

Materials selection

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Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are as far as possible intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK standards are normally based on recognised international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable standards work and according to established procedures defined in NORSOK A-001.

The NORSOK standards are prepared and published with support by The Norwegian Oil Industry Association (OLF) and Federation of Norwegian Manufacturing Industries (TBL).

NORSOK standards are administered and published by Standards Norway.

Introduction

This NORSOK standard gives recommendations, requirements and guidelines for materials use in oil and gas production. This revision 4 includes requirements from NORSOK M-CR-505 "Corrosion monitoring design", which is withdrawn. The evaluation of internal corrosivity in hydrocarbon systems is rewritten and considers corrosion inhibitor availability instead of efficiency, and the maximum hardness and yield strength requirements of materials to be cathodically protected have been lowered.

This NORSOK standard is intended to comply with the requirements of the "Pressure Equipment Directive" (PED) and the Norwegian implementation regulation "Forskrift for trykkpåkjent utstyr" issued 9 June 1999. The requirements given for materials by PED, Annex I "Essential Safety Requirements", section 4.1, are fulfilled provided the principles of materials selection of this NORSOK standard are followed and documented.

The documentation requirement in PED, Annex I "Essential Safety Requirements", section 4.3, of the materials used in main pressure retaining parts of equipment in PED categories II, III and IV, shall take the form of a certificate of specific product control. This is fulfilled by the certification requirement given by the material data sheets compiled in NORSOK M-630.

The PED requires that the manufacturer provides documentation of elements relating to compliance with the material specifications of the PED in one of the following forms:

- by using materials which comply with a harmonised European standard;
- by using materials covered by a European approval of materials;
- by a PMA.-

A particular appraisal has to be made to confirm compliance to PED for each particular installation.

1 Scope

This NORSOK standard provides general principles, engineering guidance and requirements for materials selection and corrosion protection for hydrocarbon production and processing facilities and supporting systems for fixed offshore installations. This NORSOK standard also applies for onshore terminals, except for structural and civil works.

This NORSOK standard gives guidance and requirements for

- corrosion and materials selection evaluations,
- specific materials selection where appropriate,
- corrosion protection,
- design limitations for specific materials,
- qualification requirements for new materials or new applications.

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet or exceed the requirements and guidelines of the standards referenced below.

2.1 Normative references

API Spec 15 HR,	High Pressure Fiberglass Line Pipe.	
API Spec 15 LR,	Low Pressure Fiberglass Line Pipe.	
API Spec 17J,	Unbonded Flexible Pipe.	
ASME B 31.3,	Process Piping.	
ASTM A153,	Standard Specification for Zinc Coating (Hot Dip) on Iron and Steel Hardware.	
ASTM A 193,	Specification for Alloy - Steel and Stainless Steel Bolting Materials for High - Temperature Service.	
ASTM A 194,	Specification for Carbon and Alloy Steel Nuts for Bolts for High - Pressure and High-Temperature Service.	
ASTM A 320,	Specification for Alloy Steel Bolting Materials for Low - Temperature Service.	
ASTM D 2992,	Practice for Obtaining Hydrostatic or Pressure Design Basis for Fibreglass Pipe and Fittings.	
BS 4994,	Specification for design and construction of vessels and tanks in reinforced plastics.	
BS MA 18,	Salt Water Piping in Ships.	
DIN 16965-2,	Wound glass fibre reinforced polyester resin (UP-GF) pipes, Type B pipes, dimensions.	
DIN 16966-1,	Glass fibre reinforced polyester resin (UP-GF) pipe fittings and joint assemblies; Fittings; general quality requirements and testing.	
DIN 16966-2,	Glass fibre reinforced polyester resin (UP-GF) pipe fittings and joints; Elbows; Dimensions.	
DIN 16966-4,	Glass fibre reinforced polyester resin (UP-GF) pipe fittings and joints; Tees, Nozzles; Dimensions.	
DIN 16966-5,	Glass fibre reinforced polyester resin (UP-GF) pipe fittings and joints; Reducers; Dimensions.	
DIN 16966-6,	Glass fibre reinforced polyester resin (UP-GF) pipe fittings and joint assemblies; Collars, flanges, joint rings; Dimensions.	
DIN 16966-7,	Pipe joints and their elements of glass fibre reinforced polyester resins – Part 7: Bushings, flanges, flanged and butt joints; general quality requirements and test methods.	
DIN 16966-8,	Glass fibre reinforced polyester resin (UP-GF) pipe fittings and joints; Laminated joints; Dimensions.	
DNV RP B201,	Metallic Materials in Drilling, Production and Process Systems.	
DNV OS C501,	Composite components.	
DNV OS F101,	Submarine Pipeline Systems.	
DNV RP F201,	Dynamic risers.	
PED,	Pressure Equipment Directive, 97/23/EC.	
EN 10204,	Metallic products – Types of inspection documents.	

ISO 898,	Mechanical properties of fasteners.
ISO 3506-1,	Mechanical properties of corrosion resistant stainless steel fasteners – Part 1: Bolts, screws and studs.
ISO 3506-2,	Mechanical properties of corrosion resistant stainless steel fasteners – Part 2: Nuts.
ISO 13623,	Petroleum and natural gas industries. Pipeline transportations systems.
ISO 13628-2,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 2: Unbonded flexible pipe systems for subsea and marine applications.
ISO 13628-5,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 5: Subsea control umbilicals.
ISO/DIS 13628-7,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 7: Work over/completion riser systems.
ISO 14692-1,	Petroleum and natural gas industries - Glass reinforced plastics (GRP) piping – Part 1: Vocabulary, symbols, applications and materials.
ISO 14692-2,	Petroleum and natural gas industries - Glass reinforced plastics (GRP) piping – Part 2: Qualification and manufacture.
ISO 14692-3,	Petroleum and natural gas industries - Glass reinforced plastics (GRP) piping – Part 3: System design.
ISO 14692-4,	Petroleum and natural gas industries - Glass reinforced plastics (GRP) piping – Part 4: Fabrication, installation and operation.
ISO 15156-1,	Petroleum and natural gas industries – Materials for use in H ₂ S-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 H ₂ S-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 H ₂ S-containing environments in oil and gas production – Part 3: Cracking-resistant CRAs (corrosion resistant alloys) and other alloys.
NS 3420,	Beskrivelsestekster for bygg og anlegg (Specification texts for building and construction).
NS 3472,	Prosjektering av stålkonstruksjoner. Beregnings og konstruksjonsregler.
NS 3473,	Concrete Structures. Design Rules.
NORSOK L-001,	Piping and Valves.
NORSOK N-004,	Design of steel structures.
NORSOK M-101,	Structural steel fabrication.
NORSOK M-102,	Structural aluminium fabrication.
NORSOK M-120,	Material data sheets for structural steel.
NORSOK M-121,	Aluminium structural materials.
NORSOK M-122,	Cast structural steel.
NORSOK M-123,	Forged structural steel.
NORSOK M-501,	Surface preparation and protective coating.
NORSOK M-503,	Cathodic protection.
NORSOK M-601,	Welding and inspection of piping.
NORSOK M-622,	Fabrication and installation of GRP piping systems (draft standard).
NORSOK M-630,	Material data sheets for piping.
NORSOK M-710,	Qualification of non-metallic sealing materials and manufacturers.
NORSOK R-004,	Piping and Equipment Insulation.

2.2 Informative references

DNV RP O501,	Erosive wear in piping systems.
ISO 12944-3,	Paints and Varnishes – Corrosion protection of steel structures by protective paint systems - Part 3: Design considerations.
ISO/DIS 13628-11,	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 11: Flexible pipe systems for subsae and marine applications.
MTI Manual No. 3,	Guideline Information on Newer Wrought Iron and Nickel-base Corrosion Resistant Alloys, Phase 1, Corrosion Test Methods. (Appendix B, Method MTI-2).
NORSOK M-506,	CO ₂ Corrosion rate calculation model.

3 Terms, definitions and abbreviations

For the purposes of this NORSOK standard, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1

C-glass

special fibre type that is used for its chemical stability in corrosive environments

3.1.2

can

verbal form used for statements of possibility and capability, whether material, physical or casual

3.1.3

CAPEX

capital expenditure

3.1.4

corrosion resistant alloy

alloy which in a given environment shows negligible weight loss corrosion and no significant localised corrosion nor cracking problems

NOTE In this NORSOK standard it includes all metallic materials except carbon and low alloy steels and 3,5 % Ni.

3.1.5

E-glass

general purpose fibre that is most used in reinforced plastics

3.1.6

ECR-glass

modified E-glass fibre type with improved corrosion resistance against acids

3.1.7

free machining steel

steel to which elements such as sulphur, selenium or lead, have been added intentionally to improve machinability

3.1.8

glass fibre reinforced plastic**GRP**

composite material made of thermosetting resin and reinforced with glass fibres as defined in ISO 14692-1

3.1.9

maximum operating temperature

maximum temperature predicted including deviations from normal operations, like start-up/shutdown, process flexibility, control requirements and process upsets

3.1.10

may

verbal form used to indicate a course of action permissible within the limits of the standard

3.1.11

operating temperature

temperature in the equipment when the plant operates at steady state condition, subject to normal variation in operating parameters

3.1.12

OPEX

operational expenditure

3.1.13

oxygen equivalent

mg/m³ oxygen + 0,3 mg/m³ free chlorine

3.1.14**pH stabilisation**

increase in bulk pH to reduce corrosion in condensing water systems

3.1.15**pitting resistance equivalent****PRE**

$PRE = \% \text{ Chromium} + 3,3 \times \% \text{ Molybdenum} + 16 \times \% \text{ Nitrogen}$

3.1.16**shall**

verbal form used to indicate requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted, unless accepted by all involved parties

3.1.17**should**

verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain action is preferred but not necessarily required

3.1.18**descriptors used for metallic materials**

Definitions of descriptors used for metallic materials in this NORSOK standard are given below.

Observe that non-inclusion in the table below does not imply that a material may not be used.

Generic type	UNS	Typical alloy composition			
		% Cr	% Ni	% Mo	others
Carbon and low alloy steels					
235 ^a					
235LT					
360LT					
3.5 % Ni			3.5		
Martensitic stainless steels					
13Cr		13			
13Cr 4Ni		13	4		
SM13Cr		12	6	2	C < 0,015 %
S13Cr		12	6	2	
17 - 4 PH	S17400	17	4		Cu=4
Austenitic stainless steels					
310	S31000	25	20		
316	S31600	17	12	2,5	C ≤ 0,035
6Mo (PRE ≥ 40)	S31254	20	18	6	N = 0,2
	N08926	20	25	6	N min. 0,15
	N08367	21	24	6	N = 0,2
904	N08904	21	25	4,5	Cu = 1,5
Superaustenite (PRE ≥ 40)	S34565S31	24	17	4 to 5	Mn = 6
	266				N = 0,40 to 0,60
	S32654				
Duplex stainless steels					
22Cr	S32205	22	5,5	3	N
	S31803				
25Cr (PRE ≥ 40)	S32550	25	5,5	3,5	N
	S32750	25	7	3,5	N
	S32760	25	7	3,5	N
Nickel base alloys					
Alloy C22	N26022	21	rem.	14	W = 3
Alloy C276	N10276	16	rem.	16	W = 4
Alloy 625	N06625	22	rem.	9	Nb = 4
Alloy 718	N07718	19	53	3	Nb = 5
Alloy 800H/Alloy 800HT	N08810/	21	33	-	Al + Ti

Generic type	UNS	Typical alloy composition			
		% Cr	% Ni	% Mo	others
	N08811				
Alloy 825	N08825	21	42	3	Ti
Co-base alloys					
Elgiloy	R30003	20	16	7	Co = 40
MP-35-N	R30035	20	35	10	Ti, Co rem.
Copper base alloys					
Cu-Ni 90-10	C70600	-	10	-	Fe, Cu rem.
Cu-Ni 70-30	C71500	-	31	-	Fe, Cu rem.
NiAl bronze	C95800	-	4,5	-	9Al, Fe, Mn, Cu rem.
Gun metal	C90500	-	-	-	10Sn, Zn, Cu rem.
Titanium					
Ti grade 2	R50400	-	-	-	C max. 0,10 Fe max. 0,30 H max. 0,015 N max. 0,03 O max. 0,25 Ti rem.
^a This material does not comply with PED-requirements concerning documentation of impact toughness if specified according to NORSOK M-630.					

3.2 Abbreviations

AFFF	aqueous film forming foams
AWS	American Welding Society
CRA	corrosion resistant alloy
CSCC	chloride induced stress corrosion cracking
CTOD	crack tip opening displacement
EAM	European approval of materials
EC	European Commission
GRP	glass fibre reinforced plastic
HAZ	heat affected zone
HB	Brinell hardness
HRC	Rockwell hardness
HV	Vickers hardness
HVAC	heating-ventilation-air conditioning
MDS	material data sheets
MTI	Materials Technology Institute of the Chemical Process Industries
PED	Pressure Equipment Directive
PMA	Particular material appraisal.
PRE	pitting resistance equivalent
SSC	sulphide stress cracking
SMYS	specified minimum yield strength
UNS	unified numbering system

4 General principles for materials selection and corrosion protection

4.1 Philosophy

The materials selection process shall reflect the overall philosophy regarding design life time, cost profile (CAPEX/OPEX), inspection and maintenance philosophy, safety and environmental profile, failure risk evaluations and other specific project requirements.

4.2 Materials selection requirements

Materials selection shall be optimised and provide acceptable safety and reliability. As a minimum, the following shall be considered:

- corrosivity, taking into account specified operating conditions including start up and shut-down conditions;
- design life and system availability requirements;
- failure probabilities, failure modes and failure consequences for human health, environment, safety and material assets;
- resistance to brittle fracture;
- inspection and corrosion monitoring;
- access for maintenance and repair.

For the final materials selection the following additional factors shall be included in the evaluation:

- priority shall be given to materials with good market availability and documented fabrication and service performance;
- the number of different materials shall be minimised considering stock, costs, interchangeability and availability of relevant spare parts.

Deviations from materials selections specified in this NORSOK standard may be implemented if an overall cost, safety and reliability evaluation shows the alternative to be more beneficial.

4.3 Corrosivity evaluation and corrosion protection

4.3.1 Internal corrosion allowance

A corrosion allowance of 3 mm is generally recommended for carbon steel piping, unless higher corrosion allowances are required. However, each system should be evaluated and the selected corrosion allowance be supported by corrosion evaluations. All piping classes in carbon steel grades in NORSOK L-001 have a corrosion allowance of 3 mm for standardization reasons.

For submarine pipeline systems a maximum corrosion allowance of 10 mm is recommended as a general upper limit for use of carbon steel. Carbon steel can be used in pipelines where calculated inhibited annual corrosion rate is less than 10 mm divided by design life. Otherwise corrosion resistant alloys, solid or clad or alternatively flexible pipe, should be used. For pipelines with dry gas or non-corrosive fluids, no corrosion allowance is required. Corrosion during installation and testing prior to start-up shall be considered.

4.3.2 Corrosivity evaluations in hydrocarbon systems

Evaluation of corrosivity shall as a minimum include

- CO₂-content,
- H₂S-content,
- oxygen content and content of other oxidising agents,
- operating temperature and pressure,
- organic acids, pH,
- halide, metal ion and metal concentration,
- velocity, flow regime and sand production,
- biological activity,
- condensing conditions.

A gas is considered dry when the water dew point at the actual pressure is at least 10 °C lower than the actual operation temperature for the system. Materials for stagnant gas containment needs particular attention.

NORSOK M-506 is a recommended practice for the evaluation of CO₂ corrosion.

A corrosion evaluation with inhibition should be based on the inhibitor availability, considered as the time the inhibitor is present in the system at a concentration at or above the minimum dosage.

The percentage availability (A %) is defined as:

$$A \% = 100 \times (\text{inhibitor available time})/(\text{lifetime}) \quad (1)$$

$$\text{Corrosion allowance (CA)} = (\text{the inhibited corrosion allowance}) + (\text{the uninhibited corrosion allowance}) \quad (2)$$

$$CA = (CR_{inh} \times A \% / 100 \times \text{lifetime}) + (CR_{uninh} \times \{1 - A \% / 100\} \times \text{lifetime}) \quad (3)$$

where

CR_{inh} = inhibited corrosion rate.

CR_{uninh} = uninhibited corrosion rate (from NORSOK M-506 or other model).

At the design stage an assumption may be made that inhibition can decrease the corrosion rate to 0,1 mm/year. The inhibited corrosion rate shall, however, be documented by corrosion tests at the actual conditions or by relevant field or other test data. It should be noted that to achieve the target residual corrosion rate, high dosages of inhibitor may be required.

The inhibitor availability to be used in a design calculation depends on the planned corrosion management programme, including corrosion monitoring and corrosion inhibition. Unless defined otherwise, an inhibitor availability of 90 % shall be used. Maximum inhibitor availability shall not exceed 95 %. A 95 % inhibitor availability requires that a qualified inhibitor is injected from day one and that a corrosion management system is in place to actively monitor corrosion and inhibitor injection.

The inhibited corrosion rate includes the effect of glycol and/or methanol injection. Lower inhibited corrosion rates with glycol and/or methanol can be used when documented by tests or other relevant documentation. The effect of any inhibitor depends on reservoir conditions which may change during production time.

pH stabilisation can be used in condensed water systems to reduce the corrosion rate. pH stabilisation is only applicable in combination with glycol in sweet systems. NORSOK M-506 does not apply for this case, and a corrosion rate of 0,1 mm/year shall be used for design purposes, unless field or test data are available.

Corrosion inhibitors may have low efficiency and are not recommended to reduce corrosion of carbon or low alloy steels in production wells, subsea trees and subsea piping systems.

Use of corrosion inhibitors in process systems is not recommended, but can be used provided the inhibitor in each process stream satisfies the inhibitor supplier's minimum recommended concentration for each stream and flow rate. Due to complex geometries and normally high flow rates, there is an increased risk for high inhibited corrosion rates locally in process systems compared to pipelines, which will influence the need for inspection and maintenance.

In pipeline systems carrying hydrocarbons with condensed water, the corrosivity may be reduced by application of inhibitors in combination with pH adjustment as an alternative to inhibitors alone. The combined effect of inhibitors and pH adjustment shall be qualified and documented by corrosion tests unless relevant documentation exists.

Vessel materials for oil separation and gas treating systems shall be selected based on the same corrosivity criteria as for hydrocarbon piping systems. Vessels manufactured in solid CRAs, internally CRA clad or weld overlayed, will not need additional internal corrosion protection systems.

Galvanic corrosion between CRA equipment and the vessel wall in internally paint coated (lined) carbon steel vessels shall be addressed in case of coating damages. As a minimum CRA support brackets shall be painted. Other protection methods like cathodic protection may be considered.

Possibility for "sour" service conditions during the lifetime shall be evaluated. Sour service definition, metallic materials' requirements and qualification shall be according to ISO 15156 (all parts).

Drying or use of corrosion inhibitors shall not relax the requirement to use "sour" service resistant materials if the conditions otherwise are categorised as "sour" by the above documents.

If sand production and/or particles from well cleaning and squeeze operations are expected, an erosion evaluation shall be carried out. The evaluation should be based on DNV RP O501.

4.3.3 External corrosion protection

Materials selection and surface protection shall be such that general corrosion is cost effectively prevented and chloride stress corrosion cracking, pitting and crevice corrosion are prevented. Offshore the external atmospheric environment shall be considered wet with the condensed liquid saturated with chloride salts.