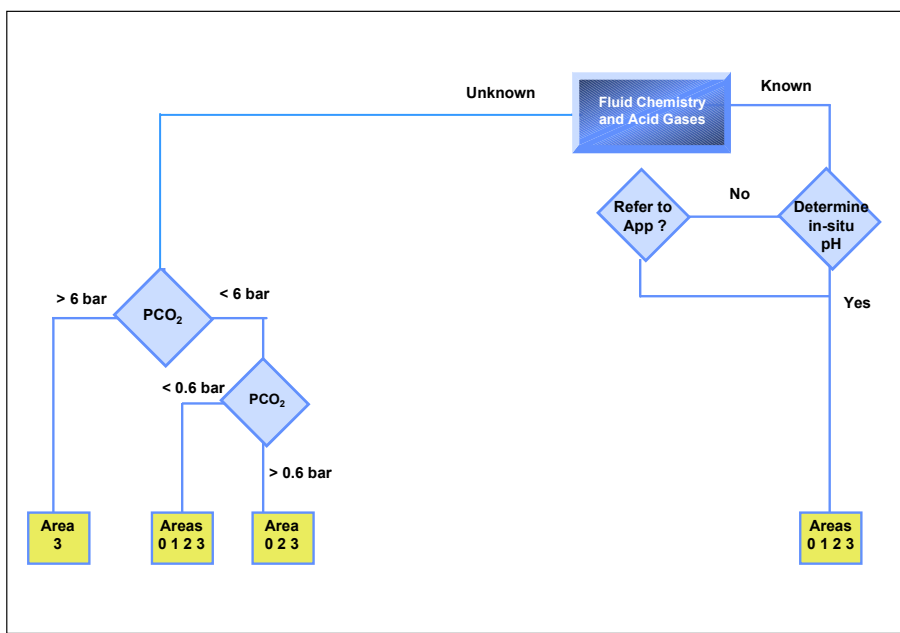


Figure 4 - A decision tree defining domains of sour service for carbon and low alloy steels

4.3.3.2 Non-strategic materials

For less strategic materials, or where usage is small, the limits of resistance to sour service may not be available. However, the performance can be determined on a case by case basis, provided that testing conditions are appropriate for the expected service conditions. A successful test at a given pH and P_{H_2S} value will qualify the use of the material for any higher pH or lower P_{H_2S} . This allows a test matrix to be tailored to the expected application of each material.

Also, ranking of non-strategic materials in specific test conditions representative of particular field conditions allows extrapolation of their domains of application beyond those already documented.

Whatever the method used for the characterisation of materials, the responsibility of the materials selection should be endorsed by the end user. The purpose of this document is to standardise the acquisition and release of this information on the comparative resistance of materials or their limits of use in sour service.

4.4 Use of the diagram

Whatever the application, the procedure to use the diagram is always the same. This is as follows:

Consider and compile the data relative to the fluid present in the equipment at the most severe operating conditions as follows:

- Design (absolute) pressure
- Maximum operating (absolute) pressure
- Minimum possible operating temperature

- H₂S and CO₂ contents in the gas phase
- Water composition.

Determine the minimum possible pH (Figures 3 and 4) according to the **minimum operating temperature**, the H₂S and CO₂ partial pressures at the **maximum operating (absolute) pressure**, or the lowest local alkalinity of water.

Determine the point corresponding to the service conditions which refers to Region of severity 0, 1, 2, or 3. Regions 3 and 2 correspond to the metallurgical requirements set forth in this Specification which must be satisfied. In Region 1, the requirements of this Specification are applicable; as such any standard grade is accepted in this Region except particularly sensitive steels (tool or spring steels, etc.).

Examples that explain how to use the above diagram are given in Appendix 3.

5. Materials for sour service

All Materials for sour service as defined in this Specification shall comply fully with the **ISO 15156 Standard** except as modified or extended below. To put the requirements into context, modifications are divided into three Regions:

- General requirements
- Testing requirements
- Requirements for specific equipment.

The SUPPLIER shall exercise special care in the selection and supervision of the fabrication conditions and heat treatment conditions, in order to eliminate heterogeneous structures, such as banded pearlite structures and aggregates of bainite and unannealed martensite.

5.1 General requirements

5.1.1 Materials selection

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

- Requirements arising from Section 5.1 of this Specification
- Resistance to general corrosion

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

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

5.1.2 Materials for sweet service conditions

No specific requirements in Region 0.

5.1.3 Materials for mild sour service conditions

The requirement for Region 1 is limited to the avoidance of particularly sensitive materials (e.g. tool or spring steels). For non welded construction steels or OCTG, a yield strength below 900 MPa (130 ksi) is acceptable.

5.1.4 Materials for intermediate sour service conditions

In case of strong economic stakes, it is possible to define the requirements for Region 2 by relaxing those for Region 3 in example through reduced quality control (e.g. nominal API L80 grade) or extended acceptance values (e.g. API N80 grade). This must be made in agreement with COMPANY, and may require application specific testing.

In case of doubt, or without specific economic impact, the materials requirements for Region 2 will be similar to those of Region 3.

5.1.5 Materials for severe sour service conditions

Materials for the "Severe Sour Service" conditions (Region 3) shall be selected from those permitted in the former [NACE Standard MR 0175](#) at test level III (Table E.1 of [ISO 15156-3](#)).

5.1.6 Castings

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. **All casting repair welds shall be heat treated** as follows:

- Carbon and carbon manganese steel: Post Weld Heat Treatment
- Martensitic stainless steel e.g. 11-13 % chromium steel: Re-heat treat completely or double temper (see [ISO 15156-3](#) Section A.6 for details of heat treatments)
- Austenitic and duplex stainless steel: Solution Anneal
- Austenitic nodular cast iron: welding is not permitted.

5.1.7 Steel grades

The ranges of chemical composition in steel product standards differ from one country to another, and especially between ASTM, API, and European Standards. In Addition, compositional limits have not been defined according to SSC or HIC resistance. Usually specific compositional requirements ensure the requested resistance to environmental cracking in sour service conditions.

Since some elements of the chemical analysis (Mn, P and S) do not act alone with respect to H₂S corrosion, the combined effects of these elements shall be taken into account. However, the maximum allowable levels shall, under no circumstances, be higher than the maximum figures given in the applicable product standard.

The required compositions of carbon steel grades for sour service are given in the appropriate PVV and PLR General Specifications for pressure vessels and piping, and for pipelines, respectively.

For other applications, guidelines of [ISO 15156-2](#) will be used. Annex A will be used for materials and Annex B for their qualification.

5.1.8 Weld repair of steel plate

For Severe and Intermediate "Sour Service" conditions (Region 2 and 3) weld repair of plate surface defects will not be permitted as stated in Company [GS PVV 612](#) and [GS PVV 622](#).

5.1.9 Copper and nickel copper alloys

Copper and its alloys are prohibited because of their poor resistance to general corrosion and mechanical strength. Alloy 400 (UNS N04400) which is a 70%Ni-30%Cu is acceptable.

Although it has been left out of [ISO 15156-3](#), it should be re-introduced in the coming revised version. However, this alloy is prohibited in equipment intended for critical parts whose failure would jeopardise the operation of the equipment in terms of safety because of its poor mechanical strength. **Alloy 500 (UNS N05500) is not acceptable unless its resistance to H₂S can be demonstrated under the service conditions by the SUPPLIER.**

5.1.10 Cast iron

- ★ Cast iron is prohibited if it is in contact or is liable to be in contact with an atmosphere containing H₂S irrespective of its concentration (Section 1.1.2). However, for the reciprocating compressor, the use of this type of material must be considered in accordance with the type of mechanical load in service. Its use shall be subject to COMPANY approval.

5.1.11 Stainless steels

- ★ Stainless steels can be used for some parts of equipment. If so, the following requirements and restrictions shall be applied:
 - 13 % Cr Stainless steel shall be heat-treated and have a hardness complying with [ISO 15156-3](#), Annex A.6
 - Austenitic stainless steels and austenitic-ferritic (duplex) stainless steels shall be in the solution annealed condition
 - Precipitation hardened martensitic stainless steels 17-4 PH shall not be used in the presence of H₂S unless the absence of water is certain and/or design stresses are below 30 to 50% of the actual material yield strength. The supplier will need to demonstrate the resistance of these materials under the actual most severe service conditions. In addition a double ageing heat treatment will be required with an appropriate QA/QC procedure approved by COMPANY
 - If welding and/or post-weld heat-treatment is required on austenitic stainless steels, only low carbon or titanium-stabilised steels will be allowed
 - If welding repairs are required to the bodies of cast equipment in type 304 or 316 stainless steel, the procedure shall be subject to approval
 - Parts of austenitic stainless steel cold-formed by rolling, bending or stamping shall be quench-annealed a second time if the permanent deformation exceeds 15 %
 - In all cases, limits of use of stainless steel and the suitability of alternative material for specific applications shall be sought from the COMPANY.

5.1.12 Miscellaneous

For the fabrication of certain parts of valves and fittings, instrumentation and machines in contact with effluent containing H₂S, the SUPPLIER shall select materials resistant to SSC, proved on itemised drawings specific to the installation planned.

- ★ Details of component materials and the material condition shall be subject to COMPANY approval prior to manufacture.

High strength steels at high levels of stress such as internal bolting, springs, bellows and parts of reciprocating compressors require specific attention and relevant part of this Specification should be used. They shall comply with the [ISO 15156](#), when in contact with any detected concentration of wet hydrogen sulphide.

5.1.13 Natural, synthetic, plastic and/or fabric materials

- ★ The packing, bonnet seals, seat rings, and seals and/or any other synthetic or fabric materials and parts shall be those regularly supplied and suitable for sour service, i.e. fluorocarbon materials, Buna N, Nylon, Viton A, etc. If other materials are proposed, they shall be subject to COMPANY approval.
- ★ In all instances, material selection shall take into account the complete operating conditions to be encountered, i.e. temperature, pressure and chemical environment especially amines. All non-metallic seal materials and seal geometry shall be subject to COMPANY approval.

5.2 Testing requirements and categories

The cracking resistance at various levels of sour service cannot be assessed through conventional or straight standardised tests. Consequently, testing is often specified in the present document, both for SSC and HIC resistance.

- ★ A detailed specification by COMPANY shall indicate test requirements set forth below which need to be satisfied in part or in full.

For pipelines, the number and location of test specimens, frequency of testing, their request and necessity with respect to sour service Regions are described in GS PLR Specifications.

Two categories of tests are described. These and their relevance are as follows:

Qualification test:

This category of testing, if specified, will be carried out *on candidate materials to qualify for a particular duty*. This is usually carried out before placing an order, on samples representative of the expected worst case in production.

Production assessment test:

This category of testing is for *critical applications* and, if specified, shall be carried out during the manufacturing.

5.2.1 SSC Testing

Test procedure shall be in accordance with **NACE Standard TM0177** (Method A) or EFC Publication No. 16 (Method A).

5.2.1.1 Qualification tests (when specified)

This category of testing, if specified, will be carried out on candidate materials to qualify for particular applications. Justification of the satisfactory behaviour of the steel, according to the specified test conditions, may be provided in the form of prior results obtained with steels of equivalent grade, quality and identical origin.

For pipelines, the testing requirements, i.e. test specimen location, frequency of testing and the number of specimens are described in **COMPANY GS PLR Specifications**.

For other components, qualification of steel batch is required as defined below:

- Tests should be performed in triplicate for each steel and each SUPPLIER
- The sample taken from a batch of the order with properties as close as possible to the maximum yield strength or hardness of the overall delivery
- Tests should be carried out one set per heat lot

- Solution chemistry shall be in accordance with the requirements of document EFC Publication No. 16
- **For a specific duty, tests should be carried out at design pH or lower.** In situations where design pH is not known, tests should be carried out in Solution A (pH 3.5) for gas/condensate production or solution B (pH 4.5) for oil production according to EFC Publication No. 16

For Regions 0 (sweet service) and 1 (mild sour service) of the diagram of Figure 1, no tests will be required.

For Region 2 (intermediate sour service) of the diagram of Figure 1, the tests will be carried out with a H₂S partial pressure of 0.01 bar for pH 3.5 and 0.1 bar for pH 4.5.

For Region 3 (severe sour service) of the diagram of Figure 1, the tests will be carried out with a H₂S partial pressure of 1 bar for pH 3.5 and pH 4.5.

- The sample shall be taken in the longitudinal direction. No crack shall occur in the 720 hours of the test under an applied stress corresponding to 90% of the actual yield strength at room temperature (at 0.2% of permanent offset)
- 0.2% permanent offset shall be the average of three samples in accordance with the requirements of ASTM A370/ [ISO 10002-1](#).

In service conditions, cracking is not steered by nominal working stresses, calculated according to the specified minimum yield strength of the grade, but by local unknown internal stresses, which may rise close to the actual surrounding yield strength; hence the requirements to test at 90% of the actual yield strength.

5.2.1.2 Production assessment tests during manufacturing

When SSC test on production materials are requested they must be in accordance with the requirements of Sections 5.2.1 and 5.2.1.1. For pipelines, GS PLR Specifications shall be used for the details and frequency of testing.

5.2.2 HIC testing

For pipelines, the testing requirements, i.e. test specimen location, frequency of testing and the number of specimens are described in the appropriate **COMPANY GS PLR Specifications**.

5.2.2.1 Categories of testing

The proposed HIC test routes includes two principal categories of testing as described in Section 5.2. Justification of the satisfactory behaviour of candidate steels, according to the specified test conditions, may be provided in the form of prior results obtained with steels of equivalent grade, quality and identical origin.

In any event, testing of candidate steel, specifically manufactured for sour service, is required as defined below:

- Tests should be performed in triplicate for each steel and SUPPLIER
- The sample taken from a heat exhibiting the highest sulphur content per type of steel and supplier and/or the highest Mn content in case of banded pearlite structure with low S

- Solution chemistry and conditions shall be in accordance with EFC Publication No. 16 or option 2 of the future standard [ISO 15156-2](#)
- **For a specific duty, tests shall be carried out at the design pH or lower if it is more acidic than the following conditions.** In situations where design pH is not known, tests shall be carried out in solution A (pH 3.5) for gas/condensate production or solution B (pH 4.5) for oil production as in EFC Publication No. 16.

Qualification Test (when specified):

This type of testing is carried out on candidate materials to qualify for particular applications.

The tests shall be carried out in accordance with the methods described **either in document [NACE Standard TM0284](#) or in Appendix 4 of this specification**, in solutions described in Section 6.2.2 according to EFC Publication No. 16. The choice of solution will depend on expected application. **In all cases the test pH will be lower than the actual service pH to be conservative.**

Note: that the method described in Appendix 4 is more sensitive and discriminating than the [NACE method TM0284](#) and hence, should be preferred for qualification testing when practical.

Production assessment test:

The tests shall be carried out in accordance with the method described in document [NACE Standard TM0284](#), in solutions described in Section 6.2.2 according to EFC Publication No. 16. The choice of solution will depend on expected application. Acceptance criteria are described below for Regions 2 and 3.

5.2.2.2 Intermediate and severe sour service conditions (Regions 2 and 3)

Qualification tests:

Justification of the satisfactory behaviour of the steel, under the specified test conditions, shall be provided in the form of prior test results obtained with steels of equivalent grade and quality and **of the same origin**.

A test is usually made before placing an order on a sample representative of the worst case in production. The choice of solution as described in Section 5.2.1 will depend on expected application and will be according to EFC Publication No. 16 for specific application as follows:

- Solution A (pH 3.5) if the lowest pH in the installation is ≤ 4.5
- Solution B (pH 4.5) if the lowest pH in the installation is > 4.5 .

For Region 2 and 3 of the diagram of Figure 1, the tests will be carried out with a H₂S partial pressure of 1 bar for pH 3.5 and for pH 4.5.

The **acceptance criteria** will be according to [NACE Standard TM0284](#) or according to those of the procedure described in Appendix 4 or an equivalent procedure with CER < 3 % at the pH defined above.

Production assessment test during manufacturing:

A test is performed according to procedure [NACE Standard TM0284](#) under the conditions described above. **Production assessment test during manufacturing will be carried out according to the [NACE Standard TM0284](#) method.**

The **acceptance requirements** will be those given in [NACE Standard TM0284](#), i.e. **CLR $\leq 10\%$, CTR $\leq 3\%$, CSR $\leq 1\%$ and, no individual crack length of more than 5 mm if the test pH ≤ 4.5 and no crack if the test pH > 4.5 .**

5.2.2.3 Mild sour service (Region 1) conditions and sweet sour service (Region 0) conditions

No testing is required.

5.3 Downhole tubulars

Specific requirements for the selection of downhole tubular steels are described according to the increasing specified maximum yield strength of the [API 5CT](#) grades:

- Region 0: up to [API Q 125](#)
- Region 1: up to [API P 110](#)
- Region 2: up to [API N 80](#)
- Region 3: up to [API L 80](#) or [C 90](#).

Proprietary grades are accepted from the ranking of their SSC resistance with the above, (e.g. [API 5CT](#), C 95 grades), or from direct application specific testing (e.g. [API 5CT](#), C110 grades). In this respect, 13 % Cr tubing in the L80 state can be used at least in Regions 0, 1 and 2, i.e. without further testing of their SSC resistance, but provided their resistance to other corrosion mechanisms will have been established. L80 13 % Cr can also be used in some parts of Region 3, but this must be verified by testing on a case by case basis.

5.4 Transmission pipelines

Pipelines and associated fittings will be subject to the requirements of **COMPANY PLR General Specifications**.

- ★ Full diameter pipe HIC/SOHIC testing may be required, details of which shall be specified by COMPANY.

5.5 Pressure vessels, heat exchangers, and process pipework

The requirements for pressure vessels, heat exchangers, fittings, castings, forgings and valves fabricated of carbon steel and low alloy steel are given in [GS PVV 612](#), [GS PVV 613](#) and [GS PVV 622](#).

5.6 Rotating machinery

5.6.1 General

Sour service for rotating machinery shall be taken as defined in Section 4 except for reciprocating compressors where the presence of any level of H₂S shall be defined as severe sour service (Region 3).

5.6.2 Materials

The materials selected and fabrication procedures employed shall comply with this Specification.

Carbon and carbon manganese steel plate for fabricated compressor casing shall be resistant to HIC and shall conform to [GS PVV 612](#) and [GS PVV 622](#).

5.6.3 Welds

- ★ All fabrication welds and repair welds shall be heat treated as follows:

- ★ Carbon and carbon manganese steel: PWHT at 580/620°C (1076/1148°F), other temperatures only as approved by COMPANY

- ★ Low alloy steel: PWHT details shall be subject to COMPANY approval

Martensitic stainless steel (11-13% chromium steel): Re-heat treat completely including double temper (A.6 of [ISO 15156-3](#)).

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

Austenitic stainless steels do not normally require PWHT

- ★ Austenitic-ferritic (duplex) stainless steels: subject to COMPANY approval.

5.6.4 Cast Iron

- ★ Cast iron or ferritic ductile (nodular) iron are unacceptable for pressure-retaining parts and for impellers etc. Austenitic cast iron is also unacceptable for pressure-retaining parts except as permitted by Section 5.7.2. The use of these materials for non-pressure, low-stressed components shall be subject to COMPANY approval. None of these materials shall be weld repaired.

5.6.5 Others components

All components such as internal bolting, springs, etc., shall comply with the relevant parts of this Specification.

5.6.6 Shafts and piston rods

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 250 HV10 (HRC22) and yield strength not exceeding 620 MPa (90 ksi).

- ★ Shafts in austenitic or austenitic-ferritic stainless steel shall be in the solution annealed condition. 17-4 PH (UNS S17400) martensitic precipitation-hardened stainless steel shall conform to the [ISO 15156-3](#) and QA/QC will need COMPANY approval. Precipitation hardened nickel alloy shafts shall be in accordance with Annex A.9 of [ISO 15156-3](#). Fitness for purpose of 17-4PH for the sour conditions will need to be demonstrated by the supplier.
- ★ The Straightening of shafts after completion of machining shall not be performed without prior approval from COMPANY.

5.6.7 Metal overlays

- ★ Approval shall be obtained from COMPANY before any attempt is made to rectify machining errors by the application of metal overlays.

5.6.8 Other equipment

All associated equipment e.g. pressure vessels, pipework, etc. shall comply with [GS PVV 612](#), [GS PVV 613](#) and [GS PVV 622](#).

All components in 11-13% chromium martensitic stainless steel shall be double tempered after quenching, and unless stated otherwise their hardness shall be in conformity with Section A.6 of the [ISO 15156-3](#).

5.7 Centrifugal pumps

5.7.1 General

Centrifugal pumps shall conform to **GS MEC 271** and **GS MEC 273** except as modified by this Specification.

5.7.2 Materials

- ★ For centrifugal pumps only, austenitic nodular iron ASTM A 439 or equivalent is acceptable in certain cases, subject to COMPANY approval. 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).

5.7.3 Shafts

Shafts in plain carbon and low alloy steels shall be totally protected from the process stream by corrosion-resistant sleeves, cap nuts, etc. (where applicable). Unprotected 11-13% chromium steel may be used only where it has adequate corrosion resistance to the process fluid.

5.8 Reciprocating compressors

For reciprocating compressors only, the service shall be regarded as severe sour (Region 3) when the gas contains any level of H₂S. In all such cases, the materials and fabrication procedures shall be in accordance with this Specification.

5.8.1 General

Reciprocating compressors shall conform to **GS MEC 261** except as modified by this Specification.

5.8.2 Piston rods

- ★ Piston rods shall be either 11-13% chromium steel or an alternative material approved by COMPANY.

The piston rods shall conform to 5.6.6 of this Specification. However, the rods may be hardened in the region of the packing by the surface induction hardening method.

5.8.3 Liners

- ★ 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 COMPANY approval.

5.8.4 Internals

- ★ Valve plate rings, channels, seats and stops shall be made from 11-13 % chromium steel, unless otherwise approved by COMPANY. The maximum hardness for these components shall be 300 HV10 (30 HRC). The double tempering requirement after quenching (see Section 5.6.8 of this Specification) still applies.

5.8.5 Valves

Valves involving flexing plates are not normally permitted. Exceptions may be made as follows:

- As stated in Section 5.8.7 of this Specification.
- Where the valve plate stresses for the application proposed are low enough to render SSC unlikely.

★ In both cases, COMPANY approval shall be obtained.

5.8.6 Valve springs

Valve springs shall be in accordance with relevant Sections of the [ISO 15156](#). The design stress shall not exceed 276 MPa (40 ksi).

5.8.7 Alternative materials

★ 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 COMPANY approval.

5.9 Centrifugal compressors

5.9.1 General

Centrifugal compressors shall conform to [GS MEC 251](#) except as modified by this Specification.

5.9.2 Fabrication processes

★ Fabrication processes that result in cold-worked material, e.g. riveting of impellers, shall not be employed unless prior approval has been obtained from COMPANY.

5.9.3 Lubrication, shaft sealing and control oil systems

Lubrication, shaft sealing and control oil systems shall conform to [GS MEC 281](#) except as modified in this Specification.

5.9.4 Impellers

Materials for impellers shall be in conformance with the appropriate sections of [ISO 15156-2](#) and [ISO 15156-3](#).

Other materials such as Virgo 38 or 39 or equivalent may be proposed with a double temper heat treatment provided it is demonstrated that they are resistant to SCC under the actual service conditions.

5.9.5 Equipment

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 with regard to material selection and fabrication procedures.

5.10 Rotary-type positive displacement compressors

Rotary-type positive displacement compressors shall conform to COMPANY requirements [API Std 619](#) except as modified by this Specification.

5.11 Instrumentation

5.11.1 General

Instrument piping shall be in accordance with the associated process line specification.

5.11.2 Equipment

Bellows, diaphragms, Bourdon tubes, components which cannot be used in the softened condition and items which cannot be heat treated after welding, shall be fabricated from materials resistant to cracking in the hardened or non-heat-treated conditions as defined in the [ISO 15156](#). In particular, for diaphragm type differential pressure transmitter, the diaphragm may be of stainless steel grade 304L, 316L or 316Ti only if the welds can be heat treated by solution annealing. Similarly, they would not be acceptable if, during operation, the stresses are liable to cause plastic deformation.

5.11.3 Materials

- ★ Alloy 825 (UNS N 08825), alloy 625 (UNS N 06625), alloy 400 (UNS N 04400) and alloy B (UNS N 06004) have given satisfactory service in certain environments, and may be proposed for COMPANY approval. Alloy 904L or equivalent highly alloyed austenitic stainless steels may also be used in replacement of 3XX stainless steels. **All these materials must be in conformance with [ISO 15156-3](#).**

5.11.4 Fittings

- ★ Compression fittings in stainless steel grade 316L may be used. For relatively high temperature and high chloride service, COMPANY may require the use of more corrosion resistant alloys (refer to Sections 5.11.2 and 5.11.3 of this Specification).

5.12 Bolting

5.12.1 General

Bolting shall comply with [ISO 15156](#) requirements when in contact with any concentration of wet H₂S (see Section 5.1.12 of this Specification).

5.12.2 Materials

Ferritic steel bolts and nuts shall conform to Section A2.2.4 of the [ISO 15156-2](#). As an example, the following materials are acceptable:

Threaded rods

- [ASTM A 307](#), grade B, carbon steel with grain refinement or normalizing after manufacture if cold-formed. Maximum hardness 22 HRC
- [ASTM A 193](#) grade B7M and [ASTM A 320](#) grade L7M Cr Mo steel with maximum hardness 22 HRC.

Nuts

- [ASTM A 194](#) grade 2HM, carbon steel, maximum hardness 22 HRC
- [ASTM A 320](#) grade L7M maximum hardness 22 HRC.

Note: Since the mechanical properties of grades B7M and L7M are lower than those of grades B7 and L7, it will be necessary to reduce the pressure/temperature combination if these grades M are used.

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 outlines as follows:

- Bolts shall be Class 1A of [ASTM A 193](#) e.g. B8MA (type 316) solution treated after all cold work including thread forming)
- 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.

Resulphurized steels are not acceptable.

5.13 Bellows

5.13.1 General

Bellows shall comply with the [ISO 15156](#) requirements when in contact with any concentration of wet Hydrogen Sulphide (see Section 5.1.12 of this Specification).

5.13.2 Materials

Austenitic stainless steel shall not be used for bellows, beyond 50 % of their minimum specified yield strength otherwise 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 COMPANY approval.

The production procedure shall comply with the requirements of [ISO 15156-3](#).

5.14 Springs and spring lock washers

5.14.1 Materials

Springs shall be made of a material resistant to environmental corrosion cracking in the presence of H₂S and shall comply with this Specification.

The materials may be selected from among alloy 625 (UNS N 06625), alloy 718 (UNS N 07718), alloy 825 (UNS N 08825), alloy 400 (UNS N 04400), alloy 17-4 PH (UNS S 17400), low alloy CrMo steel (steel 41XX and its modifications) (Section 5.1.9 of this Specification).

If large springs are used of which the cost of H₂S material is very high, materials non-resistant to H₂S may be used if suitably protected by metallic coating.

Although this coating prolongs the service life of the springs, it does not make them resistant to fracture. This must be taken into account when this type of spring is specified.

Special attention shall be paid to the application of the coating to the ends of the springs.

5.15 Metallic coating and surface treatment

5.15.1 Metallic overlay

Explosively clad, roll bonded or fusion-bonded corrosion resistant overlay such as austenitic or austenitic-ferritic stainless steel or nickel alloy are considered to be effective barriers to the H₂S environment. Where such overlays are employed the backing material need not conform to this

Specification. However, care must be taken to obtain a **100% coverage** by the metallic cladding or overlay and to **avoid any contact between the base metal and the H₂S environment**.

5.15.2 Metallic coatings

Electroless deposited nickel/phosphorus or electroless deposited nickel/phosphorus alloy for the first plating, followed by electrodeposited chromium plating can be used. The procedures are subject to COMPANY approval. However, these coatings are not acceptable for preventing sulphide stress cracking as mentioned in [ISO 15156-2](#) (see A.2.1.5).

Cadmium plating and galvanising are prohibited, because these metals corrode rapidly in contact with H₂S.

5.15.3 Other surface treatments

Chromizing, chromating, nitriding or liquid or gas phase carbonitriding are not acceptable for the prevention of sulphide stress cracking in the presence of H₂S.

5.16 Low temperature plant

- ★ The use of carbon or low-alloy ferritic steel and weld metals containing more than 1% nickel are not permitted for Intermediate and Severe Sour Service conditions (Regions 2 and 3). However, where low temperatures are encountered, such steels and weld metals may be used subject to COMPANY 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 regarded during start up and shutdown if sour gas and water are present at ambient temperature.

5.17 Sour service with alkalis/amines

For sour service in association with alkalis, amines or other alkaline process fluids, for instance amine units, [API RP 945](#) and COMPANY requirements shall be the systematic post weld heat treatment of welds with the exception of low pressure storage tanks.

6. Fabrication and repair welding

The requirements and precautions to be taken are given in COMPANY General Specifications PLR for pipelines and PVV for pipework components.

6.1 General

In addition to the general and detailed requirements given in the above general specifications, the MANUFACTURER shall comply with the following:

- Design and/or fabrication rules described in the regulations in force and the construction code adopted
- The maximum service or hydrostatic test stresses (including re-testing) limited to 80% of the minimum specified yield stress, for equipment corresponding to severe sour service conditions
- Limitation to the strict minimum of the number of taps and nozzles on pressure vessels.

The welding of temporary parts shall be limited to the minimum. No arc striking shall be accepted outside the bevel. Welds of temporary parts and accidental arc striking shall be ground. The ground zone shall be subject to magnetic particle or dye penetrant examination.

7. Identification, stamping, marking

7.1 H₂S Marking

- ★ For pipework and other topside process components, identifications are given in **GS PVV 612**, **GS PVV 613** and **GS PVV 622**. For other components, the identification will be performed with COMPANY approval.

7.2 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 Regions.

7.3 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 COMPANY, 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.

8. Inspection

In addition to normal inspection, the following shall apply:

8.1 General

- ★ 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 **EN 10204 3.1 B** or **EN 10204 3.1 C** as specified, or the SUPPLIER may submit alternative proposals for approval by COMPANY.

8.2 Hardness checking

- ★ 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. Additionally, COMPANY inspectors may carry out random hardness checks. Where hardness values in excess of the requirements of this Specification and the **ISO 15156** are obtained the part shall be rejected. This requirement does not apply to austenitic alloys supplied in the solution annealed condition.

8.3 Hardness checking on small items

- ★ 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 stored batches to ensure that the product complies fully with this Specification. Procedures for doing this shall be subject to approval by COMPANY. This requirement does not apply to austenitic alloys supplied in the solution annealed condition.



8.4 Hardness checking on welds

For welded components, hardness measurements can only realistically be taken in weld metal and parent material. Acceptability of heat affected zone hardness shall be based on HV measurements, on (i) welding procedure qualifications tests and (ii) production test plates, when these are required by the fabrication specifications.

8.5 Corrosion resistant alloys

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.

Appendix 1 Definitions and abbreviations

Standardised definitions

- API American Petroleum Institute
- ASTM American Society for Testing and Materials
- BS British Standard
- CE Carbon Equivalent
- DIN Deutsche Institute für Normung
- EFC European Federation of Corrosion
- HIC Hydrogen Induced Cracking
- HRC Rockwell Hardness Scale C
- HV Vickers Hardness
- NACE National Association of Corrosion Engineers
- PWHT Post Weld Heat Treatment
- SOHIC Stress Orientated Hydrogen Induced Cracking
- SSC Sulphide Stress Cracking
- SCC Stress Corrosion Cracking
- SWC StepWise Cracking
- TMCP Thermo-Mechanical Controlled Processing

Appendix 2 Forms of Hydrogen Induced Cracking

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.

SWC

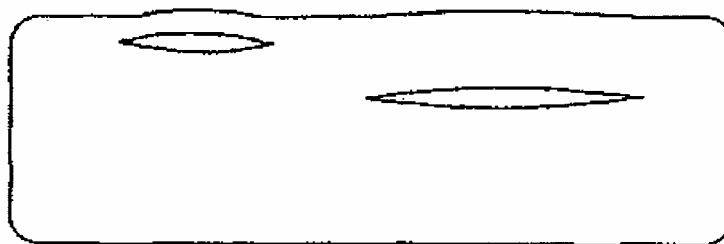
This is formed in steels by the propagation and linking up of small and moderate sized laminar cracks in a step-like manner. As more hydrogen diffuses into the steel, the areas around the area around these laminar cracks become highly strained and this can cause linking of the adjacent cracks to form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

SOHIC (Stress Orientated HIC)

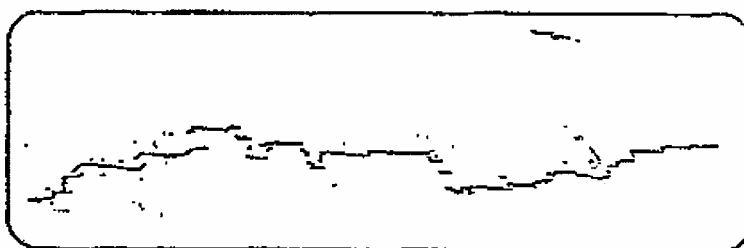
In some cases, when metal is subject to stress, small laminar HIC cracks become lined up in the through-thickness direction and step cracks form between them primarily parallel to the loading direction hence the occurrence of SOHIC. Formation of this type of damage is linked to particular locations which 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 SWC and SSC. New generations of linepipe steel are becoming available offering superior metallurgy with improved strength. These materials, reported to be resistant to either SWC 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 SWC, but adequate to cause combination of SWC/SSC in the presence of external stress, hence the occurrence of SOHIC.

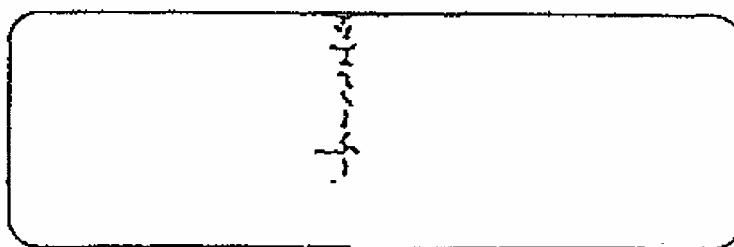
- ★ In cases where Hydrogen Blistering, SWC or SOHIC may occur, COMPANY may specify steel with increased resistance to these cracking mechanisms. Alternatively, carbon steel internally clad with stainless steel may be specified.



Blistering



Stepwise Cracking (SWC)



Stress Orientated Hydrogen Induced Cracking (SOHIC)

Figure A2.1 - Schematic Illustrations of associated failure morphologies

Appendix 3 Examples of how to use the pH versus PH₂S Diagram

The main interest of the present approach is to take into consideration the real nature and effect of the corrosive medium. The difficulty is to know these for certain, and in advance. Consequently, as soon as there is a doubt, the worst case must be considered, in the form of the pH of condensed water.

This is especially true in the presence of a gas phase. Depending on the flow pattern, the wall wetting water may be stratified water, a spray or condensing water, whose composition may differ considerably. Even the pH of condensing water does depend on the condensing rate, and the corresponding possibility of buffering by its saturation in corrosion products. Most often such situations can only be sorted out by a corrosion specialist, when it is justified by economic status.

A.3.1 Example 1: Case of a pressure vessel with a gas cap

Let us examine the case of a two-phase separator:

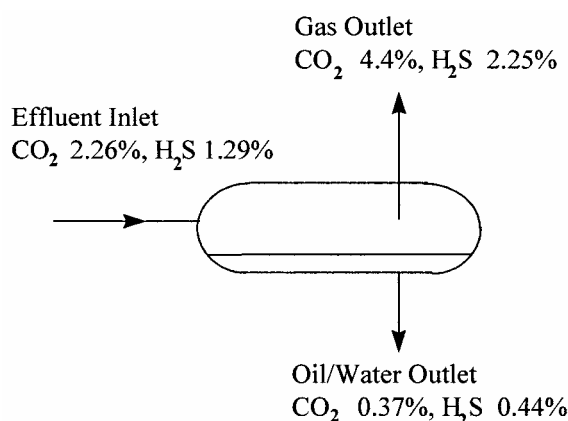


Figure A3.1 - Pressure vessel with a gas cap

- Minimum operating (absolute) pressure: 6 bar absolute
- Maximum operating (absolute) pressure: 7 bar absolute
- Design (absolute) pressure service: 70 bar absolute (exceptional service)
- Minimum operating temperature: 35°C
- Maximum operating temperature: 40°C
- Design temperature: 55°C

Step 1: Determination of pH

In this case, two different aqueous phases are present, the sedimented water and the condensing water.

The lowest possible pH is then short of the condensed water, and it will be determined from Figure 3.

Step 2: Data required

- Maximum operating (absolute) pressure: 7 bar absolute
- Minimum operating temperature: 35°C
- H₂S Content (worst case): 2.25 mol %
- CO₂ content (worst case): 4.4. mol %

Step 3: The calculation of the H₂S and CO₂ (absolute) partial pressures gives

- $P_{H_2S} = \frac{7 \times 2.25}{100} = 0.158 \text{ bar}$
- $P_{CO_2} = \frac{7 \times 4.4}{100} = 0.308 \text{ bar}$
- $P_{H_2S} + P_{CO_2} = 0.466 \text{ bar}$

Step 4: Figure 3 gives a pH of 4.1 at 35°C

Step 5: Determination of severity Level

A reading of the diagram Figure 1 with $P_{H_2S} = 0.158$ and pH 4.1 gives a point located in Region 3 corresponding to Severe Sour Service.

The requirements of this Specification corresponding to Region 3 must therefore be applied.

A.3.2 Example 2: Case of a liquid line transporting oil and formation water

Let us consider the line downstream the separator of Example 1.

The partial pressures of CO₂ and H₂S, in equilibrium with those of the separated gas, are the same as those calculated before i.e. $P_{CO_2} + P_{H_2S} = 0.466 \text{ bar}$.

However, the in-situ pH may be somewhat higher than previously determined. This will depend on the composition of formation water. At this stage, precipitation of CaCO₃ has already occurred upstream and water is no longer saturated (Figure 3).

Additional data required:

- Bicarbonate content of water = 400 mg/l

Since the molar weight of HCO₃ is 59 g and its valency one, this makes:

- $\frac{400 \times 1}{59} = 6.8 \text{ meq/L}$

Since $\log 6.8 = 0.83$, the in-situ pH is close to the line of Figure 3 for 10 meq/l, and at 17% of the distance to the line for 1 meq/l. For 0.466 bar, this gives pH = ~ 5.8.

A reading of the diagram of Figure 1 with $P_{H_2S} = 0.158$ and pH = 5.8 gives a point located in Region 1. Then much lower precautions must be taken for the liquid line downstream of the separator than for the separator itself.

In case of doubts (e.g. representative point close to the lower limit of a Region, a more detailed water analysis should be requested, including the content in acetates or other salts of fatty acids (see [EFC Publication No. 17](#)). Nevertheless, it is always possible to take the Region below that limit as a worst case of the upper one.

A.3.3 Example 3: Example of a pipeline

A.3.3.1 Unknown water

If the Gas Liquid Ratio (GLR) is large (e.g. transport of unprocessed fluid), it will be impossible to exclude a variable flow pattern. In this situation local break in the flow can lead to a strong condensing rate somewhere in the upper part of the linepipe. As for a pressure vessel, the worst case is, therefore, the pH of condensed water, according to Figure 2 or to any other calculation method. The maximum P_{CO_2} and P_{H_2S} to be considered are those at the inlet, and at the beginning of production where some pressure decline is expected.

A.3.3.2 Known water

If the GLR is non existent (e.g. separate transport of gas and liquids after raw separation) then water composition remains similar to that of the separator, i.e. for an oilfield formation water pH is then given by Figure 3 or any suitable calculation method. The P_{CO_2} and P_{H_2S} are those in this separation and they usually remain constant, even in case of pressure decline.

For the same P_{CO_2} and P_{H_2S} , the knowledge of water may relax the severity of the corrosive medium by up to one or two levels. Naturally if the composition of formation is not known, or not assured, then A.3.3.2 will not differ from A.3.3.1.

Appendix 4 HIC testing for qualification in intermediate and severe sour service

The principle of this method is to use much larger samples than the usual **NACE Standard TM0284** test method, much longer time of exposure, and to get an ultrasonic map of the defects produced by the selected test solution.

The advantage of this method is that it is much more sensitive and more discriminating because of the extent of the tested area and the long time involved. HIC is a slow process and it may take a long time before cracking takes place. In addition, the threshold CER of 3% has been shown to discriminate good materials (with a CER always close to 0%) and poor materials (with a CER always way above 3%).

A.4.1. Exposure

A test piece according to Figure A4.1 is placed in a large corrosion test rig (e.g. Figure A4.2) **for one month**. After exposure, the extension of cracking is determined by ultrasonic inspection.

A.4.2. Ultrasonic inspection

The principle of the method is based on the measurement of the attenuation of an ultrasonic beam normal to the surface, when it intercepts a crack (Figure A4.3).

The inspection can be carried out with automatic devices, or manually. An example of experimental rig is shown in Figure A4.4.

The immersion coupling process is used. The piece move under the transducer by means of two carriages with perpendicular movements by micrometer screws. The scan increment is 5 mm.

The sensor used is a transducer 11 mm in diameter, 5 MHz, with a beam diameter between 3 and 6 mm for the plates inspected.

The initial setting of the instrument is carried out with a specimen taken from the same tube as the tested sample, or more simply, whenever possible, from a crack-free zone of the sample, using an attenuation threshold of 6 dB on the background echo.

The test is taken from the middle of the sample, with its dimensions being smaller than the sample itself to eliminate edge effect. This zone shall measure at least 50 x 100 mm.

Maps such as the one in Figure A4.5 are obtained. The **Crack Extension Ratio** is the ratio of the cumulative length of the cracks to the total scan length:

$$\text{CER \%} = \Sigma \frac{\text{segments with cracks}}{\text{total scan length}} \times 100$$

A.4.3. Metallographic inspection

This inspection is intended to determine the complete characteristics of the cracks previously detected (morphology, surrounding metallographic structure). At least one micrographic section is made in the thickness, in the zones exhibiting the largest number of cracks detected by prior ultrasonic inspection.

A.4.4. HIC/SWC acceptance criteria

HIC acceptance criteria are summarised in Table 1.

Table 1 - SWC acceptance criteria

Domain	CLR(%)	CTR(%)	CSR (%)	CER(%)	Additional Requirement
Region 3 Region 2	≤ 10	≤ 3	≤ 1.0	≤ 3	No individual crack length > 5 mm if the lowest pH < 4.5 and, No individual crack if pH > 4.5
Regions 0 and 1	-	-	-	-	-

Note: No CER is required for Production Assessment Test During Manufacturing.

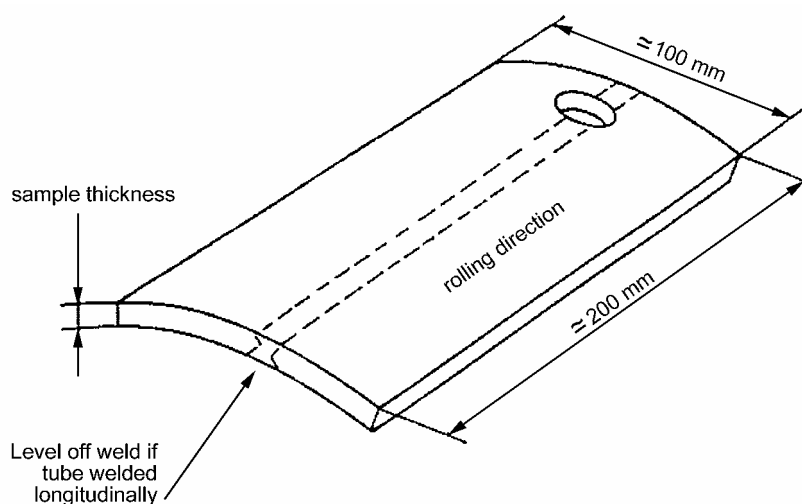


Figure A4.1 - Test sample

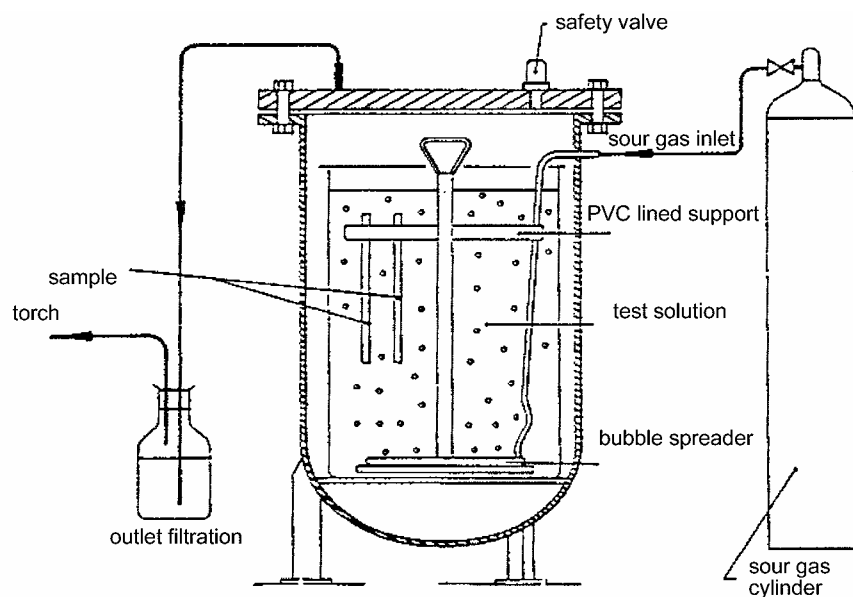


Figure A4.2 – Corrosion test rig

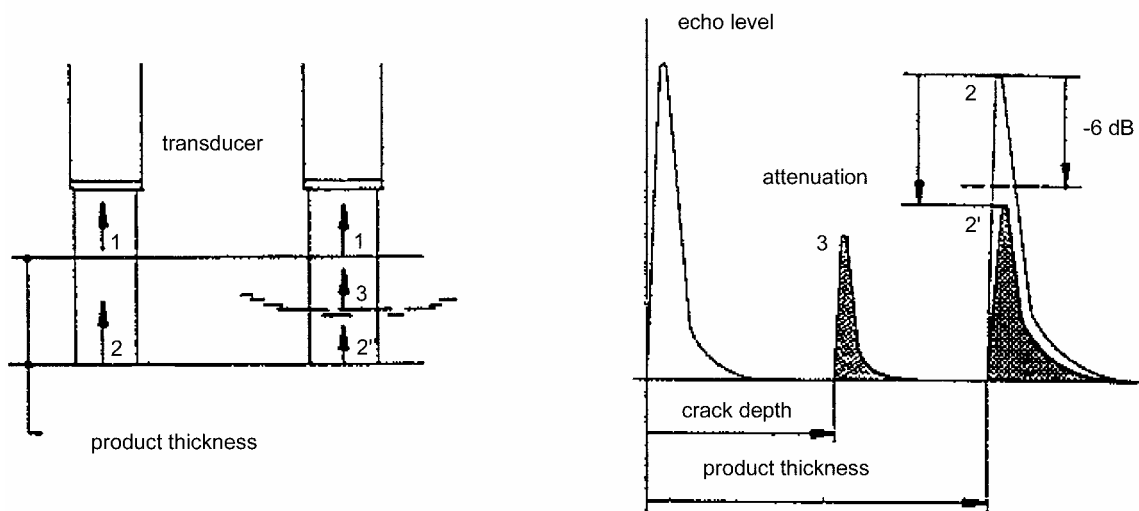


Figure A4.3 - Ultrasonic Inspection Method

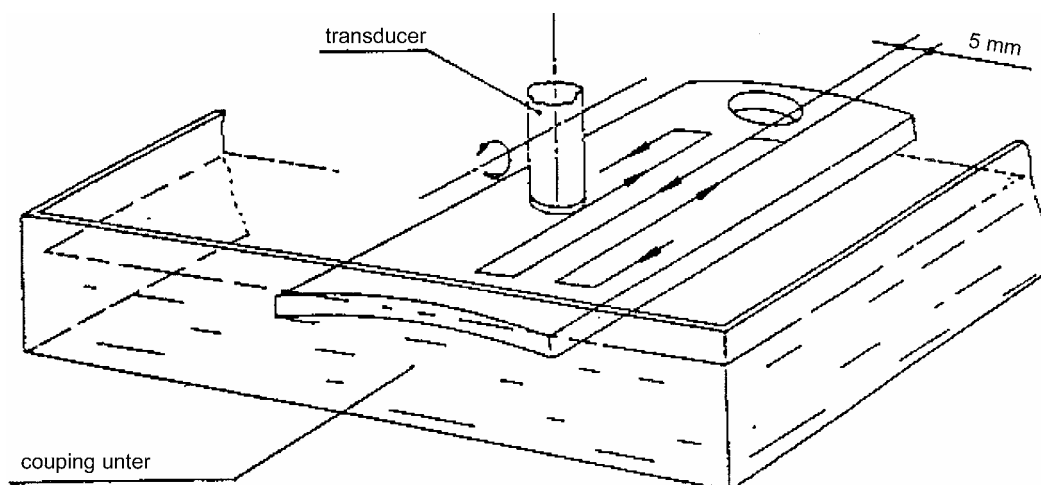


Figure A4.4 - Experimental Rig

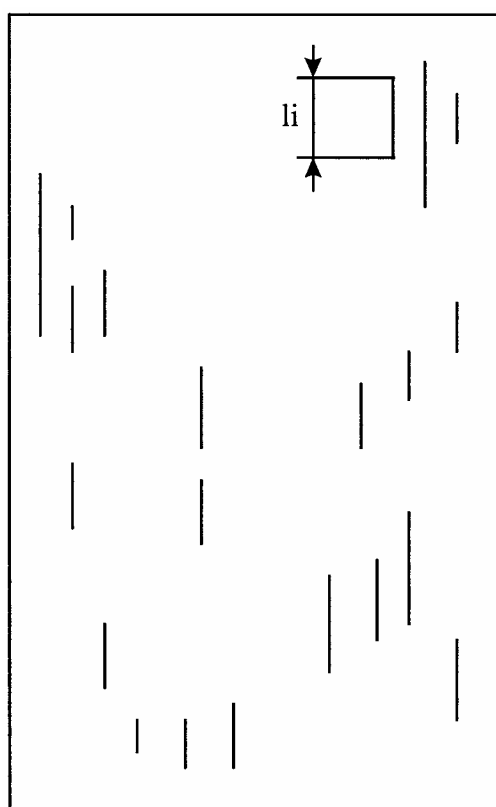


Figure A4.5 - Definition of the Crack Extension Ratio (CER)

$$\text{CER \%} = \Sigma \frac{\text{segments with cracks}(li)}{\text{total scan length}} \times 100$$