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Petroleum and natural gas industries — Materials for use in H_2S-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 (H_2S) 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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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 15156-2 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore strcutures for petroleum and natural gas industries*.

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

— *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. NACE MR0175 is complemented by NACE TM0177-96 and NACE TM0284 test methods.

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 differ in scope and detail.

This part of ISO 15156 utilizes 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.

Changes will be incorporated into this part of ISO 15156 by amendment or revision in accordance with *Interpretation and maintenance of ISO 15156* by ISO/TC 67/WG 7, copies of which can be obtained from the ISO/TC 67 Secretariat. Experts from both NACE and EFC are members of ISO/TC 67/WG 7.

Petroleum and natural gas industries — Materials for use in H_2S-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 could 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 may 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 only concerned 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 conventional elastic design criteria. For designs utilizing plastic criteria (e.g. strain-based and limit-state designs), see ISO 15156-1:2001, 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 only exposed 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)
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 referenced documents are indispensable for the application of this document. 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 (scales A, B, C, D, E, F, G, H, K, N, T)*

ISO 6892, *Metallic materials — Tensile testing at ambient temperature*

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

ISO 15156-1:2001, *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*

NACE TM0177-96[1], *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H_2S environments*

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

EFC Publications Number 16[2], *Guidelines on materials requirements for carbon and low alloy steels for H_2S-containing environments in oil and gas production*

SAE AMS-S-13165[3], *Shot peening of metal parts*

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

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

NOTE 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 % 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

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

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

3.5.4
ductile cast 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)

EXAMPLES 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 parts
those parts whose failure to function as intended would result in a release of retained fluid to the atmosphere

NOTE Examples are 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

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 relieving
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 See ISO 6892.

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

3.24
weldment
that 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
that portion of a weldment that has been molten during welding

3.26
wrought metal
metal in the solid condition that is 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

CR c-ring (test)

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

SMYS specified minimum yield strength

SOHIC stress-oriented hydrogen-induced cracking

SSC sulfide stress-cracking

SWC stepwise cracking

SZC soft-zone cracking

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 might 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, 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_{H_2S} < 0,3 kPa (0,05 psi)

The selection of materials for SSC resistance for p_{H_2S} 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. Further 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 $p_{H_2S} \geqslant$ 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, refer to 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 (SSC)

7.2.1.1 General

Option 2 allows the user to qualify and select materials for SSC resistance for specific sour service applications or for ranges of sour service.

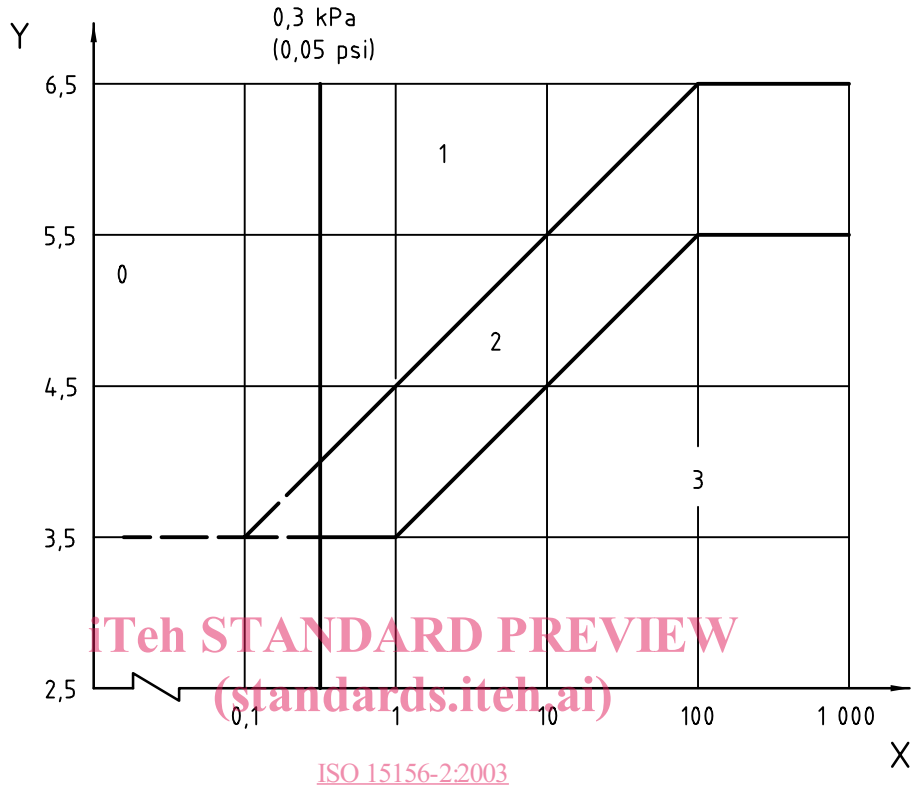
The use of Option 2 may require knowledge of both the *in situ* pH and the H_2S partial pressure and their variations with time (see ISO 15156-1).

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 might be incurred. Steels for other equipment may also be qualified. In some cases this will require 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 SSC of a carbon or low alloy steel shall be assessed using Figure 1.



Key

X H_2S partial pressure, kPa

Y *in situ* pH

0 Region 0
1 SSC Region 1
2 SSC Region 2
3 SSC Region 3

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.

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 steel's performance outside these limits (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 SSC of carbon and low alloy steels

7.2.1.3 Region 0, p_{H_2S} < 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 that can affect a steel's performance in this region should be considered, as follows.

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