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Materials for Sour Service in Exploration and Production Operations

Group Practice

**BP GROUP
ENGINEERING TECHNICAL PRACTICES**

Foreword

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Introduction

Numerous types of material are used in sour service, including carbon steel, low alloy steels, corrosion resistant alloys, and other alloys. This has resulted in an extensive amount of satisfactory service experience.

Materials need to be chosen with care, however, since they are potentially susceptible to various cracking mechanisms, of which the particular type depends on specific material. For satisfactory service, therefore, it is necessary to understand the environmental conditions and the metallurgical condition of the material that gives rise to the maximum resistance to cracking.

Responsibility is now placed on the equipment user by NACE MR0175/ISO 15156 to ensure that materials used in sour service are fit for purpose.



1. Scope

- a. This Group Practice (GP) provides requirements for selection of materials used in exploration and production operations. As such, this GP is based on NACE MR0175/ISO 15156. Refining and marketing operations are covered in separate GP 06-20 and associated NACE MR0103.
- b. This GP is supplementary to NACE MR0175/ISO 15156 and includes:
 1. Requirements to avoid environmental cracking of materials used for equipment in sour service (i.e., fluids containing water and hydrogen sulphide (H₂S)).
 2. Additional BP specific requirements, including other aspects related to cracking not included in NACE MR0175/ISO 15156.
- c. General corrosion is not covered in this GP and is therefore a separate consideration.

2. Normative references

The following referenced documents may, to the extent specified in subsequent clauses and normative annexes, be required for full compliance with this GP:

- For dated references, only the edition cited applies.
- For undated references, the latest edition (including any amendments) applies.

BP

GIS 18-013	Integral Cladding, Weld Overlay, and Limited Loose Lining of Pressure Vessels and Components.
GIS 18-014	Heat Exchanger Tube End Fixing.
GIS 36-102	Hardness Testing, Post Weld Heat Treatment, Stress Relief, and Pickling for Pressure Vessels, Piping, and Other Components.
GIS 42-101	Fabrication, Assembly, Erection, and Inspection of Carbon, Carbon Manganese, and Low Alloy Steel Pipework (ASME B31.3).
GIS 42-102	Fabrication, Assembly, Erection, and Inspection of Austenitic and Duplex Stainless Steel, Cupro-Nickel, Nickel Base Alloy, Titanium, and Zirconium Pipework (ASME B31.3).
GIS 46-010	New Pressure Vessels.
GN 36-004	Best Practice for Selection of Materials for Downhole Equipment (Revision 2.1).
GN 36-013	Guidelines for Selecting Downhole Tubing and Casing Materials for Oil and Gas Production Wells (2006 Edition).
GN 36-017	Domain Diagrams for 316L Stainless Steel in Oil and Gas Production Environments.
GP 06-20	Materials for Sour Service.
GP 36-10	Metallic Materials Selection.
GP 36-12	Amine Services.

American Petroleum Institute (API)

API RP 579	Fitness-for-Service.
API RP 945	Avoiding Environmental Cracking in Amine Units.
API Spec 5CT	Specification for Casing and Tubing.



American Society for Non-Destructive Testing (ASNT)

ASNT TC-1A Personnel Qualification and Certification in Nondestructive Testing.

American Society for Testing and Materials (ASTM)

ASTM A193/A193M Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications.

ASTM A194/A194M Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service or Both.

ASTM A264 Stainless Chromium-Nickel Steel-Clad Plate.

ASTM A265 Nickel and Nickel-Base Alloy-Clad Steel Plate.

ASTM A395/A395M Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures.

ASTM A516/A516M Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service.

ASTM A841/A841M Steel Plates for Pressure Vessels, Produced by Thermo-Mechanical Control Process (TMCP).

British Standards Institute (BSI)

BS EN 10028 Flat products made of steel for pressure purposes.

BS EN 10028-1 Flat products made of steels for pressure purposes. General requirements.

BS EN 10028-2 Flat products made of steel for pressure purposes. Non-alloy and alloy steels with specified elevated temperature properties.

BS EN 10028-3 Flat products made of steel for pressure purposes. Weldable fine grain steels, normalized.

BS EN 10028-4 Flat products made of steels for pressure purposes. Nickel alloy steels with specified low temperature properties.

BS EN 10028-5 Flat products made of steels for pressure purposes. Weldable fine grain steels, thermomechanically rolled.

BS EN 10028-6 Flat products made of steel for pressure purposes. Weldable fine grain steels, quenched and tempered.

BS EN 10028-7 Flat products made of steels for pressure purposes. Stainless steels.

BS EN 10160 Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method).

BS EN 10164 Steel products with improved deformation properties perpendicular to the surface of the product. Technical delivery conditions.

International Organization for Standardization (ISO)

ISO 6508-1 Metallic materials - Rockwell hardness test - Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T).

ISO 11960 Petroleum and natural gas industries - Steel pipes for use as casing or tubing for wells.

ISO 15156-1 Petroleum and natural 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 natural 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.



ISO 15156-3 Petroleum and natural 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.

NACE International (NACE)

NACE MR0103 Standard Material Requirements - Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments.

NACE MR0175 Petroleum and natural gas industries - Materials for use in H₂S-containing environments in oil and gas production.

NACE RP0472 Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments.

NACE TM0284 Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking.

3. Terms and definitions

For the purposes of this GP, the following terms and definitions apply:

Hydrogen flux

A flow of hydrogen per unit area that is typically measured in picolitre (pl) of gaseous hydrogen at 20°C (68°F) per cm² steel surface per second (i.e., pl/cm²/s). Hydrogen flux is affected by pH and pH₂S and other factors, such as the presence of cyanides and arsenic.

Nascent hydrogen

Hydrogen atoms that are produced by corrosion may diffuse into the steel and result in various damage mechanisms. This species is often referred to as nascent hydrogen and/or H⁰.

pH (measure of acidity/alkalinity)

Minus log of hydrogen ion concentration.

pH₂S (partial pressure of H₂S)

Pressure of H₂S that would be exerted if present alone, at the same temperature, in the total volume occupied by the mixture.

Pressure

If the NACE standards refer to pressure, this shall be taken as design pressure.

Sour service

Exposure to environments that contain H₂S and liquid water (H₂O) and can cause cracking of materials by the mechanisms addressed in this GP.

4. Symbols and abbreviations

For the purpose of this GP, the following symbols and abbreviations apply (see NACE MR0175/ISO 15156 Parts 1, 2, and 3 - Section 3 for full details):

BOF Basic oxygen furnace.

CE Carbon equivalent.

CLR Crack length ratio.



CRA	Corrosion resistant alloy.
CSR	Crack sensitivity ratio.
CTR	Crack thickness ratio.
ERW	Electric resistance welded.
FFKM	Perfluoroelastomer.
FKM	Fluoroelastomer.
FPB	Four point bend.
GHSC	Galvanically induced hydrogen stress cracking.
HAZ	Heat affected zone.
HIC	Hydrogen induced cracking.
HNBR	Hydrogenated nitrile rubber.
HP/HT	High pressure/high temperature.
HRC	Rockwell hardness.
HSC	Hydrogen stress cracking.
NBR	Nitrile rubber.
NDE	Nondestructive examination.
OD	Outer diameter.
PACR	Predicted average cracking ratio.
pl	picolitre.
ppm	Parts per million.
PTFE	Polytetrafluoroethylene.
PWHT	Post weld heat treatment.
Q+T	Quenched and tempered (steel).
RBI	Risk based inspection.
SAW	Submerged arc welded.
SCC	Stress corrosion cracking.
SOHIC	Stress oriented, hydrogen induced cracking.
SSC	Sulphide stress cracking.
SWC	Stepwise cracking.



SZC	Soft zone cracking.
TFEP	Tetrafluoroethylene polymer.
TMCP	Thermo mechanical control process.
UT	Uniaxial tension.
WFMT	Wet fluorescent magnetic particle testing.

5. General outline of a sour service plan

In view of the propensity to failure of equipment in wet H₂S environments, if not properly controlled, a sour service plan shall be developed that covers the following:

- a. Initial materials selection that complies with NACE MR0175/ISO 15156.
- b. Detailed operational aspects, including environmental conditions and inspection requirements, to confirm continued integrity (see Annex E).
- c. Additional requirements set by appropriate BP ETP specifications.

6. Factors that affect cracking

6.1. General materials factors

Background on cracking mechanisms from exposure to H₂S containing (sour) environments is given in Annex C.

6.2. Maximum allowable hardness

Unless stated otherwise in this GP, the maximum acceptable hardness levels to minimise the potential for SSC cracking shall be as specified in NACE MR0175/ISO 15156.

7. Materials selection for sour service conditions in exploration and production operations

7.1. Definition of sour environment severity

- a. H₂S
 1. In accordance with the definition of NACE MR0175/ISO 15156 and this GP, the presence of any measurable levels of H₂S can result in a sour environment, depending on the cracking mechanism being considered.
 2. If H₂S conditions vary, peak transient conditions shall be used in design.
- b. Acidity shall be defined.
- c. Chloride content shall be defined.
- d. Contaminants, such as cyanides, arsenic, and ammonia, shall be reported and considered in material selection.
- e. Defined environment - Conditions shall be clearly defined prior to establishing the suitability of a material.



7.2. Metallic materials

- a. Metallic materials selection shall comply with NACE MR0175/ISO 15156, except as modified by this GP.
- b. The following is an overview of NACE MR0175/ISO 15156 requirements:
 - 1. Mechanisms - SCC, HIC/SWC, SOHIC, SZC, SSC, and GHSC are included.
 - 2. Selection of metallic materials for sour service shall involve the following, as a minimum:
 - a) Qualifying the suitability of materials by any of the following:
 - 1) Selecting from a prequalified list in NACE MR0175/ISO 15156.
 - 2) Laboratory testing.
 - 3) Documented field experience.
 - b) Defining the service environment in terms of the aggressive species.
 - c) Documenting material properties that affect cracking and confirming that they meet sour service requirements (e.g., hardness values).
 - d) Documenting quality control of the material.
 - e) Evaluating materials for resistance to cracking by the various mechanisms.

7.3. Nonmetallic materials

- a. General
 - 1. Nonmetallic seal materials and seal geometry shall be subject to BP approval.
 - 2. Elastomer selection shall take into account the complete operating conditions to be encountered (i.e., temperature, pressure, and environment).
- b. Low H₂S levels
 - 1. NBR shall have a maximum long term limit of exposure between 10 ppm and 100 ppm H₂S, depending on seal geometry and temperature.
 - 2. HNBR shall have a maximum long term limit of exposure between 100 ppm and 1 000 ppm H₂S, depending on seal geometry and temperature.
- c. For H₂S levels less than or equal to 5%, either FKM “Viton” type fluoroelastomers or TFEP “Aflas” shall be used.
- d. H₂S levels greater than 5%
 - 1. FFKM perfluoroelastomers (Chemraz or Kalrez) shall be used.
 - 2. PTFE may also be selected, but it requires a different type of seal configuration compared with that for elastomers.

8. Application of NACE MR0175/ISO 15156 to material selection for exploration and production operations**8.1. Qualification of cracking resistant carbon and low alloy steels and cast irons (for SSC, SZC, HIC, and SOHIC resistance) (NACE MR0175/ISO 15156 - Part 2 and Part 1)**