

GENERAL SPECIFICATION

CORROSION

GS EP COR 170

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

08	10/2012	Modifications of various sections
07	01/2011	Reference document revised and limitations for the use of 17-4PH revised
06	10/2008	Modification of § 5.2 Testing requirements and categories
05	10/2006	Modifications of HIC testing requirements. Addition of testing for flexible wires
00	03/2001	First issue
Rev.	Date	Purpose of the revision

Owning entity: DEV/TEC

Managing entity: DEV/TEC/COR

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 2 of 39

Contents

1. Scope	4
2. Reference documents.....	4
3. General.....	6
3.1 Application	6
3.2 Other types of corrosion.....	7
3.3 Requirements	7
3.4 Materials concerned.....	7
3.5 Upgrading of equipment.....	7
3.6 General HIC requirement	7
4. Use of Carbon and Low Alloy Steels in the presence of wet H₂S	8
4.1 Definition of service conditions	8
4.2 Domains of sour service.....	8
4.3 Use of the diagram.....	11
5. Corrosion resistant alloys	11
6. Materials for sour service.....	11
6.1 General requirements	12
6.2 Testing requirements and categories	15
6.3 Downhole tubulars	18
6.4 Transmission pipelines.....	18
6.5 Flexible lines	18
6.6 Pressure vessels, heat exchangers, and process pipework	18
6.7 Rotating machinery	19
6.8 Centrifugal pumps.....	20
6.9 Reciprocating compressors.....	21
6.10 Centrifugal compressors	22
6.11 Rotary-type positive displacement compressors	22
6.12 Instrumentation	22
6.13 Bolting.....	23
6.14 Bellows	24

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 3 of 39

6.15	Springs and spring lock washers.....	24
6.16	Metallic coating and surface treatment.....	25
6.17	Low temperature plant	25
6.18	Sour service with alkalis/amines	25
7.	Fabrication and repair welding	26
7.1	General.....	26
8.	Identification, stamping, marking	26
8.1	H ₂ S Marking	26
8.2	Hard stamps	26
8.3	Marking paints, crayons, etc.....	26
9.	Inspection	27
9.1	General.....	27
9.2	Hardness checking	27
9.3	Hardness checking on small items.....	27
9.4	Hardness checking on welds.....	27
9.5	Corrosion resistant alloys.....	27
	Bibliography.....	28
Appendix 1	Definitions and abbreviations.....	29
Appendix 2	Hydrogen-related cracking phenomena.....	30
Appendix 3	Forms of Hydrogen Induced Cracking	31
Appendix 4	Factors affecting the resistance of materials to cracking in H ₂ S containing environments.....	33
Appendix 5	Use of the pH-P _{H₂S} sour service diagram.....	34
Appendix 6	Examples of how to use the pH versus P _{H₂S} Diagram.....	37

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 encouraged to inform Company of their experiences in all aspects of its application.

Application

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 with the specific application.

Principal features of this General Specification

This General Specification Revision 8 reminds of some of the requirements of [ISO 15156](#). It also provides additional information and/or guidance to apply the ISO Standard. Note that [ISO 15156](#) is also called [NACE MR0175/ISO 15156](#) Standard. **As a consequence, in all other Company General Specifications, [ISO 15156](#) document automatically applies when reference is made to [NACE MR0175](#) Standard.**

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 its continuous improvement.

1. Scope

This Specification specifies Company general requirements on materials of construction for equipment handling fluids containing water and hydrogen sulfide in upstream conditions. It supplements or modifies [ISO 15156](#) International Standard. Note that Technical Corrigenda published between two publications of [ISO 15156](#) are part of the Standard. Other documents such as [EFC Publication No. 16](#) and [EFC Publication No. 17](#) and [NACE TM0177](#) and [NACE TM0284](#) Standards are also referenced in the present specification.

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the effective date of this document.

Reference	Title
API 5CT	Specification for Casing and Tubing
API RP 945	Avoiding Environmental Cracking in Amine Units
API STD 619	Rotary-Type Positive-Displacement Compressors for Petroleum, Petrochemical, and Natural Gas Industries
ASTM A 193	Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications
ASTM A 194	Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both
ASTM A 307	Standard Specification for Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength
ASTM A 320	Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service
ASTM A 370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A 439	Standard Specification for Austenitic Ductile Iron Castings
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
EN 10204	Metallic Products - Type of Inspection Documents
ISO 6892-1	Metallic Materials - Tensile testing - Part 1: Method of test (at ambient temperature)
ISO 15156 (Parts 1; 2; 3)	Petroleum and Gas Industries-Materials for Use in H ₂ S-containing environments in oil and gas production - Parts 1; 2; 3
NACE Standard TM0177	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H ₂ S Environments
NACE Standard TM0284	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 6 of 39

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published in the applicable yearly collection.

Reference	Title
GS EP MEC 251	Supply of Axial and Centrifugal Compressors and Expander-compressors for Petroleum, Chemical and Gas Industry Services according to API Standard 617
GS EP MEC 261	Packaged Reciprocating Compressors for Oil and Gas Production Services According to ISO 13631
GS EP MEC 271	Packaged Reciprocating Compressors for Oil and Gas Production Services According to ISO 13631
GS EP MEC 273	Supply of Centrifugal Pump class II according to ISO 5199
GS EP MEC 281	Lubrication, Shaft Sealing, and Oil Control Systems and Auxiliaries according to ISO 10438 / API Standard 614
GS EP PLR 109	Design, fabrication and testing of submarine unbonded flexible pipes and risers
GS EP PLR 211	Fabrication of seamless pipes for pipelines (mild, intermediate and severe sour service)
GS EP PLR 212	Fabrication of longitudinally submerged arc welded pipes for pipelines (mild, intermediate and severe sour service)
GS EP PVV 612	Piping and equipment subject to severe sour service. Metallurgical and welding requirements
GS EP PVV 613	Valves materials requirements for use in sour service
GS EP PVV 622	Piping and equipment subject to intermediate sour service. Metallurgical and welding requirements

Note: In the listed Company General Specifications when [NACE MR0175](#) Standard is referenced, [ISO 15156](#) Standard automatically applies.

3. General

3.1 Application

All installations for fluid containing hydrogen sulfide 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 7 of 39

3.2 Other types of corrosion

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 in the presence of H₂S. 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.

3.3 Requirements

This Specification defines the requirements for new sour service conditions equipment for oil and gas fields, transmission lines and oil 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.

According to [ISO 15156](#) a material can be qualified if one of the three following options is fulfilled:

- The material is listed in the Standard and fulfills the metallurgical requirements of the Standard and it is used within the limits stated by the Standard,
- The material passed the appropriate sour service test under the worst case field conditions,
- The material shall be used under the same conditions for which positive experience was acquired for 2 years as long as these conditions are documented.

3.4 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.

3.5 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.

3.6 General HIC requirement

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

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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 8 of 39

4. Use of Carbon and Low Alloy Steels in the presence of wet H₂S

4.1 Definition of service conditions

The guidance is based on severity of corrosive medium as characterized 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 H₂S 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 H₂S 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.

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 behavior 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 characterizes 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 H₂S partial pressure.

4.2.3 Domains of sour service

Domains of sour service are defined in Figure 1, showing four Regions characterizing 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 except for very high strength steels

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.

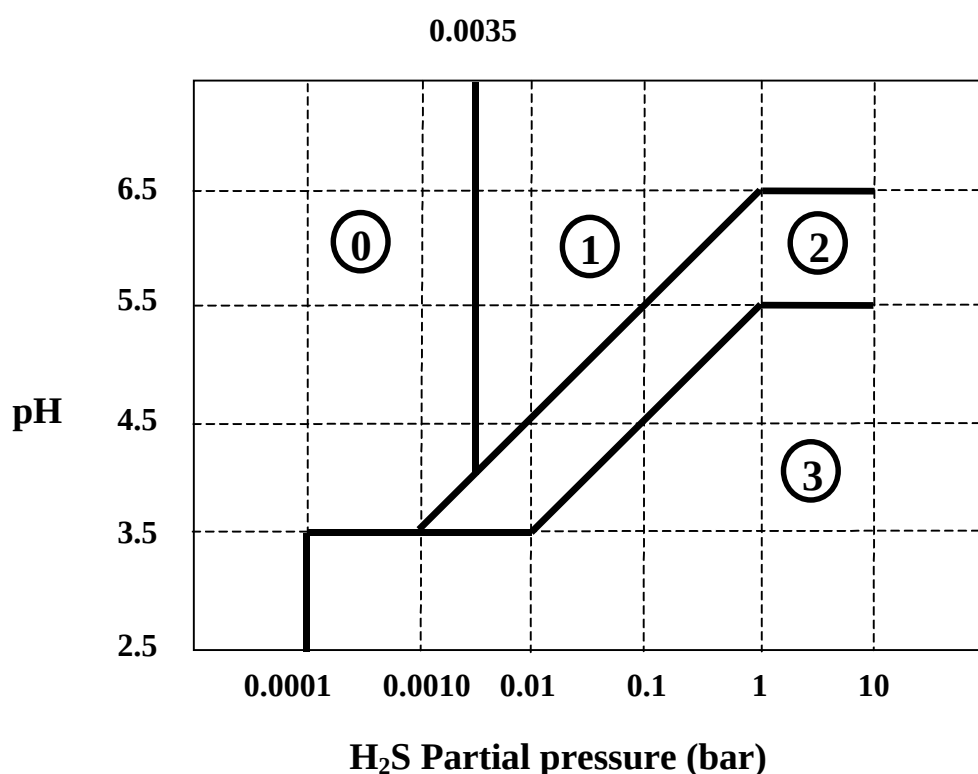
Region 2: "Intermediate Sour Service" The domain within which increasing precautions are required. An example of materials, which can be used within Region 2, includes carbon and low

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 H_2S partial pressure**
- The small triangular region above pH 3.5 and below 3.5 mbar of H_2S remains in the intermediate "sour service" region (Region 2) until precise data are available.

Note that, in practice, if P_{H_2S} is < 0.1 mbar or below the detection limit regardless of pH, the conditions are considered sweet or in Region 0. Between 1 and 0.1 mbar H_2S below pH 3.5 the SSC severity decreases as the P_{H_2S} decreases.

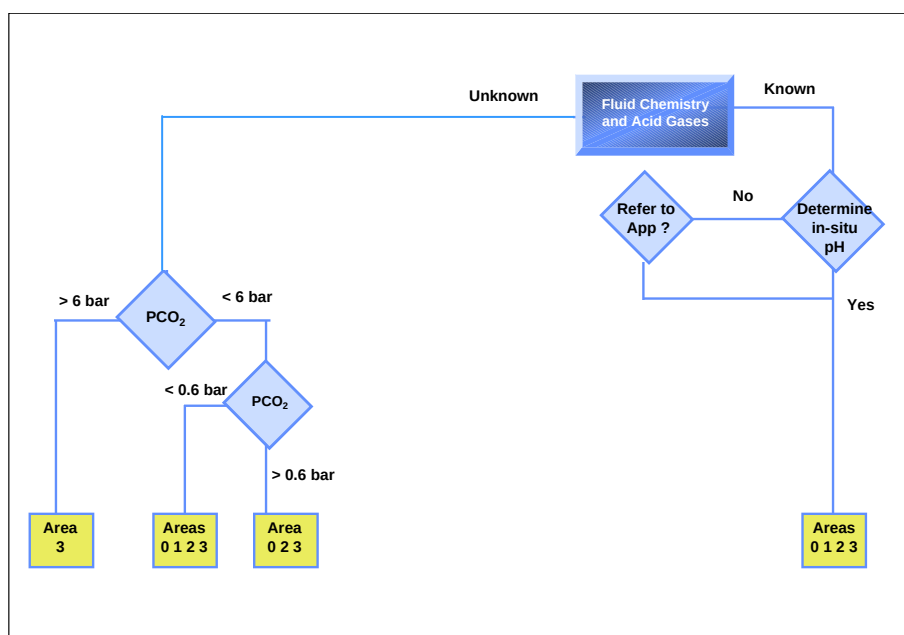
4.2.4 Characterization of materials

Except for the very high strength steels 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 in Region 3 according to the procedures defined in this Specification can be used in Regions 1, 2 and 3.

4.2.4.1 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 2 - A decision tree defining domains of sour service for carbon and low alloy steels



4.2.4.2 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 11 of 39

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

4.3 Use of the diagram

Whatever the application, the procedure to use the diagram shall be 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 A5.1 and A5.2 of Appendix 5 or Corplus Software) 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 4.

5. Corrosion resistant alloys

The SSC severity diagram does not apply to CRAs. The worst case service conditions shall be assessed in order to identify which CRAs can be used. This means that the selected CRA shall be used within its limits for each specific component in contact with the H₂S containing fluid.

The use of CRAs shall be in accordance with [ISO 15156-3](#). The limits given in [ISO 15156-3](#) may be extended in some cases according to recommendations by Company HQ corrosion specialist.

6. 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 12 of 39

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 untempered martensite.

6.1 General requirements

6.1.1 Materials selection

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

- Requirements arising from Section 6.1 of this Specification
- Resistance to general corrosion
- Mechanical properties, including low temperature toughness requirements where necessary, shall be given specific attention.

6.1.2 Carbon and low alloy steels for sweet service conditions

No specific requirements in Region 0 except for very high strength steels.

6.1.3 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.

6.1.4 Carbon and low alloy steels 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.

6.1.5 Carbon and low alloy steels for severe sour service conditions

Materials for the "Severe Sour Service" conditions (Region 3) shall be selected from those permitted in [ISO 15156-2](#).

6.1.6 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)

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 13 of 39

- Austenitic and duplex stainless steel: Solution Anneal
- Austenitic nodular cast iron: welding is not permitted.

6.1.7 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.

Armor steels used in flexible pipelines are very limited in terms of resistance to sour service. The selection of these wires must be documented by specific test results related to the particular worst service conditions (see Section 6.5).

For other applications, guidelines of [ISO 15156-2](#) will be used. Annex A will be used for carbon, low alloy steels and cast iron and Annex B for their qualification.

6.1.8 Weld repair of steel plate

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

6.1.9 Copper and nickel copper alloys

Copper and its alloys are prohibited because of their poor resistance to general corrosion and mechanical strength. Precipitation hardened copper alloys shall not be used in H₂S containing environments because of the risk of SCC/SSC. Alloy 400 (UNS N04400) which is a 70%Ni-30%Cu is acceptable according to Table A.13 of the [ISO 15156-3](#). However, this alloy is prohibited in equipment intended for critical parts whose failure would jeopardize 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.**

6.1.10 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. However, for some applications such as compressors, the use of this type of material can be considered subject to the type/level of mechanical loading in service (see Section A.2.4 of [ISO 15156-2](#)). Its use shall be subject to Company approval.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 14 of 39

6.1.11 Stainless steels

Stainless steels can be used for some parts of equipment. If so, the following requirements and restrictions shall be applied:

- **13% Cr martensitic stainless steels** shall be heat-treated and have a hardness complying with [ISO 15156-3](#), Annex A.6. It is important to state that their resistance to SSC depends not only on pH and pH₂S but also on chloride concentration. This latter parameter is not clearly recognized in [ISO 15156](#) yet.
- **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% of the actual material yield strength or the service temperature of the material is above 80°C **at all times**. 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 according to [ISO 15156-3](#) will be required with an appropriate QA/QC procedure approved by Company.
- **Austenitic stainless steels**
 - Note that [ISO 15156-3](#) does not limit the temperature of use of 3xx stainless steels in sour service for low chloride environments (< 50 ppm). For higher chloride contents, in cases where significant benefits can be obtained, the acceptable limits of use of 3xx stainless steel and the suitability of alternative materials for specific applications shall be sought from Company.
 - The use of 316L material can be extended ahead of present [ISO 15156](#) limitations at least for the following applications:
 - . Wet gas process vessels, coolers and associated piping, **for chloride content < 100 ppm**, temperature below 100°C and H₂S partial pressure below 0.1 bar
 - . Amine units, as indicated in Section 6.17.
 - Austenitic stainless steels and austenitic-ferritic (duplex) stainless steels shall be in the solution annealed condition.
 - If welding and/or post-weld heat-treatment is required on austenitic stainless steels, only low carbon or titanium-stabilized stainless steels shall 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 solution annealed and quenched a second time if the permanent deformation exceeds 15%.

6.1.12 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 and SCC, proved on itemized drawings specific to the installation planned.

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

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 15 of 39

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 [ISO 15156](#), when in contact with any detected concentration of wet hydrogen sulphide.

6.1.13 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.

6.2 Testing requirements and categories

The cracking resistance at various levels of sour service is assessed as described below, 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.

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.

6.2.1 SSC Testing

Test procedure shall be in accordance with [NACE Standard TM0177](#) Method A or [EFC Publication No. 16](#) Method A unless otherwise specified.

6.2.1.1 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**.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 16 of 39

The test requirements are defined as follows:

- For **pipelines** qualification test requirements are defined in Company [GS EP PLR 211](#) and [GS EP PLR 212](#)
- For pressure vessels and piping, API well tubing and casing grades and other components if testing is requested by Company test conditions will be according to those defined below.

For general use, 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 [NACE Standard TM0177](#) solution A.

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](#):

- Samples 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 A 370 / ISO 6892-1](#).

For Regions 0 (sweet service) and 1 (mild sour service) of the diagram of Figure 1, no test is required unless the material is expected to be particularly susceptible.

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.

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.

6.2.1.2 Production assessment tests during manufacturing

For pipelines, Company [GS EP PLR 211](#) and [GS EP PLR 212](#) shall be used.

For other components when SSC tests are requested on production materials they shall be in accordance with the requirements of Sections 6.2.1 and 6.2.1.1.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 17 of 39

6.2.2 HIC testing

6.2.2.1 Categories of testing

The proposed HIC test route includes two principal categories of testing as described in Section 6.2. Justification of the satisfactory behavior 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** and made according to the same production route.

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

- Tests shall be performed in triplicate for each steel and Supplier
- The samples shall be 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 sulfur
- Solution chemistry and conditions shall be in accordance with [NACE Standard TM0284](#) solution A.

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

No testing is required unless the material is expected to be particularly susceptible.

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

6.2.2.3.1 Qualification tests:

Justification of the satisfactory behavior 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**.

For Regions 2 and 3 of the diagram of Figure 1, tests shall be carried out in [NACE Standard TM0284](#) solution A.

The **acceptance criteria** shall be according to [NACE Standard TM0284](#):

- Crack Length Ratio (CLR): 15% maximum
- Crack Thickness Ratio (CTR): 3% maximum
- Crack Sensitivity Ratio (CSR): 1% maximum

and, no individual crack length of more than 5 mm.

These acceptance criteria shall apply on the average of the three sections of each specimen. Values will be reported for each cross section.

6.2.2.3.2 Production tests during manufacturing:

For pressure vessel plates, each heat or batch shall be tested unless otherwise specified. Specimen cutting, preparation and HIC testing shall be performed according to [NACE Standard TM0284](#).

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 18 of 39

The acceptance criteria shall be **CLR ≤ 15%, CTR ≤ 3%, CSR ≤ 1% and, no individual crack length of more than 5 mm. These acceptance criteria shall apply on the average of the three sections on each specimen.** Values will be reported for each individual cross section.

6.3 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 Q125 (with restrictions depending on actual yield strength)
- Region 1: up to API P110
- Region 2: up to API N80
- Region 3: up to API L80 or API C95.

Proprietary grades are usually accepted from the ranking of their SSC resistance with the above, (e.g. [API 5CT](#), C95 grades), or from direct **application specific testing as described in Section 6.2.1.1** (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.

6.4 Transmission pipelines

Pipelines and associated fittings shall be subject to the testing requirements of Company [GS EP PLR 211](#) and [GS EP PLR 212](#).

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

6.5 Flexible lines

Wires for flexibles lines are required to be sour resistant usually to mild environments in Region 0 or 1 of the diagram. Specific testing for resistance to SSC and HIC is required under at least the worst expected service conditions of the field (see [GS EP PLR 109](#)).

Testing normally is carried out to simulate the worst case permeation of H₂S and CO₂ gases through the polymer annulus envelope at the expected iron saturated seawater pH in case of destruction of the outer sheath or in condensed water.

The Supplier shall qualify the wires under the expected worst sour service conditions in agreement with Company requirements. The test procedure shall be submitted to Company for prior approval.

6.6 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 EP PVV 612](#), [GS EP PVV 613](#) and [GS EP PVV 622](#).

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 19 of 39

Testing if required by Company shall be performed as described in 6.2.1 for SSC testing and 6.2.2 for HIC testing.

6.7 Rotating machinery

6.7.1 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).

6.7.2 Materials

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

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

6.7.3 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.

6.7.4 Cast Iron

Cast iron or ferritic ductile (nodular) iron is unacceptable for pressure-retaining parts and for impellers etc. Austenitic cast iron is also unacceptable for pressure-retaining parts except as permitted by Section 6.8.2. 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.

6.7.5 Others components

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

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 20 of 39

6.7.6 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 minimize residual stresses, and shall have a hardness not exceeding 250 HV10 (HRC 22) 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 17-4 PH 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.

6.7.7 Metal overlays

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

6.7.8 Other equipment

All associated equipment e.g. pressure vessels, pipework, etc. shall comply with [GS EP PVV 612](#), [GS EP PVV 613](#) and [GS EP 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](#). Their limits of use will be in compliance with [ISO 15156](#).

6.8 Centrifugal pumps

6.8.1 General

Centrifugal pumps shall conform to [GS EP MEC 271](#) and [GS EP MEC 273](#) except as modified by this Specification.

6.8.2 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).

6.8.3 Shafts

Shafts in 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 and it must conform at least to the limits of [ISO 15156-3](#).

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 21 of 39

6.9 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.

6.9.1 General

Reciprocating compressors shall conform to [GS EP MEC 261](#) except as modified by this Specification.

6.9.2 Piston rods

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

The piston rods shall conform to 6.7.6 of this Specification. However, the rods may be hardened in the region of the packing by the surface induction hardening method.

6.9.3 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.

6.9.4 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 6.7.8 of this Specification) still applies.

6.9.5 Valves

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

- As stated in Section 6.9.7 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.

6.9.6 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).

6.9.7 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 22 of 39

6.10 Centrifugal compressors

6.10.1 General

Centrifugal compressors shall conform to [GS EP MEC 251](#) except as modified by this Specification. Both wet static pressurized and dynamic conditions (including normal service and upsets) shall be considered when choosing materials for centrifugal compressors.

6.10.2 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.

6.10.3 Lubrication, shaft sealing and control oil systems

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

6.10.4 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 (16Cr-4Ni) or 39 (16Cr-4Ni-1Mo) or equivalent may be proposed with the optimized double temper heat treatment provided it is demonstrated that they are resistant to SSC under the actual service conditions.

Appropriate upset (worst case) process conditions (chloride content, pH, pH₂S) shall be taken into account by the Supplier when choosing the material of the impellers, especially for the first impeller of each stage.

6.10.5 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.

6.11 Rotary-type positive displacement compressors

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

6.12 Instrumentation

6.12.1 General

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

6.12.2 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

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 23 of 39

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.

6.12.3 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. Actual sour limits of use of 3xx alloys can be extended above those of ISO 15156-3 if they are demonstrated by testing or documented 2 year experience.**

6.12.4 Fittings

Compression fittings in stainless steel grade 316L may be used according to ISO 15156-3 Table A.4. For relatively high temperature and high chloride service, Company may require the use of more corrosion resistant alloys (refer to Sections 6.12.2 and 6.12.3 of this Specification).

6.13 Bolting

6.13.1 General

Bolting shall comply with ISO 15156 requirements when in contact with any concentration of wet H₂S (see Section 6.1.12 of this Specification).

6.13.2 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 24 of 39

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.

Precipitation hardened copper alloys shall not be used for sour service bolts because of the risk of SCC.

6.14 Bellows

6.14.1 General

Bellows shall comply with the [ISO 15156](#) requirements when in contact with any concentration of wet Hydrogen Sulphide (see Section 6.1.12 of this Specification).

6.14.2 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](#).

6.15 Springs and spring lock washers

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), low alloy CrMo steel (steel 41XX and its modifications) but must comply to [ISO 15156-3](#) unless agreed by Company.

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 at the ends of the springs.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 25 of 39

6.16 Metallic coating and surface treatment

6.16.1 Metallic overlay

Explosively clad, roll bonded or fusion-bonded corrosion resistant overlay such as austenitic 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 **100% coverage** by the metallic cladding or overlay and to **avoid any contact between the base metal and the H₂S environment**.

Note that the method for weld overlay qualification is included in [ISO 15156-2](#).

6.16.2 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 galvanizing are prohibited, because these metals corrode rapidly in contact with H₂S.

6.16.3 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.

6.17 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.

6.18 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.

In amine units, 316L stainless steel can be used up to 30%mol CO₂ + H₂S in the treated gas and an amine loading up to 0.9 Mol acid gas per Mol of amine for the following components:

- Internals/packings and cladding in absorber and regenerator columns
- Piping of the rich amine section
- Tubes for the amine heat exchanger
- Heating coil of amine reboiler

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 26 of 39

- Reflux cooler
- Scrubber and associated piping downstream the regeneration process.

The use of 316L material is only acceptable for a maximum chloride content of 500 ppm in the amine.

7. 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.

7.1 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.

8. Identification, stamping, marking

8.1 H₂S Marking

For pipework and other topside process components, identifications are given in [GS EP PVV 612](#), [GS EP PVV 613](#) and [GS EP PVV 622](#). For other components, the identification will be performed with Company approval.

8.2 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.

8.3 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.

9. Inspection

In addition to normal inspection, the following shall apply:

9.1 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 2004 3.1](#) or [EN 10204 2004 3.2](#) as specified, or the Supplier may submit alternative proposals for approval by Company.

9.2 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.

9.3 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.

9.4 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.

9.5 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.



General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 28 of 39

Bibliography

GS EP PLR 231 - Induction bends for pipelines (Mild, Intermediate and Severe Sour Service)

GS EP PLR 232 - Carbon steel flanges and branch outlet fittings and forged components for pipelines (Mild, Intermediate and Severe Sour Service)

GS EP PLR 233 - Carbon steel tees for pipelines (Mild, Intermediate and Severe Sour Service)

GS EP PVV 171 - Steel piping fabrication

GS EP PVV 211 - Design and fabrication of pressure vessels according to ASME VIII

GS EP PVV 212 - Design and fabrication of pressure vessels according to BSI PD 5500

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 29 of 39

Appendix 1 Definitions and abbreviations

Standardized 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
- HQ Head quarters
- 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

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 30 of 39

Appendix 2 Hydrogen-related cracking phenomena

In-service cracking problems in upstream conditions arising from wet hydrogen sulphide (H_2S) 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 A3.1 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 H_2S 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 H_2S 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 31 of 39

Appendix 3 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.

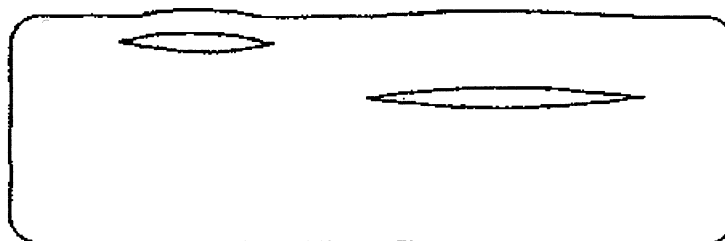
SWC

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.

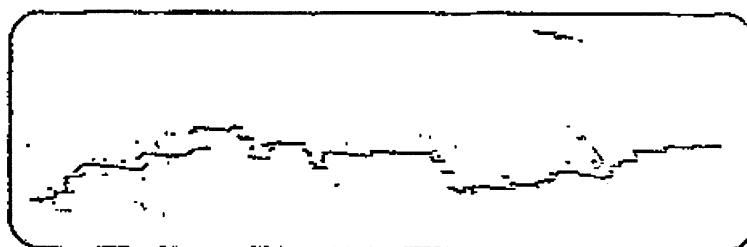
SOHIC (Stress Orientated HIC)

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.

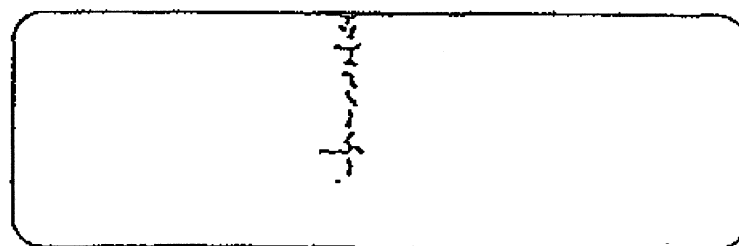
SOHIC is a phenomenon resulting from a combination of two independent forms of hydrogen damage SWC and SSC. New generations of linepipe steel are becoming available offering superior metallurgy with improved strength. These materials, reported to be resistant to either SWC or SSC, have been found to 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.

Figure A3.1 - Schematic Illustrations of associated failure morphologies


Blistering



Stepwise Cracking (SWC)



Stress Orientated Hydrogen Induced Cracking (SOHIC)

Appendix 4 Factors affecting the resistance of materials to cracking in H₂S containing environments

A4.1 Carbon and low alloy steels

1. Chemical composition (S, P, Mn, CE, minor elements)
2. Heat treatment
3. Strength
4. Hardness
5. Microstructure
6. Welding (HAZ hardness, welding factors including consumables, welding parameters)
7. Stress level

A4.2 Corrosion resistant alloys

1. Chemical composition
2. Heat treatment
3. Strength
4. Hardness
5. Microstructure
6. Welding

A4.3 Environmental factors

1. H₂S partial pressure
2. Temperature
3. Chloride content (particularly CRA)
4. Water
5. In situ pH
6. Presence of sulfur

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 34 of 39

Appendix 5 Use of the pH- P_{H_2S} sour service diagram

A.5.1. Characterization of the corrosive medium

A.5.1.1 H_2S partial pressure

Partial pressure of H_2S 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_{H_2S} means that any detectable trace of H_2S leads to the restriction of Region 3.

When no gas phase is locally present, P_{H_2S} 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.

A.5.1.2 In-situ pH

The in-situ pH depends on the partial pressures of both CO_2 and H_2S and alkalinity of the water, represented by the sum of the bicarbonate (HCO_3^-) 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 (Figures A5.1 and A5.2 issued from Appendix No. 1 in [EFC Publication No. 16](#) and Annex D in [ISO 15156-2](#) Standard)

For example, Figures A5.1 and A5.2 can be used to determine the value of the pH when H_2S and CO_2 partial pressures are known, as well as the alkalinity (or "bicarbonate") content of the produced water. When available, more accurate determination through computer Softwares are recommended (i.e. CORPLUS). **In case of doubt or lack of information on the associated water chemistry, condensed water shall be taken as the safe worst case scenario.**

In the case of export dehydrated pipelines, because of the small amount of water, the pH of iron saturated condensed water shall be used.

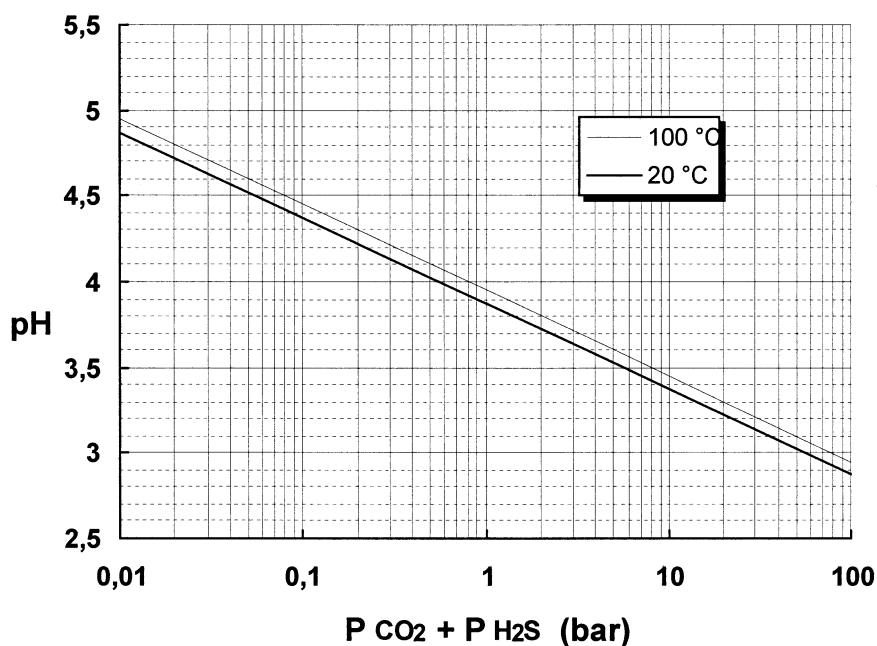
A.5.1.3 The use of a domain diagram

Domains of sour service cannot be defined without information on the partial pressure of CO_2 . For example, when $P_{CO_2} > 6$ 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 $P_{CO_2} < 0.6$ 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.

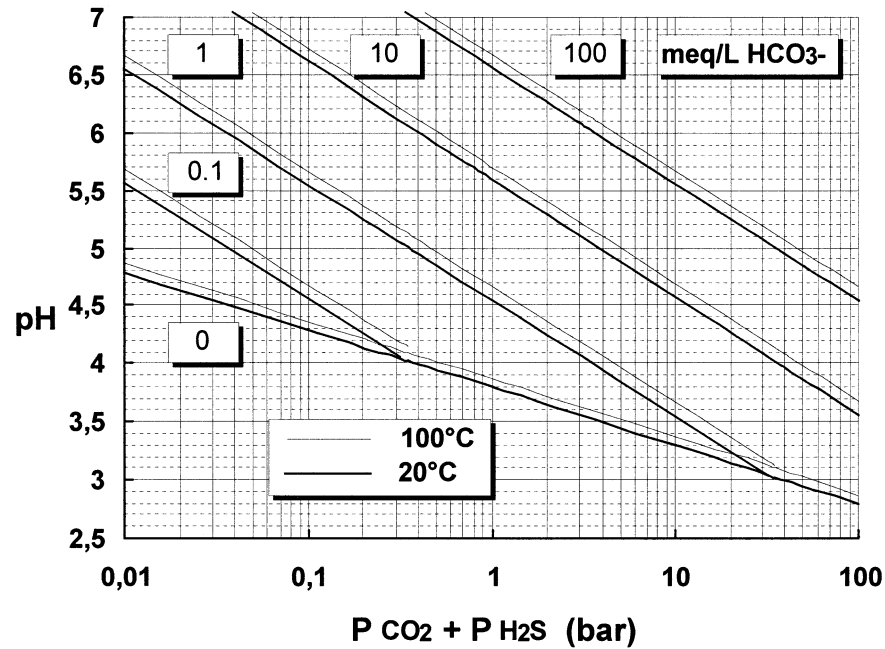
In summary, a safe and simplified decision tree defining domains of sour service is presented in Figure and is as follows:

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

Figure A.5.1 - pH of condensed water under CO_2 and H_2S pressure



Care must be taken that the analysis of water is restricted to dissolve 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 A5.2 - 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 37 of 39

Appendix 6 Examples of how to use the pH versus P_{H_2S} 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.

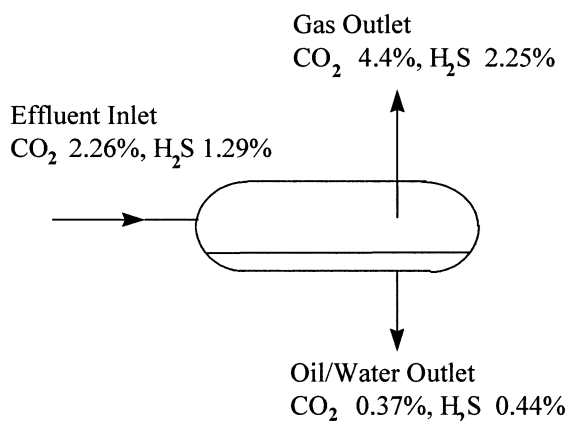
This is especially true in the presence of a gas phase. Depending on the flow pattern, the wall wetting water may be stratified water, a spray or condensing water, whose composition may differ considerably. Even the pH of condensing water does depend on the condensing rate, and the corresponding possibility 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.

For export pipelines, where the gas is dehydrated it is considered that the pH of condensed water is buffered by dissolved iron. Hence, the severity area of the H_2S environment is determined using the pH buffered by corrosion products.

A.6.1 Example 1: Case of a pressure vessel with a gas cap

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

Figure A6.1 - 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.

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 38 of 39

The lowest possible pH is then short of the condensed water, and it will be determined from Figure A.5.1.

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 A.5.1 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.6.2 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 A.5.2).

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 A.5.2 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

General Specification		GS EP COR 170
Materials for sour service (upstream applications) Specification for design		
Rev.: 08	Effective date: 10/2012	Page: 39 of 39

(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.6.3 Example 3: Example of a pipeline

A.6.3.1 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 A.5.1 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.6.3.2 Known water

If the GLR is nonexistent (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 A.5.2 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.