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Petroleum and natural gas industries — Materials selection for high content CO_2 for casing, tubing and downhole equipment

Industries du pétrole et du gaz naturel — Choix des matériaux une teneur élevée en CO_2 pour tubes de cuvelage et de production et équipements de fond

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Foreword

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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).

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

Introduction

This International Standard gives recommendations and guidelines for materials selection in oil and gas production wells, specifically for high CO_2 content gas injection and production systems, as well as for water alternating gas (WAG) injection systems. It is intended to enable responsible parties to carry out materials selection in a consistent manner as a part of the engineering work, based upon a design basis for a particular installation. The main users of this International Standard are oil and gas production companies and engineering contractors. Material manufacturers and equipment suppliers can benefit from using this International Standard for their product development.

Carbon capture and storage (CCS) has been identified as an important technology for achieving a significant reduction in CO_2 emissions to the atmosphere.

Many of the technologies and practices that have been developed for CO_2 enhanced oil recovery (EOR) can have applicability in CCS projects, assuming that each project design meets its site-specific conditions. The CO_2 EOR experiences of the oil and gas industry represent the largest collective base of technical information available on CO_2 injection and, as such, provide valuable information for development and implementation of CCS field projects as they move forward.

This International Standard does not provide detailed material requirements and recommendations for manufacturing and testing of equipment. Such information can be found in particular product standards and in manufacturing and testing standards. Other International Standards related to material usage limitations are referred to, e.g. ISO 15156 (all parts) for H_2S containing service.

In case of conflict between this International Standard and other international product standards, the requirements of the latter take precedence.

Petroleum and natural gas industries — Materials selection for high content CO_2 for casing, tubing and downhole equipment

1 Scope

This International Standard provides guidelines and requirements for material selection of both seamless casing and tubing, and downhole equipment for CO_2 gas injection and gas production wells with high pressure and high CO_2 content environments [higher than 10 % (molar) of CO_2 and 1 MPa CO_2 partial pressure]. Oil production wells are not covered in this International Standard. This International Standard only considers materials compatibility with the environment.

Guidance is given for the following:

— corrosion evaluation;

— materials selection;

— corrosion control.

This International Standard is aimed at high CO_2 content wells, where the threat of low pH and CO_2 corrosion is greatest. However, many aspects are equally applicable to environments containing lower CO_2 concentrations.

Materials selection is influenced by many factors and synergies and should be performed by either materials or corrosion engineer.

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 11960, *Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells*

ISO 13680, *Petroleum and natural gas industries — Corrosion-resistant alloy seamless tubes for use as casing, tubing and coupling stock — Technical delivery conditions*

ISO 15156 (all parts), *Petroleum and natural gas industries — Materials for use in H2S-containing environments in oil and gas production*

ISO 21457, *Petroleum, petrochemical and natural gas industries — Materials selection and corrosion control for oil and gas production systems*

ISO 23936-1, *Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 1: Thermoplastics*

ISO 23936-2, *Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 2: Elastomers*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
A-annulus
designation of annulus between the production tubing and *production casing* (3.1.12)

[SOURCE: ISO/TS 16530-2:2014, 3.1]

3.1.2
casing
pipe run from the surface and intended to line the walls of a drilled well

[SOURCE: ISO 11960:2014, 4.1.5]

3.1.3
clad
cladding
metallurgically-bonded *CRA* (3.1.4) layer produced by roll bonding, weld overlaying, powder metallurgy or explosively cladding a carbon steel plate or pipe

[SOURCE: API 5LD 2009, 3.1.2]

3.1.4
corrosion-resistant alloy
CRA
alloy intended to be resistant to general and localized corrosion by oilfield environments that are corrosive to carbon steels

[SOURCE: ISO 15156-1:2015, 3.6]

3.1.5
cross-over
short subassembly that connects two different end connections

3.1.6
dense phase
fluid state (supercritical or liquid) above critical pressure

3.1.7
dry gas
gas operating at temperature at least 10 °C above water dew point at given pressure

Note 1 to entry: See ISO 21457:2010, 6.2.3.5.

3.1.8
gas production well
well where the gas/liquid ratio is between 900 and 18 000 for condensate gas, and higher than 18 000 for *dry gas* (3.1.7)

3.1.9
intermediate casing
string that is set between the *surface casing* (3.1.19) and *production casing* (3.1.12)

Note 1 to entry: There may be more than one intermediate casing, enabling getting deeper in the well.

3.1.10
packer
mechanical device with a packing element, not installed in a designed receptacle, used for blocking fluid (liquid or gas) communication through the annular space between conduits by sealing off the space between them

[SOURCE: ISO 14310:2008, 3.26]

3.1.11
pitting resistance equivalent number
PREN
number, developed to reflect and predict the pitting resistance of a stainless steel, based upon the proportions of Cr, Mo, W and N in the chemical composition of the alloy

Note 1 to entry: For the purposes of this International Standard, PREN is calculated from the following formula:

$$PREN = wCr + 3,3\ (wMo + 0,5wW) + 16wN$$

where

wCr	is the weight percentage of chromium in the alloy;
wMo	is the weight percentage of molybdenum in the alloy;
wW	is the weight percentage of tungsten in the alloy;
wN	is the weight percentage of nitrogen in the alloy

[SOURCE: ISO 21457:2010, 3.1.18, modified.]

3.1.12
production casing
pipe run from the surface and intended to line the walls of a drilled well, isolating production zone and/or injection zone

3.1.13
production packer
packer (3.1.10) used to isolate the *A-annulus* (3.1.1), blocking fluid communication by sealing on the ID of the *production casing* (3.1.12)

3.1.14
pup joint
casing (3.1.2) or tubing of length shorter than Range 1

[SOURCE: ISO 11960:2014, 4.1.37, modified — Note 1 to entry left out here.]

3.1.15
rapid gas decompression
RGD
depressurization
explosive decompression
rapid pressure-drop in a high pressure gas-containing system which disrupts the equilibrium between external gas pressure and the concentration of gas dissolved inside any polymer, with the result that excess gas tries to escape from the solution at points throughout the material, causing expansion

Note 1 to entry: If large enough and if the pressure-drop rate is faster than the natural gas diffusion rate, blistering or rupturing can occur.

[SOURCE: ISO 23936-2:2011, 3.1.10]

3.1.16
shoe
assembly screwed to the casing with a rounded profile, in order to guide the casing string throughout the wellbore

3.1.17
slickline
thin nonelectric cable used for selective placement and retrieval of wellbore hardware, such as plugs, gauges and valves located in sidepocket mandrels

3.1.18
supercritical state
fluid state above critical pressure and temperature

3.1.19
surface casing
large-diameter pipe set on the first stage of a well

Note 1 to entry: One of its functions is to provide structural strength in order to hang the other casing strings.

3.1.20
stress corrosion cracking
SCC
cracking of metal involving anodic processes of localized corrosion and tensile stress (residual and/or applied) in the presence of water and H_2S

Note 1 to entry: Parameters that influence the susceptibility to SCC are temperature, pH, chlorides, oxidants, H_2S and CO_2.

[SOURCE: ISO 15156-1:2015, 3.21, modified — changed set of parameters in Note 1 to entry.]

3.1.21
sulfide stress cracking
SSC
cracking of metal involving corrosion and tensile stress (residual and/or applied) in the presence of water and H_2S

Note 1 to entry: SSC is a form of hydrogen stress cracking (HSC) and involves the embrittlement of the metal by atomic hydrogen that is produced by acid corrosion on the metal surface. Hydrogen uptake is promoted in the presence of sulfides. The atomic hydrogen can diffuse into the metal, reduce ductility and increase susceptibility to cracking. High strength metallic materials and hard weld zones are prone to SSC.

[SOURCE: ISO 15156-1:2015, 3.23]

3.1.22
tubing hanger
device that supports a *tubing string* (3.1.23) in the wellhead at the mudline

3.1.23
tubing string
set of pipes placed in a well to produce or inject fluids

3.1.24
wireline
one type of equipment and associated technique(s) used to perform various operations in a well using a continuous length of solid line (slick line) or stranded wire, appropriate spooling equipment at the surface and weight stem and specialized tools attached to the well (downhole) end of the wire

[SOURCE: ISO 17078-1:2004, 3.50]

3.2 Abbreviated terms

CCS carbon capture and storage

CRA corrosion resistant alloy

EOR enhanced oil recovery

FEPM copolymer of tetrafluoroethylene and propylene

FFKM perfluorelastomer

FKM fluorelastomer

GRE glass reinforced epoxy

HNBR hydrogenated nitrile butadiene rubber

ID internal diameter

PREN pitting resistance equivalent number

PA polyamide

PCTFE polychlorotrifluorethylene

PEEK polyether ether ketone

PP polypropylene

PTFE polytetrafluorethylene

PVDF polyvinylidene fluoride

RGD rapid gas decompression

pH_2S H_2S partial pressure

pCO2 CO_2 partial pressure

SCCO2 supercritical state of CO_2

TFE/P copolymer of tetrafluoroethylene and propylene

WAG water alternating gas

4 Guidelines for corrosion evaluation

4.1 General

The materials selection process shall take into account all statutory and regulatory requirements. The project design criteria, such as design lifetime, inspection and maintenance philosophy, type and frequency of interventions, safety and environmental profiles shall be considered.

In general, robust materials selection should be made to ensure operational reliability throughout the design life. For offshore installations, access for the purposes of maintenance and repair should be carefully considered in the design.

The possible scenarios covered by this International Standard are the following:

a) injection wells;

1) injection of high CO_2 content gas (with and without H_2S presence);

2) alternate injection of high CO_2 content gas (with and without H_2S presence) and water (WAG);

b) production gas wells with high CO_2 content (with and without H_2S presence).

Materials for tubing and downhole equipment exposed to produced or injected fluids shall be selected on the basis of their corrosivity considering operational conditions throughout the lifetime of the wells. The main parameters are pH, content of CO_2, H_2S, presence of O_2 and other contaminants (such as NO_x, SO_x, elemental sulfur, mercury, etc.) water chemistry, temperature and pressure. If H_2S is present in the stream, materials shall comply with ISO 15156 (all parts).

For CO_2 partial pressures considered in this International Standard (higher than 1 MPa CO_2 partial pressure), the use of carbon steel is only possible for dry gas injection. Water condensation during transient or upset conditions shall be considered.

The corrosivity of the fluids in WAG wells will be dependent upon both the characteristics of water and gas to be injected. The mixing and chemical reaction between CO_2 and water shall be considered. Dissolved CO_2 reacts with water (both injected water and naturally occurring formation water) to form carbonic acid which, over time, can produce severe corrosion.

Degradation mechanisms not specifically covered in this International Standard, such as fatigue, corrosion-fatigue, wear and galling, shall be considered for relevant components and design conditions. The stages of transportation, storage, installation, testing and preservation of materials shall be considered.

The mechanical properties for technical delivery conditions for different material grades shall comply with ISO 11960 and ISO 13680.

In addition, the following topics can also significantly affect the performance of selected materials:

— corrosion damage due to chemical products injections (acid solutions, scale dissolvers, etc.);

— erosion/erosion-corrosion;

— damage to passive layers or internal coatings on the ID surfaces due to running of wireline and slickline tools;

— environmental assisted cracking/corrosion in completions fluids (in the tubing string — production casing annulus);

— pitting and/or crevice corrosion;

— SCC (stress corrosion cracking).

The chemical products and other fluids applied in the well shall be compatible with metallic and non-metallic materials selected.

4.2 Corrosion by produced or injected fluids — Corrosion likelihood

An evaluation of materials corrosion likelihood shall be carried out to determine the corrosivity of the injected and produced fluids for the materials under consideration. For metallic materials, the corrosion mechanisms such as general, localized and environmental assisted cracking shall be assessed and considered in well design.

For wet gas systems with high content of CO_2, the use of carbon steel is not recommended. Relevant corrosion mechanisms are described in ISO 21457.

Besides the corrosion mechanisms described in ISO 21457, most materials can suffer erosion/erosion-corrosion under specific conditions and it might be necessary to consider in well design. The material related critical flow intensity indicates the highest fluid flow intensity that can be tolerated before erosion/erosion-corrosion process starts. For practical application and flow system evaluations, wall shear stresses should be used to quantify flow intensities in given flow systems.[9][10] Fluid properties, such as viscosity, solid particle characteristics, substrate materials properties, such as hardness, and system geometric characteristics, such as curves and flow constrictions, are known to affect erosion/erosion-corrosion resistance.

4.2.1 Gas production wells

Materials selection shall be based on an evaluation of corrosion, environmental assisted cracking, erosion and other degradation mechanisms. The internal environment shall be considered for the entire design life.

Beyond the corrosion parameters considered in ISO 21457, the pH of water phase is important and shall be taken into account for corrosion evaluation. The pH values are difficult to measure accurately in actual operational conditions. Those values can be simulated by pH model or using ISO 15156-2. The methodology used shall be agreed with the end user.

4.2.2 Injection wells

For alternating injection of CO_2 and water (WAG), the corrosion resistance of tubing and downhole equipment materials shall consider the interaction between water and CO_2. Besides, injection water temperature at normal operation and at shut in conditions and water quality aspects like dissolved oxygen concentration, pH, sulfides, solids, chlorination, bacterial activity and chemical products added shall be considered.

For dry gas injection systems, the use of carbon steel is allowed. The likelihood of condensation during transient or upset conditions shall, however, be considered[11] and in the presence of H_2S, the materials shall comply with ISO 15156 (all parts).

For injection of CO_2, an important parameter is the likelihood of water condensation. Other parameters like organic acids and H_2S presence shall be considered.

5 Materials selection

Tables 1 to 5 give a typical material selection for wells associated with the following:

— the injection of either dense phase or gas containing high CO_2 content, including WAG;

— the production of gas with high CO_2 content.

The chemical compositions of typical alloys used for oilfield developments are listed in ISO 11960, ISO 21457, ISO 15156 (all parts) and ISO 13680.

For dry gas injection, carbon steel can be selected with no requirements for internal corrosion control for downhole equipments.[11] However, a corrosion allowance can be required if periods of free water exposure are envisaged during the construction/conditioning phases or operational phase.

For wet gas injection and gas production, the corrosivity of the wet gas to carbon steel will be very high due to the low pH of the aqueous phase, in this case, CRA shall be considered. Additionally, corrosion inhibition might not be practical in these systems, and corrosion needs to be mitigated by the appropriate materials selection.

For CRA selection, the parameters described in 4.1 shall be considered in order to be resistant to SCC, SSC, general and localized corrosion.

5.1 Gas injection with high CO_2 content

In gas injection wells, the gas condition defines the choice of material. Typical materials for gas injection wells are presented in Table 1.

Different types and amounts of contaminants can be present in the stream and shall be considered for materials selection.

The use of internal liners is allowed, but all the issues concerning operation and compatibility shall be considered. Materials for H_2S service shall comply with ISO 15156 (all parts).

Table 1 — Typical materials for gas injection wells

Equipment	Materials
Tubing hangers	Carbon steel or low alloy steel for dry gas Carbon steel or low alloy steel, both with CRA clad for dry gas Carbon steel or low alloy steel, both with CRA clad for wet gas Solid CRA for wet gas
Tubing	Carbon steel or low alloy steel for dry gas. CRA if in contact with aquifer CRA or Carbon steel with GRE for wet gas. CRA if in contact with aquifer
Pup joints	Carbon steel or low alloy steel for dry gas. CRA if in contact with aquifer Solid CRA for wet gas
Valves and others fittings	Carbon steel or low alloy steel for dry gas. CRA if in contact with aquifer CRA for wet gas Non-metallic in accordance with the details given in 5.5
Packers	Carbon steel or low alloy steel for dry gas. CRA if in contact with aquifer CRA for wet gas Non-metallic in accordance with the details given in 5.5

5.2 Water alternating gas with high CO_2 content (WAG) injection systems

Typical materials for water alternating gas injection wells are presented in Table 2. If H_2S is present in the stream, materials shall comply with ISO 15156 (all parts).

The use of spacer pills (e.g. liquids like diesel or hydrate inhibitors, or inert gases) in the transition between water and gas injection is recommended in order to avoid mixing of the fluids in the injection string and avoid hydrate formation.

The use of internal liners is allowed, but all the issues concerning operation and compatibility shall be considered. Materials for H_2S service shall comply with ISO 15156 (all parts).

Table 2 — Typical materials for water alternating gas injection wells

Equipment	Materials
Tubing hangers	Carbon steel or low alloy steel, both with CRA clad
Tubing	CRA or Carbon steel with GRE (see 5.6). CRA if in contact with aquifer
Pup joints	CRA
Valves and others fittings	CRA Non-metallic in accordance with the details given in 5.5
Packers	CRA Non-metallic in accordance with the details given in 5.5

Materials selection for injection wells shall consider other contaminants in the water injected as presented in 4.2.2. As an initial screening for non-treated seawater application material with a minimum PREN of 40 shall be applied.

5.3 Gas production wells with high CO_2 content

Completion equipment shall be designed for reservoir fluids and for sand production control.

Typical materials for gas production wells are presented in Table 3. If H_2S is present in the stream, materials shall comply with ISO 15156 (all parts).

For hydraulic control lines for downhole valves, safety valves and chemical injection lines solid CRA should be used depending on fluid composition, pH, temperature, pH_2S, chlorides and oxygen content.

NOTE An example of gas production well material selection is described in Annex A.

Table 3 — Typical materials for gas production wells

Equipment	Materials
Tubing hangers	Carbon steel or low alloy steel, both with CRA clad
Tubing	CRA
Pup joints	CRA
Control/injection lines	CRA
Valves and other fittings	CRA Non-metallic in accordance with the details given in 5.5
Packers	CRA Non-metallic in accordance with the details given in 5.5

5.4 Production casing

In wells, casing is classified as surface, intermediate and production casing.

The most critical in terms of corrosion is the production casing, since it can be in contact with fluids from the reservoir or injected fluids.

Typical materials for production casing and other equipment are presented in Table 4. If H_2S is present in the stream, materials shall comply with ISO 15156 (all parts).

Table 4 — Typical materials for gas production casing and other equipment

Equipment	Materials	
	Above the production packer	Below the production packer
Casing	Carbon steel	CRA
Cross overs	Carbon steel	CRA
Casing hanger	Carbon steel	Not applicable
Shoe	Not applicable	Carbon steel

Carbon steel can be used below production packer, if its corrosion does not affect the well integrity or production rate; otherwise, the materials given in Table 4 shall be applied.

5.5 Sealing and packers

5.5.1 General

The selection of materials shall be compatible with all states of the rich CO_2 stream, i.e. fluid with a high CO_2 content/level. At temperatures higher than 31 °C and at pressures higher than 7 390 kPa (73 bar), pure CO_2 will be in a supercritical state ($SCCO_2$). This $SCCO_2$ can behave as an efficient solvent to certain materials and it shall be taken into account on the occasion of non-metallic seals and packers materials selection.

Regarding elastomers sealing and packers, the possibility of both swelling during $SCCO_2$ exposure and explosive decompression damage during rapid gas decompression shall be considered. Candidate materials need also to be qualified for the potential low temperature conditions that can occur during a depressurization situation (Joule-Thomson effect).

NOTE Swelling of the elastomers is attributed to the solubility/diffusion of the CO_2 into the bulk material. Explosive decompression can occur when system pressure is rapidly decreased and the gases that have permeated into the elastomers try to leave elastomer bulk material, leading to a potential mechanical damage. In such cases, elastomers can present blisters in their surfaces or even fracture as a whole, due to expansion of the diffused CO_2.

5.5.2 Non-metallic seals and packing elements

High partial pressure CO_2 can cause different types of deterioration mechanisms, in particular swelling and cracks after rapid decompression of seals, packing elements, valve seats, etc.

Non-metallic materials shall be qualified to ensure the following:

a) chemical/physical compatibility with CO_2 and other chemical components in the CO_2 stream without causing significant decomposing/extraction, swelling, hardening or unacceptable negative impact on material key properties;

b) resistance to full temperature range;

c) ability to withstand RGD if applicable.

All non-metallic seals and packing elements selected shall be qualified for the intended operational conditions. ISO 23936-1 and ISO 23936-2 shall be used as references. Concerning RGD evaluation for thermoplastics, ISO 23936-2 shall be used as reference; however, with modified acceptance criteria, no blisters nor cracks nor holes are acceptable. Table 5 presents non-metallic materials commonly used in rich CO_2 stream applications. Table 5 can be used for initial orientation purposes only. Any final decision regarding material suitability to any specific scenario should be based on testing and evaluation of specific compositions of the presented groups of materials.

Table 5 — Non-metallic materials commonly used in CO_2 applications

Category	Material type	Recommendation
Thermoplastics	PTFE	Ageing and RGD evaluation needed for specific scenarios.
	PCTFE	
	PVDF	
	PA	
	PP	
	PTFE	
Elastomers	TFE/P or FEPM	Strongly dependent on material composition. Ageing and RGD evaluation needed for specific scenarios.
	HNBR	
	FKM	
	FFKM	

5.6 Liners

The use of GRE liners is an alternative protection against corrosion of carbon steel tubing. It should be highlighted that the end use properties of the composite liner will be dependent on the mechanical and chemical properties of its components (matrix and fibre). Those properties can vary from manufacturer to manufacturer.

The main concerns regarding the use of GRE liners under high CO_2 content scenarios are presented as follows.

a) Permeation — $SCCO_2$ presents itself as a high permeation fluid, as mentioned above. Thus, there is a concern regarding the possibility of permeation not only within the composite matrix (epoxy resin) but also, and mainly, within the interface between resin and glass fibre. This $SCCO_2$ can contribute both to fibre-matrix interface disbonding and to the occurrence of trapped gas within the thickness of the liner, which can lead to blisters under rapid gas decompression processes. In a WAG injection method, water permeation shall be evaluated as well. The role of the grout in the annulus shall be considered, taking into account the possibility of its reaction with water and CO_2 (carbonation). The seals that protect the connections shall have their sealability checked.

b) RGD — As $SCCO_2$ can permeate liner bulk material, some trapped $SCCO_2$ gas can be found either within the several layers of the composite or in the annular, between composite liner and carbon steel pipe. This trapped gas can lead either to the formation of blisters within the layers of the composite or even to liner collapse (fibre exposure) if a rapid gas decompression occurs. Both events can contribute to reduction of mechanical properties of liner, as well as increase in permeation rates through material thickness.

c) Abrasion — Liners can be exposed to wireline and/or slickline operations during expected lifespan of the unit. These operations can expose the internal surface of the liner to contact with metallic tools which can, somehow, damage fibre-resin interface, exposing bulk material fibres and producing sites that would ease permeation through composite layers.

In most liner applications, the liner itself cannot present a structural function in the system but a corrosion barrier role instead. However, it is important to evaluate some mechanical properties for aged material as degradation of the composite under $SCCO_2$ can be an issue depending on operation scenario. Considering the nature of the composite material, properties like flexural modulus,[3] interlaminar shear stress,[5] surface hardness,[6] mass and volume variation and split ring tension[4] are worth being evaluated.[8]

6 Corrosion control

6.1 Corrosion prevention

6.1.1 Completion with CRA and cladding

Well completions using CRAs are recommended where carbon steel cannot be applied due to high corrosivity (high CO_2 partial pressure and presence of free water). Well equipment installed for the duration of the well's lifetime, such as sand screens, should use CRA in order to keep an extremely low corrosion rate. Well equipment where manufacturing tolerances are crucial to maintain or control the flow regime, such as control valves, mandrels and slotted liners should also use CRA in order to prevent corrosion issues.

Carbon steel or low alloy steel with CRA clad can be used for tubing hanger equipment.

6.1.2 Completion with GRE liners

GRE liners should be in accordance with 5.6.

6.2 Corrosion management

Carbon steel in combination with corrosion control measures is often used as basis for material selection of most injection wells. Requirements for corrosion monitoring on topside facility shall be defined for each fluid to be injected.

For water injection, water quality, content of oxygen, H_2S and other contaminants should be monitored. For gas injection, water content, H_2S and other contaminants should be monitored. For gas production wells, produced water chemistry, CO_2, H_2S and other contaminants should be monitored. Monitoring devices and sample points should be included as a part of detailed engineering.

Downhole corrosion monitoring capabilities are constrained by restricted access and operational issues. Therefore, apart from basic checks of annulus pressure build up to identify loss of tubing integrity, other methods of corrosion monitoring are not routinely implemented. The techniques that are available can be classified according to whether they provide direct measures of corrosion or are indicators of corrosion risk.

6.3 Internal corrosion allowance

The corrosion allowance shall be added in response to expected internal corrosion in dry gas injectors. Each well shall be evaluated and the selected corrosion allowance supported by corrosion evaluations. Possible corrosion during preservation, well completion, start-up period and operational upsets shall be included, in addition to the expected corrosion during normal operation.

For tubing with dry gas or non-corrosive fluids, corrosion during installation and testing prior to start-up should be considered.

Annex A
(informative)

Example of material selection for gas production

A.1 General

For material selection, operational conditions throughout the lifetime of the wells shall be considered. The main parameters are pH, presence of O_2, CO_2, H_2S and other contaminants, water chemistry, temperature and pressure. The use of carbon steel is only possible for dry gas at the CO_2 partial pressures considered in this International Standard.

A.2 Input data for a field case

— gas composition (see Table A.1);

NOTE Generally, in production systems, no oxygen is present.

— formation water chemistry (see Table A.2);

— reservoir temperature: 110 °C;

— reservoir pressure: 500 bar (50 000 kPa);

— pH_2S: 0,138 bar (13,8 kPa);

— pCO_2: 51,26 bar (5 126 kPa);

— erosion-corrosion is not expected.