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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

Industries du pétrole et du gaz naturel — Matériaux pour utilisation dans des environnements contenant de l'hydrogène sulfuré (H2S) dans la production de pétrole et de gaz —

Partie 2: Aciers au carbone et aciers faiblement alliés résistants à la fissuration, et utilisation de fontes

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This third edition cancels and replaces the second edition (ISO 15156-2:2009), of which it constitutes a minor revision, specifically by the following:

— replacement in the Scope of the term "conventional elastic design criteria" by the term "load controlled design methods";

— inclusion in both 7.2.1.1 and A.2.1.1 of information that emphasizes the possibilities for the qualification for a specific sour service or range of sour service of carbon and low alloy steels not listed in Annex A;

— replacement of paragraph 6 of A.2.1.4 to improve the guidance on the welding of carbon and low alloy steels not covered elsewhere in this subclause.

ISO 15156 consists of the following parts, under the general title *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*

— *Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons*

— *Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

Introduction

The consequences of sudden failures of metallic oil and gas field components, associated with their exposure to H_2S-containing production fluids, led to the preparation of the first edition of NACE MR0175, which was published in 1975 by the National Association of Corrosion Engineers, now known as NACE International.

The original and subsequent editions of NACE MR0175 established limits of H_2S partial pressure above which precautions against sulfide stress-cracking (SSC) were always considered necessary. They also provided guidance for the selection and specification of SSC-resistant materials when the H_2S thresholds were exceeded. In more recent editions, NACE MR0175 has also provided application limits for some corrosion-resistant alloys, in terms of environmental composition and pH, temperature and H_2S partial pressures.

In separate developments, the European Federation of Corrosion issued EFC Publication 16 in 1995 and EFC Publication 17 in 1996. These documents are generally complementary to those of NACE though they differed in scope and detail.

In 2003, the publication of the ISO 15156-series and NACE MR0175/ISO 15156 was completed for the first time. These technically identical documents utilized the above sources to provide requirements and recommendations for materials qualification and selection for application in environments containing wet H_2S in oil and gas production systems. They are complemented by NACE TM0177 and NACE TM0284 test methods.

The revision of this part of ISO 15156 involves a consolidation of all changes agreed and published in the Technical Circular 1, ISO 15156-2:2009/Cir.1:2011(E) and the Technical Circular 2, ISO 15156-2:2009/Cir.2:2014(E), published by the ISO 15156 Maintenance Agency secretariat at DIN.

The changes were developed by and approved by the ballot of, representative groups from within the oil and gas production industry. The great majority of these changes stem from issues raised by document users. A description of the process by which these changes were approved can be found at the ISO 15156 maintenance website: www.iso.org/iso15156maintenance.

When found necessary by oil and gas production industry experts, future interim changes to this part of ISO 15156 will be processed in the same way and will lead to interim updates to this part of ISO 15156 in the form of Technical Corrigenda or Technical Circulars. Document users should be aware that such documents can exist and can impact the validity of the dated references in this part of ISO 15156.

The ISO 15156 Maintenance Agency at DIN was set up after approval by the ISO Technical Management Board given in document 34/2007. This document describes the make up of the agency, which includes experts from NACE, EFC and ISO/TC 67, and the process for approval of amendments. It is available from the ISO 15156 maintenance website and from the ISO/TC 67 Secretariat. The website also provides access to related documents that provide more detail of ISO 15156 maintenance activities.

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

WARNING — Carbon and low-alloy steels and cast irons selected using this part of ISO 15156 are resistant to cracking in defined — H_2S-containing environments in oil and gas production but not necessarily immune to cracking under all service conditions. It is the equipment user's responsibility to select the carbon and low alloy steels and cast irons suitable for the intended service.

1 Scope

This part of ISO 15156 gives requirements and recommendations for the selection and qualification of carbon and low-alloy steels for service in equipment used in oil and natural gas production and natural gas treatment plants in H_2S-containing environments, whose failure can pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials requirements of the appropriate design codes, standards or regulations.

This part of ISO 15156 addresses the resistance of these steels to damage that can be caused by sulfide stress-cracking (SSC) and the related phenomena of stress-oriented hydrogen-induced cracking (SOHIC) and soft-zone cracking (SZC).

This part of ISO 15156 also addresses the resistance of these steels to hydrogen-induced cracking (HIC) and its possible development into stepwise cracking (SWC).

This part of ISO 15156 is concerned only with cracking. Loss of material by general (mass loss) or localized corrosion is not addressed.

Table 1 provides a non-exhaustive list of equipment to which this part of ISO 15156 is applicable, including permitted exclusions.

This part of ISO 15156 applies to the qualification and selection of materials for equipment designed and constructed using load controlled design methods. For design utilizing strain-based design methods, see ISO 15156-1:2015, Clause 5.

Annex A lists SSC-resistant carbon and low alloy steels, and A.2.4 includes requirements for the use of cast irons.

This part of ISO 15156 is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

Table 1 — List of equipment

ISO 15156 is applicable to materials used for the following equipment	Permitted exclusions
Drilling, well construction and well-servicing equipment	Equipment exposed only to drilling fluids of controlled composition[a] Drill bits Blowout preventer (BOP) shear blades[b] Drilling riser systems Work strings Wireline and wireline equipment[c] Surface and intermediate casing
Wells, including subsurface equipment, gas lift equipment, wellheads and christmas trees	Sucker rod pumps and sucker rods[d] Electric submersible pumps Other artificial lift equipment Slips
Flow-lines, gathering lines, field facilities and field processing plants	Crude oil storage and handling facilities operating at a total absolute pressure below 0,45 MPa (65 psi)
Water-handling equipment	Water-handling facilities operating at a total absolute pressure below 0,45 MPa (65 psi) Water injection and water disposal equipment
Natural gas treatment plants	—
Transportation pipelines for liquids, gases and multiphase fluids	Lines handling gas prepared for general commercial and domestic use
For all equipment above	Components loaded only in compression

[a] See A.2.3.2.3 for more information.

[b] See A.2.3.2.1 for more information.

[c] Wireline lubricators and lubricator connecting devices are not permitted exclusions.

[d] For sucker rod pumps and sucker rods, reference can be made to NACE MR0176.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 6507-1, *Metallic materials — Vickers hardness test — Part 1: Test method*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 10423, *Petroleum and natural gas industries — Drilling and production equipment — Wellhead and Christmas tree equipment*

ISO 15156-1:2015, *Petroleum and natural gas industries — Materials for use in* H_2S*-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-3:2015, *Petroleum and natural gas industries — Materials for use in* H_2S*-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

NACE TM0177[1)], *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H2S environments*

NACE TM0284, *Evaluation of pipeline and pressure vessel steels for resistance to hydrogen-induced cracking*

EFC Publications Number 16, *Guidelines on materials requirements for carbon and low alloy steels for* H2S*-containing environments in oil and gas production*[2)]

SAE AMS-2430[3)], *Shot Peening, Automatic*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15156-1 and the following apply.

3.1
Brinell hardness
HBW
hardness value, measured in accordance with ISO 6506-1, normally using a 10 mm diameter tungsten ball and a force of 29,42 kN

Note 1 to entry: For the purposes of this provision, ASTM E10 is equivalent to ISO 6506-1.

3.2
bubble-point pressure
p_B
pressure under which gas bubbles form in a liquid at a particular operating temperature

Note 1 to entry: See C.2.

3.3
burnish
process of smoothing surfaces using frictional contact between the material and some other hard pieces of material, such as hardened steel balls

3.4
casting
metal that is obtained at or near its finished shape by the solidification of molten metal in a mould

3.5
cast iron
iron-carbon alloy containing approximately 2 % to 4 % mass fraction carbon

3.5.1
grey cast iron
cast iron that displays a grey fracture surface due to the presence of flake graphite

3.5.2
white cast iron
cast iron that displays a white fracture surface due to the presence of cementite

3.5.3
malleable iron
white cast iron that is thermally treated to convert most or all of the cementite to graphite (temper carbon)

1) NACE International, P.O. Box 2183140, Houston, Texas 77218-8340, USA.

2) European Federation of Corrosion, available from The Institute of Materials, 1 Carlton House Terrace, London SW1Y 5DB, UK [ISBN 0-901716-95-2].

3) Society of Automotive Engineers (SAE), 400 Commonwealth Drive, Warrendale, PA 15096-0001 USA.

3.5.4
ductile iron
nodular cast iron
cast iron that has been treated while molten with an element (usually magnesium or cerium) that spheroidizes the graphite

3.6
cementite
microstructural constituent of steels composed principally of iron carbide (Fe_3C)

3.7
cold working
cold deforming
cold forging
cold forming
deforming metal plastically under conditions of temperature and strain rate that induce strain-hardening, usually, but not necessarily, conducted at room temperature

3.8
fitness-for-purpose
suitability for use under the expected service conditions

3.9
free-machining steel
steel to which elements such as sulfur, selenium and lead have been added intentionally to improve machineability

3.10
lower critical temperature
temperature of a ferrous metal at which austenite begins to form during heating or at which the transformation of austenite is completed during cooling

3.11
nitriding
case-hardening process in which nitrogen is introduced into the surface of metallic materials (most commonly ferrous alloys)

EXAMPLE Liquid nitriding, gas nitriding, ion nitriding and plasma nitriding.

3.12
normalizing
heating a ferrous metal to a suitable temperature above the transformation range (austenitizing), holding at temperature for a suitable time and then cooling in still air (or protective atmosphere) to a temperature substantially below the transformation range

3.13
plastically deformed
permanently deformed by stressing beyond the limit of elasticity, i.e. the limit of proportionality of stress to strain

3.14
pressure-containing part
part whose failure to function as intended results in a release of retained fluid to the atmosphere

EXAMPLE Valve bodies, bonnets and stems.

3.15
quenched and tempered
quench hardened and then tempered

3.16
Rockwell C hardness
HRC
hardness value, measured in accordance with ISO 6508, obtained using a diamond cone indenter and a force of 1 471 N

Note 1 to entry: For the purposes of this provision, ASTM E18 is equivalent to ISO 6508-1.

3.17
shot-peening
inducing compressive stresses in the surface layer of a material by bombarding it with a selected medium (usually round steel shot) under controlled conditions

3.18
stress relief
heating a metal to a suitable temperature, holding at that temperature long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses

3.19
tempering
heat treatment by heating to a temperature below the lower critical temperature, for the purpose of decreasing the hardness and increasing the toughness of hardened steel, hardened cast iron and, sometimes, normalized steel

3.20
tensile strength
ultimate strength
ratio of maximum load to original cross-sectional area

Note 1 to entry: See ISO 6892-1.

3.21
test batch
group of items representing a production batch whose conformity with a specified requirement can be determined by testing representative samples in accordance with a defined procedure

3.22
tubular component
cylindrical component (pipe) having a longitudinal hole, used in drilling/production operations for conveying fluids

3.23
Vickers hardness
HV
hardness value, measured in accordance with ISO 6507-1, obtained using a diamond pyramid indenter and one of a variety of possible applied loads

Note 1 to entry: For the purposes of this provision, ASTM E384 is equivalent to ISO 6507-1.

3.24
weldment
portion of a component on which welding has been performed, including the weld metal, the heat-affected zone (HAZ), and the adjacent parent metal

3.25
weld metal
portion of a weldment that has been molten during welding

3.26
wrought
(metal in the solid condition) formed to a desired shape by working (rolling, extruding, forging, etc.), usually at an elevated temperature

4 Symbols and abbreviated terms

For the purposes of this document, the abbreviated terms given in ISO 15156-1 and the following apply.

AYS	actual yield strength
CLR	crack length ratio
CSR	crack surface ratio
CTR	crack thickness ratio
DCB	double cantilever beam (test)
FPB	four-point bend (test)
HBW	Brinell hardness
HIC	hydrogen-induced cracking
HRC	Rockwell hardness (scale C)
HSC	hydrogen stress cracking
HV	Vickers hardness
OCTG	oil country tubular goods, i.e. casing, tubing and drill pipe
p_{H_2S}	partial pressure of H_2S
$R_{p0,2}$	0,2 % proof stress in accordance with ISO 6892-1
SMYS	specified minimum yield strength
SOHIC	stress-oriented hydrogen-induced cracking
SSC	sulfide stress-cracking
SWC	stepwise cracking
SZC	soft-zone cracking
T	temperature
UNS	Unified Numbering System (from SAE-ASTM, *Metals and alloys in the Unified Numbering System*)
UT	uniaxial tensile (test)

5 Purchasing information

5.1 The preparation of material purchasing specifications can require co-operation and exchange of data between the equipment user, the equipment supplier and the material manufacturer to ensure that the material purchased complies with ISO 15156-1 and this part of ISO 15156.

5.2 The following information shall be provided:

— preferred material types and/or grades (if known);

— equipment type (if known);

— reference to this part of ISO 15156;

— acceptable bases for selection of materials for SSC resistance (see Clause 7);

— requirements for HIC resistance (see Clause 8).

5.3 The equipment user and the equipment supplier/material manufacturer may agree that carbon or low-alloy steels other than those described and/or listed in Annex A may be selected subject to suitable qualification testing in accordance with Annex B and ISO 15156-1. The qualification requirements may be extended to include resistance to SOHIC and SZC.

If the purchaser intends to make use of such agreements, extensions and qualifications, the appropriate additional information shall be clearly indicated in the materials purchasing specification. This information may include

— requirements for SSC testing (see 7.1 and 7.2),

— service conditions for specific sour-service application, and

— other special requirements.

5.4 Annex C describes how to calculate the H_2S partial pressure and Annex D gives guidance on how to determine the pH-value of a fluid.

5.5 The information required for material purchasing shall be entered on suitable data sheets. Suggested formats are given in Annex E.

6 Factors affecting the behaviour of carbon and low alloy steels in H_2S-containing environments

The behaviour of carbon and low-alloy steels in H_2S-containing environments is affected by complex interactions of parameters, including the following:

a) chemical composition, method of manufacture, product form, strength, hardness of the material and its local variations, amount of cold work, heat-treatment condition, microstructure, microstructural uniformity, grain size and cleanliness of the material;

b) H_2S partial pressure or equivalent concentration in the water phase;

c) chloride ion concentration in the water phase;

d) acidity (pH) of the water phase;

e) presence of sulfur or other oxidants;

f) exposure to non-production fluids;

g) exposure temperature;

h) total tensile stress (applied plus residual);

i) exposure time.

These factors shall be considered when using this part of ISO 15156 for the selection of materials suitable for environments containing H_2S in oil and gas production systems.

7 Qualification and selection of carbon and low-alloy steels with resistance to SSC, SOHIC and SZC

7.1 Option 1 — Selection of SSC-resistant steels (and cast irons) using A.2

7.1.1 For p_{H2S} < 0,3 kPa (0,05 psi)

The selection of materials for SSC resistance for p_{H2S} below 0,3 kPa (0,05 psi) is not considered in detail in this part of ISO 15156. Normally, no special precautions are required for the selection of steels for use under these conditions, nevertheless, highly susceptible steels can crack. Additional information on factors affecting susceptibility of steels and attack by cracking mechanisms other than SSC is given in 7.2.1.

7.1.2 For p_{H2S} ≥ 0,3 kPa (0,05 psi)

If the partial pressure of H_2S in the gas is equal to or greater than 0,3 kPa (0,05 psi), SSC-resistant steels shall be selected using A.2.

NOTE 1 The steels described or listed in A.2 are considered resistant to SSC in oil and natural-gas production and natural-gas treatment plants.

NOTE 2 Users concerned with the occurrence of SOHIC and/or SZC can refer to Option 2 (see 7.2.2).

NOTE 3 For HIC and SWC, see Clause 8.

7.2 Option 2 — Selection of steels for specific sour-service applications or for ranges of sour service

7.2.1 Sulfide stress-cracking

7.2.1.1 General

Option 2 allows the user to qualify and select materials for sulfide stress-cracking (SSC) resistance for specific sour-service applications or for ranges of sour service.

For a given material, the limits of environmental and metallurgical variables defined for specific sour service or for a range of sour service by qualification in accordance with Option 2 may replace any limits of environmental and metallurgical variables listed for that material in A.2 (Option 1).

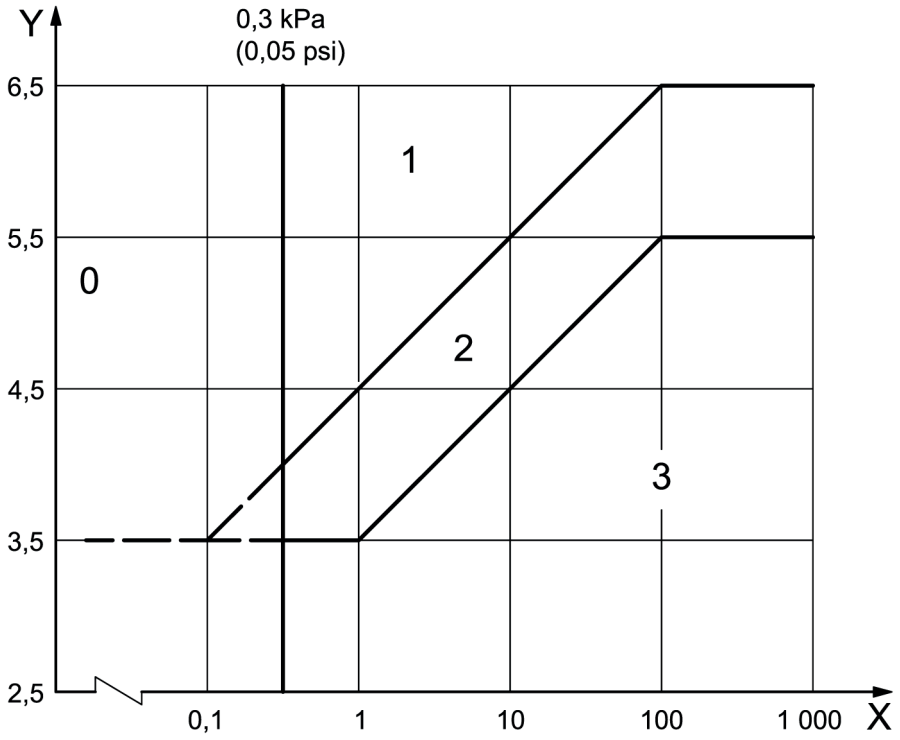
The use of option 2 can require knowledge of both the *in situ* pH and the H_2S partial pressure and their variations with time; see ISO 15156-1.

Option 2 facilitates the purchase of bulk materials, such as OCTG or line pipe, where the economic incentive to use materials not described nor listed in Annex A outweighs the additional qualification and other costs that can be incurred. Steels for other equipment may also be qualified. In some cases, this requires an agreement between the supplier and the equipment user with respect to test and acceptance requirements. Such agreements shall be documented.

Option 2 can also facilitate fitness-for-purpose evaluations of existing carbon or low-alloy steel equipment exposed to sour-service conditions more severe than assumed in the current design.

7.2.1.2 SSC regions of environmental severity

The severity of the sour environment, determined in accordance with ISO 15156-1, with respect to the SSC of a carbon or low-alloy steel shall be assessed using Figure 1. In defining the severity of the H_2S-containing environment, the possibility of exposure to unbuffered, condensed aqueous phases of low pH during upset operating conditions or downtime, or to acids used for well stimulation and/or the backflow of stimulation acid after reaction should be considered.



Key

X H_2S partial pressure, expressed in kilopascals

Y *in situ* pH

0 region 0

1 SSC region 1

2 SSC region 2

3 SSC region 3

NOTE 1 The discontinuities in the figure below 0,3 kPa (0,05 psi) and above 1 MPa (150 psi) partial pressure H_2S reflect uncertainty with respect to the measurement of H_2S partial pressure (low H_2S) and the steel's performance outside these limits (for both low and high H_2S).

NOTE 2 Guidance on the calculation of H_2S partial pressure is given in Annex C.

NOTE 3 Guidance on the calculation of pH is given in Annex D.

Figure 1 — Regions of environmental severity with respect to the SSC of carbon and low-alloy steels

7.2.1.3 Region 0 — For p_{H2S} < 0,3 kPa (0,05 psi)

Normally, no precautions are required for the selection of steels for use under these conditions. Nevertheless, a number of factors, as follows, that can affect a steel's performance in this region should be considered.

— Steels that are highly susceptible to SSC and HSC can crack.

— Steel's physical and metallurgical properties affect its inherent resistance to SSC and HSC; see Clause 6.

— Very high-strength steels can suffer HSC in aqueous environments without H_2S. Above about 965 MPa (140 ksi) yield strength, attention should be given to steel composition and processing to ensure that these steels do not exhibit SSC or HSC in region 0 environments.

— Stress concentrations increase the risk of cracking.