PTT Exploration and Production Public Company Limited

PTTEP Engineering General Specification

(Engineering and Development Group)

Standard

Material for Sour Service

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Revision History

Rev	Description of Revision	Date
Old	Material for Sour Service Refer: PEGS-12059-COR-032	17-Oct-16
R00	Revision note : New document code and formatting ***Item No./Clause*** ***Description of Change*** All Update document number and format align to PTTEP library standard	19-Oct-17

TABLE OF CONTENTS

1.0 INTRODUCTION

PEGS (PTTEP Engineering General Specification) is the PTT Exploration and Production PCL internal publishes standard. The objective of PEGS is to promote the best practices collecting from all PTTEP execution projects and to standardize those best practice to the future projects.

Every 5 years or upon request by the internal user, PEGS will be reviewed by related subject experts to reach decisions/agreements, then the document will be updated and publish to PTTEP intranet website. This is to ensure that all lesson learns from users can be applied to the future projects as the benefit to PTTEP.

2.0 PURPOSE

Purpose of the document is to provide a good practice in term of protection of oil and gas production facilities against corrosion. It is to be used as general guidelines by corrosion and inspection engineers either for future or existing installations.

3.0 SCOPE

This specification shall be considered as a complement to the standard ISO 15156 providing additional information, clarification and guidance.

In this specification, references have been made to the 3 parts of ISO 15156. It is simplified as ISO 15156-1, ISO 15156-2 and ISO 15156-3 respectively

As a mandatory rule, all materials of construction for COMPANY Oil and Gas facilities in contact with fluid containing hydrogen sulphide and water (sour service) shall meet the requirements of the standard ISO 15156. This rule applies to subsurface and surface equipment including tubing, casing, process piping, pressure vessels, instrumentation and pipelines. The parts concerned are:

1) All wetted parts which are in direct contact with the H2S containing fluid.
2) 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.

It is to be noted that this specification does not cover services without H2S and it does not provide materials requirements resulting from other corrosion mechanisms.

When a material is selected for sour service according to the requirements of this specification, it is understood that the selected material is also sufficiently resistant to metal loss corrosion or pitting or erosion or cracking due to other parameters than H2S in the operating conditions. This aspect of resistance to the various corrosive factors shall be considered in Particular COMPANY Specifications or Project Specifications.

In all COMPANY General Specifications, ISO 15156 document automatically applies when reference is made to NACE MR 0175 Standard or NACE MR 0175 /ISO15156 standard.

4.0 RESPONSIBLE ACTION PARTIES

N/A

5.0 DEFINITIONS

A number of different terms are commonly used to describe the work stages, processes, and approvals which take place during the early stages of a development. This can often be a source of confusion so the following section is intended to show the PTTEP preferred terminology as used in this document.

5.1 LANGUAGE

In this document, the words should and shall have the following meanings:

Shall	Indicates a course of action with a mandatory status. The term "shall" shall be used if a requirement is considered to be necessary to claim compliance with a PEGS document.
Should	Indicates a preferred course of action. Should is a non-mandatory word and is not forbidden, but use in the body of the text should be the exception. Where none mandatory terms are used, each paragraph within these clauses shall also have an associated commentary paragraph that provides the rationale for why the stated choices and modifications are appropriate and circumstance under which the stated choices and modifications might be different.

5.2 TERMINOLOGY

Terminology	Description
Approval	The authorization in writing given by the COMPANY to the Contractor to proceed the work without releasing in any way the Contractor from any of his obligations to conform with the technical specifications, requisitions, etc. The words "Approve", "Approved" and "Approval" shall be construed accordingly
Company	PTT Exploration and Production Public Company Limited and affiliates.
Contract Documents	The material requisitions, material specifications, etc. Issued by the COMPANY and attached to the contract or the purchase order
Contractor	Per contract: Contractor – 'The contractor who is a PARTY to this CONTRACT and where the context so requires including, SUBCONTRACTORS utilized by CONTRACTOR for the performance of the WORK'
Inspector	The COMPANY's representatives or members from COMPANY elected inspection bodies for the time being or from time to time duly appointed in writing by the COMPANY to act as its representatives for the purpose of the contract shall be referred to herein as the inspector.
Manufacturer	The company or its sub-contractors selected by the COMPANY or the Contractor or the Supplier (as applicable) as the Manufacturer of the said material.
Purchase Order	The order issued by Purchaser consisting terms and Conditions and attachments thereto including but not limited to data sheets and drawings, specifications including referenced documentation therein, and all other documents and attachments
Purchaser	The COMPANY or the Contractor or the Supplier (as applicable) which have placed the Purchase Order to the Supplier/Vendor/Manufacturer.

Terminology	Description
Supplier/Vendor	The company designed on the Purchase Order form or Contract as being the selected supplier of the said materials.

5.3 COMMON ACRONYMS

Set out below in alphabetical order are common acronyms as found within this document:

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
CAR	Crack Area Ratio
CE	Carbon Equivalent
Pcm	Carbon Equivalent for Carbon Steel < 0.12 %
CLAS	Carbon and Low Alloy Steel
CLR	Crack Length Ratio
CRA	Corrosion Resistant Alloys
CSR	Crack Sensivity Ratio
CTR	Crack Thickness Ratio
DAC	Distance-Amplitude Correction
DIN	Deutsche Institute für Normung
EFC	European Federation of Corrosion
FSH	Full Screen Height
HIC	Hydrogen Induced Cracking
HRC	Rockwell Hardness Scale C
HV	Vickers Hardness
MPI	Magnetic Particle Inspection
NACE	National Association of Corrosion Engineers
PWHT	Post Weld Heat Treatment
SCC	Stress Corrosion Cracking
SOHIC	Stress Orientated Hydrogen Induced Cracking
SSC	Sulphide Stress Cracking
SWC	Step Wise Cracking
TCG	Time Correction Gain
TMCP	Thermo-Mechanical Controlled Processing
UT	Ultrasonic Testing
WT	Wall Thickness

Note: For the definitions of Sour Service, Sulphide Stress Cracking (SSC), Hydrogen Induced Cracking (HIC), Stress Oriented Hydrogen Induced Cracking (SOHIC) and Stress Corrosion Cracking, to refer to ISO 15156-1.

6.0 REFERENCES

The reference documents listed below, including Industry Codes and Standards and COMPANY specifications, form an integral part of this Engineering General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published on the effective date of a contract.

The overall order of precedence of the applicable documents shall be:

1. Applicable Laws, Rules and Regulations of the country in which the system/equipment will be operated (if any);
2. Purchase Order/ Service Order/ Contract Documents (Only applicable for direct purchase by COMPANY);
3. Project Particular Specification (PPS), and relevant data sheet(s) if any;
4. COMPANY General Specification;
5. Codes and Standards in reference.

Any conflict between any of the Contract Documents, or between this specification and any other Contract Documents, shall be reported to COMPANY for decision. In such a case, and unless otherwise agreed or decided by COMPANY, it is understood that the more stringent requirement shall apply.

Exceptions to, or deviations from this specification are not permitted unless previously accepted in writing by COMPANY. For this purpose, requests for substitutions or changes of any kind shall be completed with all pertinent information required for COMPANY assessment. COMPANY's approval, nevertheless, will not, in any way, relieve the responsibility of the Contractor to meet the requirements of the industry Codes and Standards referred to and amended herein, in the event of conflict.

6.1 PTTEP INTERNAL REFERENCES

Internal documents applicable to this document are indicated in the table below.

Document Number	Document Title
10008-STD-6-PIP-012, PEGS-12059-PIP-006	Valves
10008-STD-6-PIP-009, PEGS-12059-PIP-007	Piping Material Classes
10008-STD-6-PLR-011, PEGS-0710-PLR-003	Design, Materials and Fabrication of Carbon Steel Tees for Carbon Steel Pipelines (Mild, Intermediate and Severe Sour Service)
10008-STD-6-PLR-008, PEGS-12059-PLR-004	Induction Bends for Carbon Steel Pipelines (Mild, Intermediate and Severe Sour Service)
10008-STD-6-PLR-006, PEGS-12059-PLR-005	Longitudinally Submerged Arc Welded (LSAW) Pipes for Carbon Steel Pipelines (Mild , Intermediate and Severe Sour Service)
10008-STD-6-PLR-009, PEGS-0710-PLR-007	Design, Materials and Fabrication of Flanges and Branch Outlet Fittings for Carbon Steel Pipelines (Mild, Intermediate and Severe Sour Service)
10008-STD-6-PLR-012, PEGS-0710-PLR-008	Design, Materials and Fabrication of Pig Launchers and Receivers (Mild, Intermediate and Severe Sour Service)
10008-STD-6-PLR-025, PEGS-12059-PLR-012	Welding of Onshore and Offshore Carbon Steel Pipelines to API 1104 (Mild, Intermediate and Severe Sour Service)
10008-STD-6-PLR-005, PEGS-12059-PLR-017	Seamless Pipes for Carbon Steel Pipelines (Mild, Intermediate and Severe Sour Service)
10008-STD-6-COR-030, PEGS-12059-COR-030	Internal Corrosion and Erosion Control and Monitoring

6.2 INTERNATIONAL STANDARDS

International standards applicable to this document are indicated in the table below i.e. ISO, IEC or ITU.

Document Number	Document Title
EN 10028 Series	Flat Products Made of Steels for Pressure Purpose
EN 10204	Metallic Products - Type of Inspection Documents
EN 10160	Ultrasonic Testing of Steel Flat Product of Thickness Equal or Greater Than 6 mm (Reflection Method)
ISO 6892-1	Metallic Materials-Tensile Testing-Part 1: Method of Test at Room Temperature
ISO 15156-1	Petroleum and Gas Industries-Materials for Use in H2S-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 H2S - Containing Environments in Oil and Gas Production - Part 2: Cracking - Resistant Carbon and Low Alloy Steels, and the Use of Cast Irons

Document Number	Document Title
ISO 15156-3	Petroleum and Gas Industries - Materials for Use in H2S - Containing Environments in Oil and Gas Production - Part 3: Cracking - Resistant CRAs (Corrosion Resistant Alloys) and Other Alloys

6.3 CODE AND OTHER STANDARDS

Codes, standards and regional legislation applicable to this document are indicated in the table below.

Document Number	Document Title
API 5 CT	Specification for Casing and Tubing
API 5L	Specification for Line Pipe
API STD 619	Rotary-Type Positive Displacement Compressors for Petroleum, Petrochemical, and Natural Gas Industries
ASTM A 193	Alloy-Steel and Stainless Steel Bolting Materials for High - Temperature or High Pressure Service and Other Special Purpose Applications
ASTM A 194	Carbon and Alloy Steel and Stainless Steel Nuts for Bolts for High Pressure and High Temperature Service, or Both
ASTM A 216	Steel Castings, Carbon, Suitable for Fusion Welding, for High Temperature Service
ASTM A 217	Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service
ASTM A 307	Carbon Steel Bolts, Studs, and Threaded Rod 60,000 PSI Tensile Strength
ASTM A 320	Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
ASTM A 370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A 395	Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures
ASTM A 439	Austenitic Ductile Iron Castings
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)
EFC Publication No. 16	European Federation of Corrosion Publication No 16;Guidelines on Material Requirements for Carbon and Low Alloy Steels for H2S–Containing Environments in Oil and Gas Production

Document Number	Document Title
EFC Publication No. 17	Corrosion Resistant Alloys for Oil and Gas Production: Guideline on General Requirements and Test Methods for H2S Service
NACE TM 0177	Laboratory Testing of Metals for Resistance to Sulphide Stress Cracking and Stress Corrosion Cracking in H2S Environments
NACE TM 0284	Evaluation of Pipeline and Pressure Vessels Steels for Resistance to Hydrogen - Induced Cracking

7.0 REQUIREMENTS FOR MATERIALS FOR SOUR SERVICE

7.1 APPLICATION OF INTERNATION STANDARD ISO 15156

General principle for selection of cracking resistance material is mentioned in ISO15156-1.

This standard is basically a combination of ISO 15156 and EFC 16 and 17 documents.

This specification is based on ISO15156 with some modifications or additional information where necessary.

Note that in ISO 15156 a material can be qualified according to one of the three options:

1) It shall be used within the limits stated by the standard.

2) It passed the appropriate SSC or SCC test under the worst case field conditions.

3) It shall be used under the same conditions for which positive experience has been acquired for 2 years as long as these conditions are documented.

For some materials the limits in H2S partial pressure and pH, given in ISO 15156, can be adjusted to specific environments.

In future, if the limits of ISO 15156 become more stringent for a given material, the existing equipment made from this material shall be considered as acceptable referring to the version of the standard at time of construction.

Material selection for sour service is based on the following two aspects:

a) Determination of the severity of operating conditions

b) Material characteristics (mechanical properties and corrosion resistance of each alloy considering the limits of use, in term of pH, H2S partial pressure, chloride and temperature)

7.2 DETERMINATION OF OPERATONS SEVERITY FOR CARBON AND LOW ALLOY STEELS (CLAS) AND CAST IRONS

Sour service severity of production conditions for CLAS and cast irons shall be characterised by the in-situ pH and the H_2S partial pressure and operating conditions (ISO 15156-2 Clause 6).

7.2.1 SOUR SERVICE DOMAINS

Four sour service “domains” are identified on the graphical presentation of Figure 1. The severity of the environment depends on the H_2S partial pressure and pH. This diagram is slightly different from the one adopted in ISO 15156-2 which are defined as follows :-

Region 0: “Sweet Service” (only negligible traces of H_2S). The domain within which no specific metallurgical precautions are required except for very high strength steels. Very high strength CLAS are not permitted for use in this Region, unless otherwise approved by the Company. Examples of such CLAS include upper range of API SPEC 5CT grade Q125 with yield strength in excess of 140ksi, springs and armour wires.

Region 1: “Mild Sour Service” The domain within which minor metallurgical measures are required (ISO 15156-2 Clause A.4). 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 metallurgical measures are required (ISO 15156-2 Clause A.3). 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.

Region 3: “Severe Sour Service” The domain within which the most stringent metallurgical measures are required (ISO 15156-2 Clause A.2). 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

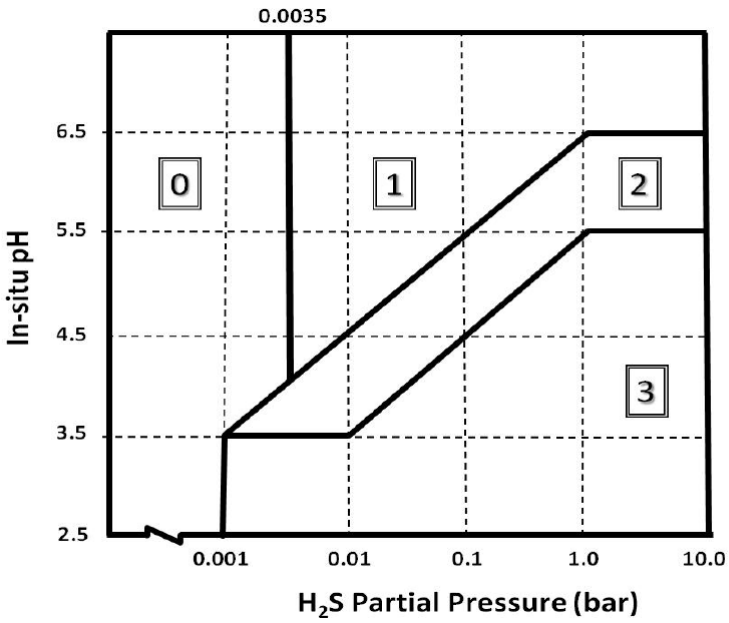


Figure 1 - Limits of Sour Service

Material selection for regions 0, 1, 2 and 3 are explained in ISO 15156-2 Paragraphs 7.2.1.3 and 7.2.1.4.

7.2.2 CALCULATIONS OF H_2S PARTIAL PRESSURE AND pH

H_2S partial pressure and in-situ pH shall be calculated according to ISO 15156, Annex C and Annex D respectively. For the calculation of CO_2 and H_2S partial pressures, maximum operating absolute pressures shall be considered. For pH calculation, the CO_2 partial pressure and water chemistry shall be taken into account. pH can be calculated by software approved by COMPANY. 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.

7.2.3 DEFINITION OF MOST SEVERE CONDITIONS

Even though the severity of the environment can be easily defined by H_2S partial pressure and pH, the determination of conditions for which "the partial pressure of H_2S is highest and the pH is lowest" should be done carefully. The following summarizes the guidelines:

1) Operating conditions:
   a) The lowest operating temperature and lowest local alkalinity shall be used for the pH calculation.
   b) For the multiphase gas lines and pressure vessels, both the pH of the formation water at the bottom of the line/vessel and the pH of the condensed water at top of the line/vessel shall be taken into account.
   c) Highest operating pressure shall be used for H_2S and CO_2 partial pressures calculation.
2) Shut-in conditions:
   a) The ambient temperature and lowest local alkalinity shall be used for the pH calculation.
   b) For the multiphase gas lines and pressure vessels, both the pH of the formation water at the bottom of the line/vessel and the pH of the condensed water at top of the line/vessel shall be taken into account
   c) For tubing, only pH of the condensed water shall be considered.

Highest shut-in pressure shall be used for H_2S and CO_2 partial pressures calculation.

7.2.4 GENERAL HIC/SWC REQUIREMENTS

As a general rule, Figure 1 does not apply to HIC/SWC, whereas degree of severity increases with lowering the in-situ pH and increasing H_2S partial pressure. In addition to the requirement ISO 15156-2 (Clause 8) for HIC/SWC, company may require demonstration of satisfactory performance against hydrogen blistering and HIC/SWC irrespective of H_2S partial pressure. In such cases, the Company may specify steel with increased resistance to these corrosion cracking threats. Alternatively, CLAS internally clad with corrosion resistant steels may be specified subject to Company approval.

7.3 MATERIAL CHARACTERISTICS

All Materials for sour service as defined in this specification shall comply fully with ISO15156 except as modified or extended below. Modifications are divided into following categories:

1) General requirements
2) Requirements for specific material
3) Requirements for specific equipment
4) Requirements for specific environment
5) Testing requirements

7.3.1 GENERAL REQUIREMENTS

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.

For the fabrication of certain parts:

1) Which may be subject to high stresses
2) For which high strength steels are going to be used and
3) In contact with effluent containing H_2S

The Supplier shall select materials resistant to SSC and SCC, proved itemised drawings specific to the installation planned. Details of component materials and the material condition shall be subject to COMPANY approval prior to manufacture.

Material selection for regions 1, 2 and 3 are explained in ISO 15156-2 Paragraphs 7.2.1.3 and 7.2.1.4. Some additional requirements are given below:

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

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

2) Materials for the “Severe Sour Service” conditions (Region 3) shall be selected from those permitted at test level III as described in Table E.1 of ISO 15156-3.

7.3.2 REQUIREMENTS FOR SPECIFIC MATERIAL

7.3.2.1 CARBON STEEL AND LOW ALLOY STEELS

Carbon steel and low alloy steels intended for handling wet H2S containing environments shall be in accordance with the requirements of ISO 15156-2 together with additional amendments included in this section.

- **CARBON STEEL GRADES AND CHEMICAL COMPOSITION**

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 H_2S 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 tables 1 through 5 give the chemical composition requirements for different equipment. In these tables, the definitions of CE and Pcm are as follows:

1) CE IIW = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15

2) Pcm = C + Si /30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B

For other applications, guidelines of ISO 15156-2 shall be used.

Table 1 - Chemical Compositions for Seamless Pipelines - Ladle/Check Analysis – % Weight Max.

Chemical elements *	X- 42 and X - 46	X-52 to X - 65
C	0.15 / 0.16	0.13 / 0.14
Mn	1.10 / 1.25	1.25 / 1.35
Si	0.40 / 0.45	0.45 / 0.50
Al (total**)	0.06 / 0.06	0.06 / 0.06
Ca	0.006 / 0.006	0.006 / 0.006
S	0.005 / 0.008	0.005 / 0.008
P	0.020 / 0.025	0.02 / 0.025
Nb	0.05 / 0.05	0.05 / 0.05
V	0.06 / 0.06	0.08 / 0.08
Nb + V	-	0.10 / 0.10

Chemical elements *	X- 42 and X - 46	X-52 to X - 65
Ni	-	0.30 / 0.30
Cr	-	0.20 / 0.20
Cu	0.30 / 0.30	0.30 / 0.30
Mo	-	0.25 / 0.25
Ti	-	0.04 / 0.04
N **	0.012 / 0.014	0.010 / 0.012
CE	0.41 / 0.42	0.38 / 0.39
Pcm	(0.24 / 0.25)	0.21 / 0.22

* The intentional addition of elements not specified above shall not be permitted without prior approval of the COMPANY. The maximum working percentages of residual elements shall be as follows (ladle and product check) for Grade X52 up to Grade X65:

Sn = 0.015 %, As = 0.015 %, Sb = 0.010 %, B = 0.0005 % (no intentional addition), Bi = 0.005 %, Pb = 0.005 %.

**The soluble aluminum to nitrogen ratio (Al/N) shall be at least 2.

Table 2 - Chemical Compositions for Longitudinally Submerged Arc Welded Pipes Ladle/Check Analysis - % Weight Max.

Chemical Elements *	X-42	X-46	X-52	X-60	X-65
C	0.10	0.10	0.10	0.10	0.10
Mn	1.45	1.45	1.45	1.45	1.45
Si	0.35	0.35	0.40	0.40	0.40
Al (total**)	0.050	0.050	0.050	0.050	0.050
S***	0.003	0.003	0.003	0.003	0.003
P	0.015	0.015	0.015	0.015	0.015
Nb	0.05	0.05	0.06	0.06	0.06
V	0.04	0.04	0.05	0.07	0.08
Ni	0.30	0.30	0.30	0.30	0.30
Cr	0.25	0.25	0.25	0.25	0.25
Cu	0.35	0.35	0.35	0.35	0.35
Mo	0.25	0.25	0.25	0.25	0.25
Ti	-	-	0.02	0.02	0.02
N **	0.012	0.012	0.012	0.012	0.012
CE	0.38	0.38	0.38	0.38	0.39
Pcm	0.22	0.22	0.22	0.20	0.21

* The intentional addition of elements not specified above shall not be permitted without prior approval of the COMPANY. The maximum working percentages of residual elements shall be as follows (ladle and product check) for Grades X52 up to Grade X65: Sn = 0.015 %, As = 0.015 %, Sb = 0.010 %, B = 0.0004 % (no intentional addition), Bi = 0.005 %, Pb = 0.005 %, O = 0.0025 %

** The soluble aluminum to nitrogen ratio (Al/N) shall be at least 2.

*** If S < 15 ppm, then 0.001 ≤ Ca ≤ 0.004. If S ≥ then Ca/S = 2 to 5 with Ca ≤ 0.004

Table 3 - Chemical Compositions for Flanges, Fittings and Forged Components for Pipelines (Weight% Max)

Chemical Elements	Ladle	Product
C	0.16	0.18
Mn	1.30	1.40
Si	0.35	0.40
Al (total)	0.050	0.050
S	0.01	0.01
Ca	0.006	0.006
P	0.02	0.02
Nb	0.06	0.06
V	0.06	0.06
Ni	0.60	0.60
Cr	0.25	0.25
Cu	0.30	0.30
Mo	0.20	0.20
Cr + Mo + Cu	0.5	0.5
Ti	0.015	0.015
Nb + V+ Ti	0.12	0.12
N	0.012	0.012
O	0.003	0.003
Hydrogen	2 ppm	2 ppm
CE	0.42	0.44
Pcm	0.23	0.24

Table 4 - Chemical Compositions for Carbon Steel Tees for Pipelines (Weight% Max)

Chemical Elements	Ladle	Product
C	0.15	0.17
Mn	1.20	1.30
Si	0.35	0.40
Al (total)	0.060	0.060
S	0.005	0.005
Ca	0.006	0.006
P	0.02	0.02
Nb	0.06	0.06
V	0.06	0.06
Ni	0.60	0.60
Cr	0.25	0.25
Cu	0.30	0.30
Mo	0.20	0.20
Cr + Mo + Cu	0.5	0.5
N	0.015	0.015
O	0.003	0.003
CE	0.42	0.43
Pcm	0.22	0.23

Table 5 - Chemical Compositions for Carbon Steel for Piping and Equipment (Ladle, <% Weight)

Chemical Elements	Severe Sour Service	Intermediate Sour Service
C	0.20	0.20
Mn	1.0	1.30
Si	0.35	-
Al (total)	0.045	-
S	0.008	0.015
Ca *	See *	-
P	0.015	0.02
Nb**	0.0051	0.0051
V**	0.0051	0.0051
Ni	0.15	-
Cr	0.25	-
Cu	0.40	-
Ni + Cu	0.15	-
Mo	0.05	-
Nb + V+ Ti + Cr + Mo	0.5	-
Ti	0.02	-
N	0.010	-
O	0.002	-
B	0.0005	-
CE ***	0.42	0.42

*Ca < 0.025 with 2 ≤ Ca / S ≤ 4 and Ca / (1.25 x S + 0.625 x O) ≥ 1.5. Calcium treatment is not necessary if S ≤ 0.002

**If CE ≤ 0.360, Vanadium and Niobium contents may be increased up to Nb < 0.05, V < 0.08 with V + Nb < 0.08

***CE ≤ 0.430 is acceptable for plate thicknesses of 2 inches and above If C < 0.12, Pcm shall apply and if C > 0.12, CE is only applicable.

- **CAST IRONS**

Cast irons intended for exposure to sour service conditions shall be in accordance with the requirements of ISO 15156-2 together with additional amendments and modifications as follows :-

- Cast irons shall not be used in sour service conditions.
- For non-pressure bearing application, the use of cast irons (ISO 15156-2 Clause A.2.4) may be allowed but subject to Company approval.
- Cast irons or ferritic ductile (nodular) irons are not acceptable for pressure-retaining parts and for impellers etc.
- Austenitic cast iron is not acceptable for pressure-retaining parts. 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.

7.3.2.2 CRACKING RESISTANT CORROSION RESISTANT ALLOYS (CRAS) AND OTHER ALLOYS

CRAs and other alloys intended for handling wet H2S containing environments which may result in corrosion threats described in section 7.3 shall be in accordance with the requirements of ISO 15156-3 together with additional amendments included in this section.

Sour service severity of production conditions for CRAs and other alloys (ISO 15156-3 Clause 5) shall be characterised by the in-situ pH, the H_2S partial pressure, temperature, maximum anticipated chloride and the presence of elemental sulphur. The severity of sour service to cause H_2S related cracking is generally enhanced with decreasing pH and/or increasing H_2S partial pressure, increasing temperature and chloride content. Increasing cracking severity shall require the use of more resistant alloys with higher PREN (alloying element contents) and more stringent metallurgical requirements.

- **MARTENSITIC 13 % CR AND SUPER 13 % CR FOR TUBING**

The following limits shall apply for CRA grades (ISO 15156-3):

- API 5CT grade L80 13% Cr tubing (ISO 15156-3 Table A.19) is acceptable for use in Regions 0, 1 and 2 provided its resistance to other corrosion threats is established.
- API 5CT grade L80 13% Cr are permitted for application in some parts of Region 3 subject to satisfactory performance in application specific testing and approved by the Company.

Martensitic 13 % Cr and super 13 % Cr can be used in the region 3 (severe sour) with the following limitations.

- L80 Grade 13 % Cr can be used for pH values above pH 3 if the partial pressure of H_2S is below 0.015 bar. This is valid for both operating and shut-in conditions.
- L80 Grade 13 % Cr can be used for pH values above pH 3 and H_2S partial pressure up to 0.035 bar if:
  - ✓ The minimum operating temperature at wellhead head remains above 60 °C.
  - ✓ The maximum H_2S partial pressure during shut-in does not exceed 0.035 bar.

Some Super 13 % Cr alloys Grade C95 can be used for pH values above pH 3 if the partial pressure is below 0.05 bar however, each alloy should be tested according to ISO 15156 requirements.

Finally:

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 has been established. L80 13 % Cr can also be used in some parts of Region 3 as mentioned above. For more severe conditions, their suitability must be verified by testing on a case by case basis.

➢ AUSTENITIC STAINLESS STEELS

ISO 15156-3 does not limit the temperature of use of 3xx stainless steels in sour service for low chloride environments (< 50 ppm).

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 H_2S partial pressure below 0.1 bar.
- Wet gas process vessels, coolers and associated piping, for chloride content < 7000 ppm, temperature below 140 °C and H_2S partial pressure below 0.015 bar.

To be noted that:

1) Austenitic stainless steels shall be in the solution annealed condition.
2) 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
3) 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
4) 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 %.

➢ PRECIPITATION HARDENED MARTENSITIC STAINLESS STEELS

The terms and conditions of ISO 15156-3 (Clause A.8) shall apply when using 17-4 PH SS including the following amendments and exclusions.

• 17-4 PH items shall be subject to double ageing heat treatment according to ISO 15156-3 (Clause A.8) with an appropriate quality assurance/quality control (QA/QC) procedure approved by Company.

• 17-4 PH steels shall not be used in the presence of H_2S unless the item is non-pressure retaining and one of the following conditions prevails:

- Total absence of water
- Certainty that the design stresses are continually below 30% of the actual yield strength
- The service temperature of the material is continually above 80°C

- The Supplier's demonstration satisfactory resistance of these materials to SSC under the actual most severe service conditions.

➢ COPPER AND NICKEL COPPER ALLOYS

Copper and its alloys shall not be used in H2S containing environments. Precipitation hardened copper alloys shall not be used in H2S containing environments. Alloy 400 (UNS N04400

containing 70%Ni-30%Cu) is acceptable according to Table A.13 of ISO 15156-3. This alloy shall not be used in equipment intended for critical parts as specified by the Company. Alloy 500 (UNS N05500) is not acceptable unless its resistance to H2S is demonstrated under the service conditions by the Supplier.

- **METALLIC CLADDING**

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 H_2S environment and the backing material does not need to be sour service. However, care must be taken to obtain 100 % coverage by the metallic cladding to avoid any contact between the base metal and the H_2S containing environment. For other cladding, lining, coating and overlays to refer to ISO 15156-2 paragraph A 2.1.5 and ISO 15156 -3 paragraph A 13.1.

- **WELD OVERLAY**

The terms and conditions of ISO 15156-2 (Clause 7.3.3.3 and A.2.1.5) and ISO 15156-3 (Clauses 6.2.2.2.3, A.1.5.1, A.13) shall apply for weld overlays. In addition the following amendments and exclusions shall apply. Explosively clad, roll bonded or fusion-bonded corrosion resistant metallic overlay such as austenitic SS or nickel alloys are permitted as corrosion barriers to the H_2S environment. Where such overlays are employed the backing C-Mn steel or LAS is not required to conform to this GS. This is subject to meeting Company requirements and a demonstration by the supplier with an appropriate NDE method that 100% coverage by the metallic cladding or overlay is achieved as to avoid any contact between the base metal and the H_2S environment. In the event of erosion threat, the backing steel shall be a sour service grade.

- **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 (provided that they are suitable for the service conditions) 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.

7.3.3 REQUIREMENTS FOR SPECIFIC EQUIPMENT

7.3.3.1 DOWNHOLE TUBULAR STEELS

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

1) Region 0: up to API Q 125 with maximum yield strength not exceeding 140 ksi
2) Region 1: up to API P 110 with maximum yield strength not exceeding 130 ksi)
3) Region 2: up to API N 80
4) Region 3: up to API L 80 or C 90 or T95

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).

For 13 % Cr and Super 13 % Cr, see paragraph 5.3.2.2 (above).

7.3.3.2 FLEXIBLE LINES

Steels used in flexible wires are very limited in terms of resistance to sour service. For low H_2S environments, typically region 0 and region 1, wires should be sour service suitable at least for the region 1. Specific testing for resistance to SSC and HIC is required under at least the worst expected service conditions of the field. Testing normally is carried out to simulate the worst case permeation of H_2S and CO_2 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 approval.

7.3.3.3 INSTRUMENTATION

Some items / components require high strength alloys and some of them cannot be heat treated after welding. These items /components 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.

Alloy 825 (UNS N 08825), alloy 625 (UNS N 06625), alloy 400 (UNS N 04400) and alloy B (UNS N 06004) are acceptable (provided that they are suitable for other types of corrosion in the service environment like external pitting in marine environment). 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.

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.

7.3.3.4 BELLOWS

Bellows shall comply with the ISO 15156 requirements when in contact with any concentration of wet Hydrogen Sulphide.

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)

7.3.3.5 SPRINGS AND SPRING LOCK WASHERS

Springs shall be made of a material resistant to environmental corrosion cracking in the presence of H_2S. 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.

If large springs are used of which the cost of H_2S material is very high, materials non-resistant to H_2S 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.

7.3.3.6 BOLTING

The following completes the requirements of ISO 15156-2.

1) 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.
2) Where austenitic stainless steel bolts and nuts are required, these items shall be free from cold work; they shall be solution treated after thread forming, etc. as outlined as follows:
    a) Bolts shall be Class 1A of ASTM A 193 e.g. B8MA (type 316) solution treated after all cold work including thread forming.
    b) Nuts shall be of the “A” suffix variety of ASTM A 194 e.g. Grade 8MA (type 316) solution treated after all hot or cold working.

c) Resulphurized steels are not acceptable.

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

7.3.3.7 ROTATING MACHINERY

Sour service for rotating machinery shall be determined as defined in Section 7.2 except for reciprocating compressors where the presence of any level of H_2S shall be defined as severe sour service (Region 3).

Carbon and carbon manganese steel plates for fabricated compressor casing shall be resistant to HIC.

All fabrication welds and repair welds shall be subject to PWHT (carbon and carbon manganese steel at 580 / 620 °C, for example) or complete re-heat treatment, (martensitic stainless steel as per paragraph A.6 of ISO 15156-3, for example). If for certain welds complete heat treatment is not possible, double tempering treatment is acceptable. Austenitic stainless steels do not normally require PWHT.

7.3.4 REQUIREMENTS FOR SPECIFIC ENVIRONMENT

7.3.4.1 START UP AND SHUT DOWN OF DRY GAS SYSTEMS

In dry gas systems free water may be present during startup of production (only wet gas is available) and also during shut down.

The necessity to use sour service material is to be evaluated case by case depending on the operating conditions, the water condensation rate and evolution of the pH and duration of degraded mode.

Export gas pipes transporting dry gas can be sweet service if dry gas is available during production startup. If a small amount of water is condensed during normal operations, water film pH will increase, quickly reducing the severity of the environment.

7.3.4.2 SOUR SERVICE WITH ALKALIS/AMINES

In amine units the risk of SSC is minor as the pH is high. For sour service in association with alkalis, amines or other alkaline process fluids, for instance amine units, the main requirement of API RP 945 and COMPANY is the systematic post weld heat treatment of welds, with the exception of low pressure storage tanks, to prevent cracking by other mechanisms than SSC.

In amine units, 316L stainless steel can be used up to 30 % mol CO_2 + H_2S in the treated gas and an amine loading up to 0.9 Mol acid gas per Mol of amine for the following components:

1) Internals/ packing and cladding in absorber and regenerator columns

2) Piping of the rich amine section

3) Tubes for the amine heat exchanger

4) Heating coil of amine reboiler
5) Reflux cooler
6) 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 units.

7.3.4.3 LOW TEMPERATURE EQUIPMENT AND PIPING

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 provided that the formation of liquid water can be prevented at all times.

There will be no 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.

7.3.5 TESTING REQUIREMENTS

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

For carbon steel material, test requirement includes both SSC and HIC. For CRA, SSC and SCC test are required.

Dominant cracking mechanisms / temperatures for each alloy type are as follows:

1) Martensitic stainless steel: SSC at ambient temperature
2) Duplex stainless steel: SSC/SCC over a range of temperature. Widely reported to be worst in the range 80-120 °C. Austenitic stainless steel, nickel alloys and titanium alloys: SCC at maximum service temperature

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

Objectives of the tests could be classified in two categories as follows:

A: 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.

B: Production assessment test

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

7.3.5.1 SSC TESTING

General requirements

Test procedure shall be in accordance with NACE TM 0177 or 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 regions 2 and 3, for any component, qualification of steel batch is required as defined below:

a) Tests shall be performed in triplicate for each steel and each Supplier

b) 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

c) Tests should be carried out one set per heat lot

d) Solution chemistry shall be in accordance with the requirements of document EFC Publication No. 16

e) For a specific condition, tests should be carried out at design pH or lower

f) 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).

g) 0.2 % permanent offset shall be the average of three samples in accordance with the requirements of ASTM A370/ ISO 6982-1.

A CRA or other alloys may be qualified by testing for use under operating conditions that are more severe than the environmental limits given in ISO 15156. Exposure that might occur during system upset or shutdown, etc shall be considered. Such exposures can include unbuffered, low pH, condensed water and acids used for well simulation.

For martensitic stainless steel, SSC tests may be performed in simulated well shut-in conditioni.e. condensed water without chloride content and calculated in situ pH of condensed water.

All SSC tests shall be conducted at the % actual yield strength (% AYS) of pipe base material. The measurement of applied stress shall be made using either electrical strain gauges or the deflection method. If deflection method is used, the deflection shall be measured using a dial gauge with an accuracy of 0.01 mm. 90 % of the actual yield strength will be used for the test.

For the test conditions, for region 2 and 3, the supplier shall choose between the three following options.

OPTION 1: ALL CONDITIONS/ EFFLUENTS

The test solution shall be the NACE test solution "A" as described in NACE TM 0177. The H_2S partial pressure shall be 1 bar. The supplier shall ensure that saturation is obtained after one hour. Hydrogen sulphide concentration in the solution shall be measured by the iodine titration method at the start and end of the test.

The temperature of the solution shall be maintained at 24 °C ± 3 °C and regularly recorded from start to test completion.

The pH of the solution shall be recorded at the start and end of the test. The pH values shall be within the limits of NACE TM 0177 (i.e. initial pH = 2.7 ± 0.1 and pH max = 4 at the end of test). Tests shall have duration of 30 days (720 hours) minimum.

Pipeline Sour Service	Area	Pipeline Effluent	Test Conditions	Stress Level (% AYS)
Mild	1	All	NA	NA
Intermediate & severe	2 & 3	All	NACE TM0177 1 pH = 2.7 – PH_2S – 1 bar	80

OPTION 2: SPECIFIC APPLICATION WITH KNOWN pH

The test solution shall be according to EFC 16.

As the in situ pH can be determined, tests will be carried out according to ISO 15156-2 Table B.1 with lowest pH encountered in service and the maximum design H_2S partial pressure.

OPTION 3: SPECIFIC APPLICATION WITH UNKNOWN pH

If the actual pH is unknown, test solution, pH and H_2S partial pressure will be as stated in the Table below according to sour service severity and type of pipeline effluent.

Pipeline Sour Service	Area	Pipeline Effluent	Test Conditions	Minimum H_2S Concentration (ppm)	Stress Level (% AYS)
Intermediate	2	Oil	EFC 16 solution B pH 4.5, pH_2S 0.1 bar	230	90
		Gas Multiphase Condensates	EFC 16 solution A pH 3.5, pH_2S 0.01 bar	23	90
Severe	3	Oil	EFC 16 solution B pH 4.5, pH_2S 0.1 bar	2300	90
		Gas Multiphase Condensates	EFC 16 solution A pH 3.5, pH_2S 0.01 bar	2300	90

For Option 2 and Option 3 (above):

- EFC 16 test solutions shall consist of 50 g/L NaCl + 4 g/L of sodium acetate

(CH_3 COONa) in distilled or deionised water. Throughout the test, pH shall be measured, recorded and periodically adjusted to the specified pH with an allowance of ± 0.1 by addition of HCl or NaOH. All reagents added to the test solution shall be measured to
± 1.0 % of the quantities specified. H_2S gas purity shall be 99.5 % minimum).

- The solution shall be saturated by using H_2S + CO_2 gas mixtures to obtain the desired H_2S partial pressure.
- Tests shall have duration of 30 days (720 hours) minimum. The temperature of the solution shall be maintained at 24 °C ± 3° and regularly recorded from the start to the end of test.
- The volume of test solution to the total exposed surface area of test specimens shall be 30 ± 10 ml/cm^2 minimum.
- The H_2S concentration of the solution shall be recorded at the start of test, after initial H_2S saturation and at the end of the test.

Notes: If the test conditions simulate the shut-in conditions in wells, distilled or deionised water shall be used without addition of chloride, acetate or bicarbonate. The lowest pH and highest actual H_2S partial pressure shall be used. The temperature shall be 24 °C.

7.3.5.2 TESTS FOR PIPELINE AND BENDS

For the fabrication of seamless carbon steel pipeline grade X42 up to X65 of API spec 5L for intermediate and sever sour service, qualification of pipe manufacturing procedure shall include SSC test. SSC tests shall be carried out on pipe material for each pipe size (diameter and WT), steel source, steel grade and manufacturing process.

SSC tests shall be performed during qualification of pipe manufacturing procedure for 720 hours. Production tests shall then be carried out at ¼, ½, ¾ and end of pipe production, except that test duration shall be 360 hours only (15 days).

Spare test specimens shall also be cut out and shall be available for additional tests if needed.

For bends, SSC tests are required on finished bends.

a) Specimen Examination

Following failure or at the end of the test (whichever happens first), samples shall be cleaned and inspected by visual examination and MPI. Photographs shall be made at x1 and x10 magnifications of the stressed surfaces of each specimen.

Whenever a crack is found, the specimen shall be cut longitudinally at crack location, polished and etched. Photographs of the stressed surface and macro-section shall then be taken. It shall be metallurgical examined and the metallurgical features recorded with photomicrographs. Specimens which do not exhibit crack on their external surface,

shall be cut transverse to weld (transverse to rolling direction) at 5 mm and at 10 mm from their external transverse faces. The sectioned surfaces shall be ground smooth with 600 grit emery paper, minimum, following machining.

Visual examination of unetched sections shall be made at X1, X10 and X100 magnifications. If cracks are observed, specimens shall be properly etched. Photographs shall be made at a suitable magnification before and after etching.

b) Test Acceptance Criteria

No crack (or rupture) shall be accepted in any of the tested pipes within the 30 day period of testing. Cracks initiated in base material inclusion will not be considered. Little grooves or pits caused by corrosion loss will not be considered, in mutual agreement between supplier and inspector.

For production test, if there is a failure the COMPANY may accept to have four pipes of the same heat retested. If a re-test fails, the said heat shall be rejected and all heats of the said casting sequence shall be tested on two pipes minimum before release or reject of each individual heat of the sequence.

In all cases, re-test pipes shall be selected in mutual agreement between the Supplier and the Inspector.

The Supplier shall investigate and clarify the cause of any failure in order to initiate corrective actions / re-testing, to the satisfaction of COMPANY.

c) Reporting

At end of testing, the Supplier shall provide a test report giving the following data:

i). Measurement of the actual applied stress (strain gauges, etc.)

ii). Individual result for each specimen tested per set, with photographs and photomicrographs (when applicable)

iii). Type of solution used for the tests. pH of solution at start and end of test and during the test for EFC 16 solutions. H_2S concentration at start and end of test.

iv). Location and dimensions of specimens

v). Mill certificates of materials tested showing full chemical analysis and mechanical properties.

vi). Testing procedure specification

vii). Conclusions and pertinent explanations (where needed) or concluding information.

7.3.5.3 HIC TESTING

For Region 0 and Region 1 conditions, no testing is required.

For Region 2 and Region 3, qualification testing (candidate steels from different suppliers) or production assessment testing shall be as defined below:

1) Tests should be performed in triplicate for each steel
2) 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 sulfur
3) Solution chemistry and conditions shall be in accordance with NACE TM 0284 solution A

The acceptance criteria will be according to NACE TM 0284:

- 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.

Production of seamless carbon steel pipeline grade X42 up to X65 of API spec 5L.

The Supplier shall prepare a detailed HIC test procedure (including the UT procedure of specimens) and submit it to the COMPANY for approval.

HIC tests shall be carried out for each pipe size (diameter and WT), steel source, steel grade and manufacturing process using uncoated specimens.

Qualification of pipe manufacturing procedure shall include HIC test. The pipe to be used for manufacturing procedure qualification shall be from one of the first three heats.

For production assessment test, one test pipe from each of the first three heats (i.e. three test pipes) and then at a frequency of one test pipe per 10 heats shall be used for HIC testing.

Six test specimens shall be taken from each test pipe as follows:

1) Two specimens cut transverse to the pipe axis
2) Two specimens cut in base material in a direction parallel to the rolling direction at 90° from weld and at 180° from weld.

For specimen dimension, refer to section 6 of the NACE TM 0284. For wall thickness (WT) above 30 mm, the specimens shall be staggered at each location as per “Pressure Vessel Plate” in NACE TM 0284, with an overlap of 1 ± 0.5 mm between adjacent specimens. After machining, all specimen surfaces shall be ground and finished to 320 grit paper.

The specimen cross-sections shall be ground dry employing a number of intermediate grinding steps to remove any metal deformation. The surface shall be finished by fine

grinding with 800 grit paper or finer paper and then polished with diamond paste (grain size: 3 microns, 1 micron) and AL_2O_3 alumina paste or diamond paste (max. grain size: 0.25 micron). The consecutive steps of grinding and polishing shall be detailed in the HIC procedure. The surface shall finally be cleaned using water, alcohol and hot air.

Test solution A as per NACE TM 0284 shall be used. The ratio of solution volume to specimen surface area shall be a minimum of 30 ml/cm^2. The solution shall be de-aerated by bubbling nitrogen and then H_2S saturated as per NACE TM 0284.

H_2S partial pressure shall be 1 bar. The H_2S concentration in water is 2300 ppm (measured by the iodometric titration method). The pH value shall be measured after initial hydrogen sulphide saturation and just prior to test termination. The test pH shall be within the limits of NACE TM 0284 (i.e. initial pH = 2.7 ± 0.1 and pH max. = 4.0 at end of test). The test temperature shall be maintained at 25 °C ± 3 °C.

No applied stress is required. After 96 hours immersion, damage due to hydrogen pressure induced cracking related features such as blistering, straight and stepwise cracks shall be measured and reported. The procedure for determining HIC sensitivity and acceptance criteria shall be the same as above.

HIC tests shall be carried out on samples from finished bends.

Sample examination

Specimens shall be first examined by automatic UT using compression waves and the immersion technique (Appendix 1). The Supplier shall submit a detailed UT procedure to the COMPANY prior to approval. COMPANY requirements are given below.

Extent of UT inspection shall cover 100 % of specimen surface plus a peripherical band of at least half the diameter of transducer (i.e. scanning over 100 % of specimen volume). The scan resolution shall be 0.5 x 0.5 mm, or better.

A chart in A-scan or B-scan, as a minimum, shall be produced. C-scan chart may also be produced but as additional only. The cartography shall give the sizing and location of detected cracks with an accuracy of ± 0.05 mm. Amplitudes of echoes from cracks may be referenced with different colours. Print-outs shall be properly marked (specimen number, heat number, date of tests, etc.).

The total Crack Area Ratio (CAR) per specimen shall be reported. CAR is defined as follows:

CAR % = Total Area of Specimen / (Total Area of Indications x 100)

Acceptance criteria for UT examination of specimens is CAR = 5 % max. of specimen area, per specimen. The CAR shall include all cracks and all laminations, whether they are associated or not associated with cracks. In this evaluation, cracks that lie within 1.0 mm of the internal or external surface of the test specimen shall be disregarded. Cracks separated by less than 0.5 mm shall be considered a single crack.

Each of the specimens shall be sectioned transversely at the largest indication (if any) obtained at UT. For specimens in base material, the two other locations shall be:

1) 25 mm apart if the largest UT indication is between 35 % and 65 % of specimen length
2) Or at a distance of 25 mm and 50 mm, if the largest UT indication is between 0 % and 34 % or 66 % and 100 % of specimen length.

When there are no indications at UT scanning, then the specimen shall be cut at three equidistance locations within the specimen length as per NACE TM 0284 (i.e. 25 mm apart). The sections shall be mounted in epoxy resin or equal and polished similar as sample preparation for testing (explained above). Each section shall be suitably etched and microscopically examined for hydrogen induced cracking at magnification of X100.

For microscopic examination of cross-sections, the criteria is the same as ultrasonic examination which is CAR = 5 % max. of specimen area. The CAR shall include all cracks and all laminations, whether they are associated or not associated with cracks. In addition, all cracks visible at magnification X100 (as said above) shall be measured and reported. In this evaluation, cracks that lie within 1.0 mm of the internal or external surface of the test specimen shall be disregarded. Cracks separated by less than 0.5 mm shall be considered a single crack.

CLR, CTR and CSR shall be calculated and reported for each section and the average for each test specimen as per NACE TM 0284 as mention above. In addition, no individual crack shall exceed 5 mm in length.

For production test, in case of failure to meet the acceptance criteria, the COMPANY may accept having four pipes of the same heat retested. If a re-test fails, the said heat shall be rejected and all heats of the said casting sequence shall be tested on two pipes minimum before release or reject of each individual heat of the sequence. The Supplier shall investigate and clarify the cause of any failure in order to initiate corrective actions, to the satisfaction of COMPANY.

In all cases, re-test pipes shall be selected in mutual agreement between the Supplier and the Inspector.

For reporting, the following data shall be provided in the Supplier report per each heat tested for COMPANY acceptance:

1) The printed charts of UT scanning of specimens, unless the UT cartography does not show any defects.
2) The CAR percentage result per each specimen.
3) Individual CLR, CTR and CSR for each of the three sections per specimen, and the average CLR, CTR and CSR per each specimen, with photographs of all unetched sections at X5 and X25 magnifications.

4) Type of solution and pH of solution at start and end of test and also at end of each day of test. H_2S concentration at start and end of test.

5) Locations and dimensions of specimens in tested pipe

6) Photomicrographs of typical micro-structures X 200 of weld and parent material, with definition of the microstructures

7) Mill certificates of material tested showing full chemical analysis and mechanical properties.

All pertinent explanations (where needed) and concluding comments. Any failure shall be analysed by the Supplier and the causes of failure made clear to the COMPANY, before any re-tests or remedial actions are decided.

7.3.5.4 SCC TESTING

Test procedure shall be in accordance with NACE TM 0177 or EFC Publication No. 17.

For duplex stainless steels, austenitic stainless steel, nickel alloys and titanium alloys, SCC should be carried out at maximum service temperature. In addition, for duplex stainless steel, the SCC test shall be also done at 80 ^{o}C which is the most susceptible cracking temperature for duplex stainless steel. Simulated formation water with bicarbonate and chloride and calculated in-situ pH of formation water shall be used for the test.

Test Criteria

a) Specimen Examination

After 30 days of the test, samples shall be cleaned and inspected by visual examination and MPI. Photographs shall be made at x1 and x10 magnifications of the stressed surfaces of each specimen.

Whenever a crack is found, the specimen shall be cut longitudinally at crack location, polished and etched. Photographs of the stressed surface and macro-section shall then be taken. It shall be metallurgically examined and the metallurgical features recorded with photomicrographs. Specimens which do not exhibit crack on their external surface, shall be cut transverse to weld (transverse to rolling direction) at 5 mm and at 10 mm from their external transverse faces. The sectioned surfaces shall be ground smooth with 600 grit emery paper, minimum, following machining.

Visual examination of unetched sections shall be made at X1, X10 and X100 magnifications. If cracks are observed, specimens shall be properly etched. Photographs shall be made at a suitable magnification before and after etching.

b) **Test Acceptance Criteria**

No crack (or rupture) shall be accepted in any of the tested pipes within the 30 day period of testing. Little grooves or pits caused by corrosion loss will not be considered, in mutual agreement between supplier and inspector.

For production test, if there is a failure the COMPANY may accept to have four pipes of the same heat retested. If a retest fails, the said heat shall be rejected and all heats of the said casting sequence shall be tested on two pipes minimum before release or reject of each individual heat of the sequence.

In all cases, re-test pipes shall be selected in mutual agreement between the Supplier and the Inspector.

The Supplier shall investigate and clarify the cause of any failure in order to initiate corrective actions / re-testing, to the satisfaction of COMPANY.

7.3.6 FABRICATION AND WELD REPAIRS

7.3.6.1 FABRICATION

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

1) Design and/or fabrication rules described in the regulations in force and the construction code adopted.
2) 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
3) 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.

7.3.6.2 WELD REPAIR OF STEEL PLATE AND CASTINGS

For Severe and Intermediate “Sour Service” conditions (Region 2 and 3) weld repair of plate surface defects will not be permitted.

All castings shall be suitably heat treated after any performed welding operation. This requirement applies also to the weld repair of defects, irrespective of size. All casting weld repairs 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.

Note: As mentioned in ISO 15156 -2, paragraphs A.2.4, cast iron is prohibited if it is in contact or is liable to be in contact with an atmosphere containing H_2S irrespective of its concentration.

7.3.7 INSPECTION

In addition to normal inspection, the following shall apply:

7.3.7.1 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.

7.3.7.2 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.

7.3.7.3 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.

7.3.7.4 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.

7.3.7.5 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.

8.0 APPENDICES

Appendix 1. ULTRASONIC TESTING METHODS (For HIC Test)

Ultrasonic testing shall be fully automatic. It shall be made using the pulse-echo method, compression waves and immersion technique (clean fresh water). It shall be made from one side of specimen with ultrasonic beam perpendicular to specimen surface. Water path distance transducer/specimen shall be defined.

Ultrasonic Generator shall have been calibrated within the past six months by an independent and recognized laboratory. A copy of the calibration certificate shall be made available to the Inspector. It shall be able to perform, as a minimum, one of the two following adjustments:

1) The Distance-Amplitude Correction (DAC)
2) The equalization of heights of echoes from several artificial reflectors: Time Correction Gain (TCG)

Transducer shall have the following characteristics:

1) Mono or double transducer
2) Focalized or of cylindrical type ultrasonic beam
3) Frequency = 10 to 15 MHz

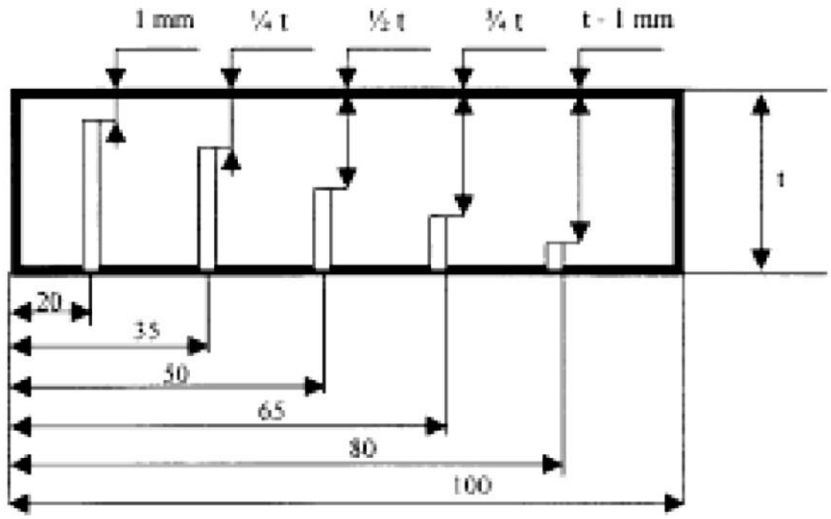
The following shall also be defined by the Supplier:

1) Transducer type, characteristics, serial number
2) Active diameter

The manufacturer's data sheet of transducer shall be available.

Calibration of the UT equipment shall be performed as follows:

1) Calibration of time base shall be made using a block cut from a pipe sample having the dimensions of specimens to be tested (thickness x width x length). The distance shall be measured between water/specimen interface echo and the first back wall echo, or between first and second back wall echo.
2) Calibration of sensitivity shall be made with a block of same dimensions as above which includes five transverse flat bottom notches 1 mm wide, with depths 1 mm, ¼ t, ½ t, ¾ t and t less 1 mm, as shown on sketch below: Sensitivity may be made using either the DAC curve method or the TCG level method. The echo from the 1 mm deep notch shall be adjusted to 80 % Full Screen Height (FSH), whatever the selected method (i.e. DAC curve method or TCG level method). The threshold/referenced level shall be the said DAC curve or TCG level. All indications equal to or above DAC curve or TCG level (when applicable) shall be recorded.



3) Transducer Movement shall comply with the following:
   a) Strictly parallel to specimen surface within 0.5 % in all directions and any correction will be made easily, where necessary
   b) Distance transducer/specimen surface accurately adjusted, measured and recorded
   c) Smooth movement, without any stopping
   d) Speed less than 130 mm/second
   e) Scanning pitch to ensure an overlapping of 20 % min of transducer diameter

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