



BSI Standards Publication

Petroleum, petrochemical and natural gas industries – Cathodic protection of pipeline systems

Part 1: On-land pipelines (ISO 15589-1:2015)

National foreword

This British Standard is the UK implementation of EN ISO 15589-1:2017. It is identical to ISO 15589-1:2015. It supersedes BS ISO 15589-1:2015, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic protection.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 92587 0

ICS 75.200

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2018.

Amendments/corrigenda issued since publication

Date	Text affected
31 January 2018	This corrigendum renumbers BS ISO 15589-1:2015 as BS EN ISO 15589-1:2017

English Version

**Petroleum, petrochemical and natural gas industries -
Cathodic protection of pipeline systems - Part 1: On-land
pipelines (ISO 15589-1:2015)**

Industries du pétrole, de la pétrochimie et du gaz
naturel - Protection cathodique des systèmes de
transport par conduites - Partie 1: Conduites terrestres
(ISO 15589-1:2015)

Erdöl- und Erdgasindustrie - Kathodischer Schutz für
Transportleitungssysteme - Teil 1: On-land pipelines
(ISO 15589-1:2015)

This European Standard was approved by CEN on 23 August 2017.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

European foreword

The text of ISO 15589-1:2015 has been prepared by Technical Committee ISO/TC 67 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 15589-1:2017 by Technical Committee CEN/TC 219 “Cathodic protection” the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2018, and conflicting national standards shall be withdrawn at the latest by March 2018.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Endorsement notice

The text of ISO 15589-1:2015 has been approved by CEN as EN ISO 15589-1:2017 without any modification.

Contents

Page

Foreword	vi
Introduction	vii
1 Scope	1
2 Normative references	1
3 Terms and definitions	2
4 Symbols and abbreviations	5
4.1 Symbols	5
4.2 Abbreviations	7
5 CP personnel competence	7
6 Cathodic protection criteria	8
6.1 General	8
6.2 Protection potentials	8
6.3 Alternative methods	10
6.3.1 100 mV cathodic potential shift	10
6.3.2 Other methods	10
6.4 Criteria in the presence of a.c.	10
7 Pre-requisites for the application of cathodic protection	10
7.1 General	10
7.2 Electrical continuity	10
7.3 Electrical isolation	11
7.3.1 General	11
7.3.2 Locations	11
7.3.3 Isolating joints	11
7.3.4 Internal corrosion risks at isolating joints	12
7.3.5 Contacts between metallic structures	13
7.3.6 Electrical earthing system	13
7.4 Lightning and overvoltage protection	14
7.5 Coating	15
7.5.1 General	15
7.5.2 Factory-applied coatings	15
7.5.3 Field joint coatings	15
7.5.4 Coating for trenchless pipelines	15
7.5.5 Air to electrolyte interface	16
7.5.6 Compatibility of coatings and wraps with cathodic protection	16
7.5.7 Thermal insulation	16
7.5.8 Reinforced concrete weight coating	17
7.6 Selection of pipe trench backfill material	17
7.7 Buried casings for pipelines	17
7.7.1 General	17
7.7.2 Casings that shield cathodic protection current	17
7.7.3 Casings that pass cathodic protection current	18
7.8 Equipment for the reduction of a.c. interference	18
7.9 Equipment for the mitigation of d.c. interference	18

8	Basic requirements for cathodic protection design	18
8.1	General	18
8.2	Basic information for cathodic protection design	19
8.3	Contents of cathodic protection design report	20
8.4	Cathodic protection current demand	20
8.4.1	Calculation of the theoretical total current demand	20
8.4.2	Current demand based on coating breakdown factors	21
8.4.3	Current demand based on current density values for coated pipelines	22
8.5	Cathodic protection equipment	23
8.5.1	Cathodic protection cables	23
8.5.2	Cable connection	24
8.5.3	Precautions to respect for distribution boxes and test stations	25
8.6	Temporary protection	26
8.7	Specific case of existing pipelines	26
8.7.1	General	26
8.7.2	Parallel pipelines	27
8.7.3	Parallelism or crossing with a.c. power systems	27
8.8	Trenchless installation methods	27
9	Impressed current stations	28
9.1	General	28
9.2	Power supply	28
9.3	Groundbeds	29
9.3.1	General	29
9.3.2	Deep-well groundbeds	29
9.3.3	Shallow groundbeds	30
9.3.4	Impressed-current anodes and conductive backfill	31
9.4	Output control	32
9.4.1	General	32
9.4.2	Current distribution for multiple pipelines	32
9.4.3	Potential control	33
10	Galvanic anode systems	33
10.1	General	33
10.2	Design requirements	34
10.3	Zinc anodes	34
10.4	Magnesium anodes	35
10.5	Design of the anode system	37
10.6	Anode backfill	38
10.7	Cables and cable connections	39
10.8	Anode installation	39
11	Monitoring facilities	39
11.1	General	39
11.2	Locations of test stations	39
11.3	Description of test stations	40
11.4	Use of probes and coupons	40
11.5	Bonding to other pipelines	41
11.6	Test facilities at cased crossings	41
11.7	Test facilities at isolating joints	41
11.8	Line current monitoring test stations	41
11.9	Drain-point test facilities	41
11.10	Miscellaneous monitoring facilities	41

12	Commissioning	41
12.1	General	41
12.2	Preliminary tests	42
12.3	Start up	43
12.3.1	Impressed current stations	43
12.3.2	Galvanic anodes	43
12.3.3	Drainage stations	44
12.3.4	Test stations	44
12.4	Verification of cathodic protection effectiveness	44
12.4.1	General	44
12.4.2	Measurements of d.c. potential and a.c. voltage	44
12.4.3	Current measurements	45
12.4.4	Adjustments	45
12.5	Commissioning report	45
12.5.1	Installation documentation	45
12.5.2	Commissioning measurements	45
13	Monitoring, inspection, and maintenance	46
13.1	General	46
13.2	Implementation of inspection	47
13.3	Periodicities of inspection	47
13.4	Remote monitoring	50
13.5	Specialized surveys	50
13.6	Monitoring plan	50
13.7	Monitoring equipment	50
13.8	Maintenance and repair	51
14	Documentation	51
14.1	Design documentation	51
14.1.1	General	51
14.1.2	Construction details and installation procedures	52
14.2	Commissioning documentation	53
14.3	Operating and maintenance documentation	53
14.3.1	General	53
14.3.2	Inspection and monitoring data	54
14.3.3	Maintenance records	54
	Annex A (normative) Cathodic protection measurements	55
	Annex B (normative) Electrical interference	63
	Annex C (informative) Fault detection of impressed-current systems during operation	67
	Annex D (informative) Description of specialized surveys	69
	Annex E (informative) Attenuation of protection	76
	Annex F (informative) Electrical tests for isolating joints before installation	79
	Bibliography	80

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*, Subcommittee SC 2, *Pipeline transportation systems*.

This second edition cancels and replaces the first edition (ISO 15589-1:2003), which has been technically revised with the following changes:

- cathodic protection criteria have been extended with further clarification on the application of the criteria;
- requirements for design have been more detailed and periodicities for inspection of cathodic equipment have been enlarged, and the option for remote monitoring added;
- requirements for measurements and testing during commissioning have been further detailed.

ISO 15589 consists of the following parts, under the general title *Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems*:

- *Part 1: On-land pipelines*
- *Part 2: Offshore pipelines*

Introduction

Pipeline cathodic protection is achieved by the supply of sufficient direct current to the external pipe surface, so that the steel-to-electrolyte potential is lowered to values at which external corrosion is reduced to an insignificant rate.

Cathodic protection is normally used in combination with a suitable protective coating system to protect the external surfaces of steel pipelines from corrosion.

It is necessary that users of this part of ISO 15589 be aware that further or differing requirements can be needed for individual applications. This part of ISO 15589 is not intended to inhibit the use of alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. It is necessary that, where an alternative is offered, any variations from this part of ISO 15589 be identified and documented.

Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems —

Part 1: On-land pipelines

1 Scope

This part of ISO 15589 specifies requirements and gives recommendations for the pre-installation surveys, design, materials, equipment, installation, commissioning, operation, inspection, and maintenance of cathodic protection systems for on-land pipelines, as defined in ISO 13623 or EN 14161 for the petroleum, petrochemical, and natural gas industries, and in EN 1594 or EN 12007-1 and EN 12007-3 used by gas supply industries in Europe.

All contents of this part of ISO 15589 are applicable to on-land pipelines and piping systems used in other industries and transporting other media such as industrial gases, waters, or slurries.

This part of ISO 15589 applies to buried pipelines, landfalls of offshore pipeline sections protected by on-shore based cathodic protection installations, and to immersed sections of on-land pipelines such as river or lake crossings.

This part of ISO 15589 specifies requirements for pipelines of carbon steel, stainless steel, cast iron, galvanized steel, or copper. If other pipeline materials are used, the criteria to apply are defined under the responsibility of the pipeline operator.

This part of ISO 15589 does not apply to pipelines made of reinforced concrete for which EN 12696 can be applied.

NOTE Special conditions sometimes exist where cathodic protection is ineffective or only partially effective. Such conditions can include shielding (e.g. disbonded coatings, thermal-insulating coatings, rocky soil, etc.) and unusual contaminants in the electrolyte.

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 8044, *Corrosion of metals and alloys — Basic terms and definitions*

ISO 10012, *Measurement management systems — Requirements for measurement processes and measuring equipment*

ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems*

ISO 13847, *Petroleum and natural gas industries — Pipeline transportation systems — Welding of pipelines*

ISO 21809 (all parts), *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems*

IEC 60079-10-1, *Explosive atmospheres — Part 10-1: Classification of areas — Explosive gas atmospheres*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

EN 1594, *Gas infrastructure — Pipelines for maximum operating pressure over 16 bar — Functional requirements*

EN 12007-3, *Gas supply systems — Pipelines for maximum operating pressure up to and including 16 bar — Part 3: Specific functional recommendations for steel*

EN 12496, *Galvanic anodes for cathodic protection in seawater and saline mud*

EN 14161 *Petroleum and natural gas industries — Pipeline transportation systems (ISO 13623:2009 modified)*

EN 50164-3, *Lightning Protection Components (LPC) — Part 3: Requirements for isolating spark gaps*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

- 3.1**
anode backfill
added material immediately surrounding a buried anode
- 3.2**
bond
metal conductor, usually copper, connecting two points on the same or on different structures
- 3.3**
cathodic protection system
all active and passive components associated with the provision of active external corrosion protection and its monitoring

Note 1 to entry: Cathodic protection is obtained either by impressed current or by galvanic anodes using one or more stations.

Note 2 to entry: Impressed current and galvanic anode systems consist of all the equipment necessary for the application of cathodic protection, such as impressed current stations, galvanic anodes, bonds, and isolating joints.

- 3.4**
coupon
metal sample of defined dimensions made of a metal equivalent to the metal of the pipeline
- 3.5**
coating breakdown factor
ratio of current density required to polarize a coated steel surface as compared to a bare steel surface
- 3.6**
d.c. decoupling device
equipment that provides a low-impedance path for a.c. and high resistance for d.c.

EXAMPLE Polarization cells, capacitors, or diode assemblies.

- 3.7**
drain point
location of the cable connection to the protected pipeline through which the protective current returns to its source

- 3.8**
drainage
transfer of stray current between structures by means of a deliberate bond

Note 1 to entry: See EN 50162 for drainage devices (direct drainage bond, resistance drainage bond, unidirectional drainage bond, and forced drainage bond).

- 3.9**
drainage station
equipment and materials required to provide drainage of stray currents from affected systems

3.10**galvanic anode**

electrode that provides current for cathodic protection by means of galvanic coupling

3.11**galvanic anode station**

equipment and materials required to provide cathodic protection by the use of galvanic anodes

Note 1 to entry: Such materials and equipment include galvanic anodes and cables.

3.12**geological cell**

corrosion cell constituted between two different parts of a single metallic pipeline in contact with different soils

3.13**groundbed**

system of buried or immersed galvanic or impressed current anodes

3.14**impressed current anode**

electrode that provides current for cathodic protection by means of impressed current

3.15**impressed current station**

equipment and materials required to provide cathodic protection by impressed current

Note 1 to entry: Such materials and equipment include impressed current anodes, cables, and a d.c. source.

3.16**instant-OFF potential**

OFF potential measured with a short delay after interruption with the aim of approaching as much as possible the IR-free potential

Note 1 to entry: A typical delay for direct measurements on pipeline is about 300 ms to prevent the influence of voltage spikes. On coupons, shorter delays are used.

3.17**IR drop**

voltage that is the product of all currents flowing through the cathodic protection circuit and the resistance of the current path (mainly the electrolyte and the pipeline)

Note 1 to entry: This is derived from Ohm's law ($U = I \times R$).

3.18**IR-free potential****polarized potential**

pipe to electrolyte potential without the voltage error caused by the IR drop due to the protection current or any other current

3.19**isolating joint**

electrically insulating component inserted between two lengths of pipe to prevent electrical continuity between them

EXAMPLE Monobloc isolating joint, isolating flange.

3.20

isolating spark gap

ISG

component with discharge distance for isolating electrically conductive installation sections

Note 1 to entry: In the event of lighting strike, the installation sections are temporarily connected conductively as the result of response of the discharge.

3.21

local earthing

earthed metallic electrode not directly electrically connected to any other main earthing system

3.22

measuring point

location where the actual potential measurement takes place

Note 1 to entry: In the case of pipe-to-electrolyte potential measurement, this refers to the location of the reference electrode.

3.23

ON potential

pipe-to-electrolyte potential measured while the cathodic protection system is continuously operating

3.24

OFF potential

pipe-to-electrolyte potential measured after interruption of all sources of applied cathodic protection current with the aim of approaching an IR-free potential

Note 1 to entry: The delay before measurements varies according to the circumstances.

3.25

pipe-to-electrolyte potential

difference in potential between a pipeline (or coupon) and a specified reference electrode in contact with the electrolyte at a point sufficiently close to, but without actually touching, the pipeline

3.26

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

3.27

polarization

change of pipe-to-electrolyte potential caused by the application of an external electrical current

3.28

probe

device incorporating a coupon that provides measurements of parameters used to assess the effectiveness of cathodic protection and/or corrosion risk

3.29

protection potential

pipe-to-electrolyte potential at which the metal corrosion rate is acceptable for the pipeline

3.30

reference electrode

electrode, having a stable and reproducible potential that is used as a reference in the measurement of electrode potentials

[SOURCE: ISO 8044]

3.31**remote earth**

part of the electrolyte in which no measurable voltages, caused by current flow, occur between any two points

Note 1 to entry: This condition generally prevails outside the zone of influence of an earth electrode, an earthing system, an anode groundbed, or a protected pipeline.

3.32**rock jacket coating**

coating that provides mechanical protection to the pipeline and is applied as bendable flexible coating

3.33**stray current**

current flowing through paths other than the intended circuits

[SOURCE: Adapted from ISO 8044]

3.34**surge protective device****SPD**

device intended to limit transient overvoltages and direct surge currents

Note 1 to entry: It contains at least one nonlinear component.

[SOURCE: IEC 62305-1]

3.35**telluric current**

current in the earth as a result of geomagnetic fluctuations

3.36**test station****monitoring station**

installation that provides measuring and test facilities

Note 1 to entry: Such installations include cabling and pipeline connections.

3.37**utilization factor**

fraction of the anodic material weight of a galvanic anode that can be consumed before the anode ceases to provide the minimum required current output

4 Symbols and abbreviations**4.1 Symbols**

D_a	anode diameter
D_b	backfill diameter
ε	electrochemical capacity of the anode material
E	potential measured at the metal/electrolyte interface
ΔE	potential shift due to cathodic protection current measured against a remote reference electrode
E_a	design closed-circuit potential of a galvanic anode

E_c	design protection potential (minimum negative potential)
E_{cor}	free corrosion potential (also called natural potential)
E_{IRfree}	IR free potential
E_l	limiting critical potential
E_{ON}	ON-potential
E_{OFF}	OFF-potential
E_p	protection potential
f_c	coating breakdown factor
f_f	final coating breakdown factor
f_i	initial coating breakdown factor
Δf	average yearly increase in the coating breakdown factor
I_{tot}	total current demand
I_{af}	actual end-of-life individual anode current output
I_{cf}	total current demand for the cathodic protection of a specific pipeline section at the end of life (for maximum coating breakdown factor)
I_{cm}	mean current demand
I_f	required end-of-life individual anode current output
j	current density for bare steel
j_c	current density for coated pipelines
k	contingency factor
L	length of the pipeline
m	total net anode mass
m_a	individual net anode mass
n	number of anodes
r_{co}	average coating resistance
R_a	total circuit resistance for a galvanic anode cathodic protection system (assumed to be equivalent to the anode resistance)
$R_{a/b}$	anode resistance relative to backfill
$R_{b/s}$	backfill bed resistance relative to the natural electrolyte
ρ	resistivity of an electrolyte
T	temperature
t_{dl}	design life

<i>U</i>	<i>voltage</i>
<i>u</i>	utilization factor

4.2 Abbreviations

a.c.	alternating current
ACVG	alternating current voltage gradient
CIPS	close interval potential survey
CP	cathodic protection
CSE	copper–copper sulphate (saturated) reference electrode
d.c.	direct current
DCVG	direct current voltage gradient
ER	electrical resistance
FBE	fusion-bonded epoxy
LPC	lightning protection component
MMO	mixed metal oxide
PREN	pitting resistance equivalent numbers
SCC	stress corrosion cracking
SCE	saturated calomel reference electrode
SRB	sulphate reducing bacteria
UV	ultraviolet
3LPE	three layer polyethylene
3LPP	three layer polypropylene

5 CP personnel competence

Personnel who undertake the design, supervision of installation, commissioning, supervision of operation, measurements, monitoring, and supervision of maintenance of cathodic protection systems shall have the appropriate level of competence for the tasks undertaken.

EN 15257 or NACE Cathodic Protection Training and Certification Programme constitute suitable methods of assessing and certifying competence of cathodic protection personnel.

Competence of cathodic protection personnel to the level appropriate for tasks undertaken should be demonstrated by certification in accordance with prequalification procedures such as EN 15257, NACE Cathodic Protection Training and Certification Programme, or by any other equivalent scheme.

6 Cathodic protection criteria

6.1 General

The pipe-to-electrolyte potential at which the corrosion rate is less than 0,01 mm per year for carbon steel and cast iron is the protection potential, E_p . This corrosion rate is sufficiently low so that corrosion will be acceptable for the design life. The criterion for CP is therefore, given by the condition in Formula (1):

$$E_{IRfree} \leq E_p \quad (1)$$

where

E_p is the protection potential criterion;

E_{IRfree} is the potential at the metal/electrolyte interface, i.e. the potential that is free from the IR drop in the corrosive environment (IR-free potential, also commonly known as “polarized potential”).

The protection potential of a metal depends on the corrosive environment (electrolyte) and on the type of metal used.

Application of potentials that are too negative can result in cathodic over-protection leading to coating disbondment and blistering and hydrogen embrittlement of some metals.

The IR-free potential, E_{IRfree} , shall not be more negative than the limiting critical potential, E_l .

In such cases, the criterion for CP is given by the condition in Formula (2):

$$E_l \leq E_{IRfree} \leq E_p \quad (2)$$

6.2 Protection potentials

The IR-free potential, E_{IRfree} , shall meet the criteria given by Formula (1) and, if applicable, Formula (2). [Table 1](#) presents free corrosion potentials, E_{COR} , protection potentials, E_p , and limiting critical potentials, E_l , for different metals in different environmental conditions.

Table 1 — Free corrosion potentials, protection potentials, and limiting critical potentials of common metallic materials in soils and waters (except seawater) measured against CSE

Metals or alloys	Environmental conditions	Free corrosion potential range (indicative values) E_{cor} V	Protection potential (IR-free) E_p V	Limiting critical potential (IR-free) E_l V
Carbon steels, low alloyed steels and cast iron	Soils and waters in all conditions except those hereunder described	–0,65 to –0,40	–0,85	a
	Soils and waters at $40\text{ °C} < T < 60\text{ °C}$	—	b	a
	Soils and waters at $T > 60\text{ °C}$ c	–0,80 to –0,50	–0,95	a
	Soils and waters in aerobic conditions at $T < 40\text{ °C}$ with $100 < \rho < 1\,000\ \Omega\cdot\text{m}$	–0,50 to –0,30	–0,75	a
	Soils and waters in aerobic conditions at $T < 40\text{ °C}$ with $\rho > 1\,000\ \Omega\cdot\text{m}$	–0,40 to –0,20	–0,65	a
	Soils and waters in anaerobic conditions and with corrosion risks caused by Sulfate Reducing Bacteria activity	–0,80 to –0,65	–0,95	a
Austenitic stainless steels with PREN < 40	Neutral and alkaline soils and waters at ambient temperatures	–0,10 to + 0,20	–0,50	d
Austenitic stainless steels with PREN > 40		–0,10 to + 0,20	–0,30	-
Martensitic or austeno-ferritic (duplex) stainless steels		–0,10 to + 0,20	–0,50	e
All stainless steels	Acidic soils and waters at ambient temperatures	–0,10 to + 0,20	e	e
Copper	Soils and waters at ambient temperatures	–0,20 to 0,00	–0,20	-
Galvanized steel		–1,10 to –0,90	–1,20	

NOTE 1 All potentials are IR free and refer to a copper/saturated copper sulfate reference electrode, $E_{Cu} = E_H - 0,32\text{ V}$.

NOTE 2 During the lifetime of the pipeline, any possible changes of resistivity of the medium around the pipeline are to be taken into account.

a To prevent hydrogen embrittlement on high strength non alloyed and low alloyed steels with designed yield strength exceeding $550\text{ N}\cdot\text{mm}^{-2}$, the critical limit potential shall be documented or determined experimentally.

b For temperatures $40\text{ °C} \leq T \leq 60\text{ °C}$, the protection potential may be interpolated linearly between the potential value determined for 40 °C (–0,65 V, –0,75 V, –0,85 V or –0,95 V) and the potential value for 60 °C (–0,95 V).

c The risk of high pH stress corrosion cracking increases with increase of temperature.

d In case of presence of any martensitic or ferritic phase (e.g. due to hardening), the risk of hydrogen embrittlement should be determined by documentation or experimentally.

e Determination by documentation or experimentally.

To prevent disbondment and/or blistering of the coating, the limiting critical potential, E_l , should not be more negative than –1,20 V (CSE) for the currently used pipeline coatings.

6.3 Alternative methods

6.3.1 100 mV cathodic potential shift

If the criteria defined in [Table 1](#) cannot be achieved, a minimum cathodic potential shift of 100 mV is considered as an acceptable alternative method to reduce the corrosion rate (see NACE Publication n°35108[1]). A residual corrosion rate less than 0,01 mm/y might not be achieved. The formation or decay of potential shift shall be measured in accordance with the method defined in [Annex A](#).

The application of the 100 mV potential shift shall be avoided at operating temperatures above 40 °C, in SRB-containing soils, when interference currents, equalizing currents, or telluric currents might be present, or when there is a risk of external stress corrosion cracking. Furthermore, the potential shift method shall not be used in the case of pipelines connected to or consisting of mixed metal components.

6.3.2 Other methods

Alternative methods may be used if it can be demonstrated that the control of corrosion is achieved.

6.4 Criteria in the presence of a.c.

In locations where a.c. interference is possible, measurements of a.c. voltage and/or current density shall be carried out to evaluate the level of the a.c. influence.

In the presence of a.c. voltage on the pipeline, the protection criteria defined in [Table 1](#) shall be fulfilled although they do not necessarily provide protection against a.c. corrosion. The IR-free potential, E_{IRfree} , shall meet the criterion given by Formula (1).

EN 15280 gives guidelines for the a.c. corrosion likelihood and defines detailed criteria that may be applied.

7 Pre-requisites for the application of cathodic protection

7.1 General

For application of cathodic protection, the pipeline, or section of the pipeline to be protected, shall be electrically continuous. The pipeline should be coated and electrically isolated from other structures and earthing systems. Justification shall be provided if the pipeline is not electrically isolated from other structures and earthing systems.

NOTE Coatings are universally applied to buried pipelines to provide the primary corrosion protection with cathodic protection to protect areas of coating damage. Coatings reduce the overall cathodic protection current requirement and, as a consequence, the risk of interference to adjacent buried structures.

7.2 Electrical continuity

The electrical continuity of the pipeline, or any section of the pipeline to be protected, shall achieve a low longitudinal resistance and the components which may increase the longitudinal resistance of the pipeline shall be short-circuited, e.g. by using cables or low-resistance metal bonds with a suitable cross sectional area.

On non-welded pipelines, the electrical continuity shall be achieved on the length to be protected by the installation of permanent bonds across the high-resistance mechanical connectors using reliable bond attachment methods. The continuity of non-welded pipelines shall be checked by carrying out resistance and potential measurements.

When necessary, bonding may be carried out across isolating devices for measurement or other purposes. If it is necessary that electrical continuity be established permanently, this bonding should be done in a test station.

7.3 Electrical isolation

7.3.1 General

Metallic contacts or resistive contacts between the pipeline and other structures, or direct connection to earthing systems, should be avoided; otherwise, the corrosion risk can be increased.

For this reason, pipelines should be electrically isolated from foreign structures including compressor stations, pump stations, pressure reducing, metering and delivery stations, water pumping and storage facilities, wellsites, offshore pipelines and structures, terminals and processing facilities, and at interfaces with other pipelines.

Electrical isolation can also be installed to divide the system into sections, e.g. in stray current areas.

Isolation should be achieved by installation of isolating joints (monolithic isolation joints or isolating flange kits) or non-conductive pipe sections.

If electrical isolation is not possible, then the cathodic protection design shall provide for sufficient current and effective current distribution to ensure that the pipeline is cathodically protected without adverse effect on other structures.

If there is a contact between the protected pipeline and any other less electronegative structure, EN 14505 considers they constitute a complex structure and gives recommendations that can help in that case.

7.3.2 Locations

The location of the electrical isolation points should be carefully considered, particularly in the case of d.c. stray current. This requires, for example, detailed measurements and analysis of the electrolyte surface gradients (see EN 50162 for further guidance).

Electrical isolation can be required

- between pipeline sections consisting of different metallic materials,
- at the extremities of the pipeline,
- at significant changes in electrolyte resistivity,
- on pipelines requiring different cathodic protection systems,
- on pipelines with different current density requirements,
- in areas influenced by stray currents, a.c., or telluric currents,
- on some pipeline networks to facilitate the cathodic protection maintenance or measurements, and
- at interfaces with unprotected structures or earthed equipment.

In the case of distribution systems, electrical isolation shall be installed at the interface with customer facilities.

7.3.3 Isolating joints

The mechanical design, materials, dimensions, and construction of the isolating joints shall meet the requirements of ISO 13623, EN 14161, EN 1594 or EN 12007-3, as applicable.

Monobloc isolation joints should be used wherever possible. They can be installed above-ground, in a pit or buried.

Monobloc isolation joints should be electrically tested before installation.

NOTE 1 Electrical tests are proposed in [Annex F](#).

NOTE 2 Installing the isolation joint above ground provides the advantage of easier visual, electrical, and ultrasonic inspection. On the other hand, buried isolating joints are less exposed to mechanical or fire hazards, voluntary or involuntary damage, and can prevent the product inside the pipeline from freezing (sometimes referred to as “frost-proof grounding”).

NOTE 3 Installing an isolating joint in a pit provides the advantages of a buried isolation joint but with the added risk of gas entrapment. For this reason, local regulations can prevent installation of an isolation joint in a pit.

When a pipeline is connected to above-ground facilities, an above-ground isolating joint ensures that cathodic protection is applied to the entire buried section. If the isolation joint is buried, then the pipeline operator shall take additional measures for corrosion protection of the section of the pipeline that is isolated from the main cathodic protection system.

If multiphase fluids containing a significant percentage of water are transported in the pipeline, installation of the isolating joint on a vertical or angled transition section should be considered to prevent a continuous water phase inside the pipeline becoming the source of internal corrosion (see [7.3.4](#)).

Buried isolation joints shall be externally coated with materials that are compatible with the coating applied to the pipeline.

Isolating flanges are subject to degradation by atmospheric weathering, dirt, and moisture ingress and shall be protected against ingress of dirt and moisture by the use of flange protectors or viscoelastic compounds.

A major cause of failure of isolating flanges is poor installation techniques. To reduce this risk, the manufacturer's instructions should be followed or factory preinstalled kits utilized.

Principal installation errors are

- over-tightening of the flange bolts (isolating flanges require a lower tightening torque than flanges without isolating gaskets),
- incorrect alignment of flange faces, and
- improper surface preparation of flange faces.

The isolation materials shall be designed to withstand service conditions (e.g. transported medium, temperature, pressure, mechanical stress) and shall have an appropriate dielectric strength. Other important properties of the isolating flange kit include mechanical (e.g. flexural and tensile strength, etc.), isolation efficiency, and water absorption.

Isolating joints shall be installed in such a manner as to eliminate the risk of accidental shorting.

To avoid damage from high voltages due to lightning strikes or a.c. fault currents caused by electric power lines, protective devices shall be considered (e.g. appropriate isolating spark gap, surge protective device, and appropriate electrical earthing).

Isolating joints installed in areas classified as hazardous in accordance with EN 60079-10-1 shall conform to the certification and operational requirements of the hazardous area.

Isolating joints shall be provided with accessible test facilities.

7.3.4 Internal corrosion risks at isolating joints

In pipelines carrying fluids with a separate water phase, there is a risk of internal corrosion caused by current leaving the internal surface of the pipe close to the isolating joint on the side that has a less negative internal potential (anodic side). This is mainly dependent on the conductivity of the fluid and the voltage between both sides of the isolating joint.

To prevent or mitigate this internal corrosion risk, a lining (internal coating with an electrically isolating material) should be applied on the side of the pipeline with the more negative internal potential (cathodic side).

The length of the section being lined internally increases with increasing electrolyte conductivity, increasing pipeline diameter and increasing voltage on the sides of the isolating joint. If there is no prior knowledge from previous experience, then the length of pipeline being lined should be determined by calculations or tests.

The length of internal coating can be determined by defining an internal ohmic resistance of the internal fluid. This assessment can be made using simulation software or by calculation (Ohm's law), and shall be documented. This study shall be made considering the fluid resistivity, the potential drop between each part of the isolating joint, and the absence of external coating defect on the anodic side of the pipeline.

NOTE 1 Based on feedback and experience, a value of 100 Ω for the internal ohmic resistance is commonly used for the evaluation of the length of the internal coating.

NOTE 2 For long lengths of lining, an entire pipe length lined in a factory is generally used.

In practice, if both sides of isolating joints are lined, the length of the lining on the cathodic side shall be at least the calculated length.

NOTE 3 When custom made asymmetrical lined isolating joints are used, the risk incurred by installing the longer liner on the wrong side of the isolating joints can be significant.

The lining should be of a type that does not deteriorate when in contact with the internal fluid, especially in the case of a lining exposed to salt water.

An alternative to internal lining is to install a sacrificial steel pipe spool piece next to the isolating joint on the side that has a less negative internal potential (anodic pipeline side). The spool piece should be periodically inspected to monitor the progress of internal corrosion and replaced in time to prevent leakage.

7.3.5 Contacts between metallic structures

Where entries, restraints, supports, and anchors are made of concrete, there should be no contact (direct or resistive) between reinforcing steel and the protected pipeline. For this reason, a wall entry fitting made of insulating material should be provided and a high-quality coating should be applied to the protected pipeline. The possibility of shielding effect shall be considered.

Where the pipeline crosses a bridge above ground or enters a tunnel and includes isolating joints at each end of the bridge or the tunnel, the pipe between isolating joints may be equipotentially bonded to the bridge or the tunnel to provide protection from inadmissible touch potentials. In order to provide cathodic protection to the pipeline on either side of the bridge or the tunnel from a common cathodic protection system, an equipotential bond is required to connect the pipeline on both sides of the bridge or the tunnel.

If the pipeline crosses a bridge in a service trough containing an electrolyte (e.g. sand), the pipe may be cathodically protected by galvanic anodes (e.g. magnesium ribbon) and not connected to the bridge.

If there are no isolating joints, then the pipe shall be electrically isolated from the metallic parts of the bridge or the tunnel. This is especially important in the case of metal bridges carrying d.c. traction systems.

7.3.6 Electrical earthing system

Electrical earthing of devices installed on the protected pipeline can be required for safety reasons or pipeline earthing can be required to mitigate the effect of induced electrical voltages.

If an earthing system is required, it shall be made compatible with the cathodic protection system. When allowed by regulations, this may be achieved by installing suitably rated d.c. decoupling devices in the earthing circuit. Local earthing using zinc or galvanized earth electrodes directly connected to the pipeline may be used, but there can still be future adverse effects on the cathodic protection.

NOTE 1 These adverse effects on cathodic protection effectiveness are due to one or both of the following:

- the resistance of local earth, with respect to remote earth, can be much lower than the resistance of coating defects, which results in reduced CP current at the coating defect;
- zinc or galvanized steel potential can drift with time towards less negative potentials.

If earthing is being installed to mitigate the effect of a.c. voltages on the pipeline, the earthing locations should be established through a specific study and detailed design.

NOTE 2 EN 15280 and EN 50443 provide guidance on the corrosion and safety aspects related to a.c. influences.

Detection and control of electrical interference shall be in accordance with [Annex B](#).

When an earthing (local or remote) is connected to electrically operated equipment, e.g. valves or pumps, the resistance to earth of the pipeline is decreased at these points, which can impede or prevent cathodic protection. To maintain effective cathodic protection, one of the remedies listed below may be applied (subject to relevant national or local safety regulations):

- isolation of the electrically operated equipment from the protected pipeline;
- isolation of the part of the pipeline (e.g. valve) connected to the electrical operated equipment from the rest of the pipeline by means of isolating joints, with a continuity bond between the two parts of the pipeline and separate corrosion protection for the isolated part of the pipeline (e.g. valve);
- installation of isolating transformers;
- installation of fault current circuit breaker in conjunction with a local earthing made of galvanized steel, zinc, or magnesium;
- installation of d.c. decoupling devices between the electrically operated equipment and the main earthing system (e.g. isolating spark gaps, surge protective device, polarization cell, electrical isolation).

7.4 Lightning and overvoltage protection

Pipelines can be affected by overvoltage and current strikes made by lightning or by nearby external power lines (e.g. earth short circuits).

To protect the isolating joint against overvoltage, an isolating spark gap should be connected across the isolating joint.

To mitigate the effect of all kinds of electrical strikes or electrical interference, isolating spark gaps, surge protective devices (SPD), or d.c. decoupling devices may also be installed between the pipeline and an earthing system, subject to national or local regulations or safety standards.

Cable length, cross section, and type have a high influence on the overvoltage protection effectiveness. They shall be matched to the isolating spark gap or SPD electrical characteristics. Cable length should be as short as possible, ensuring any loop formed on the installation is as small as possible.

NOTE To choose the type of isolating spark gaps, the following parameters are typical for cathodic protection applications for a 50 Hz case:

- d.c. spark over voltage: from 500 V to 1 kV;
- 100 % lightning impulse spark over voltage (1,2/50 μ s): $\leq 1,30$ kV for both class 1 and class 2 isolating joints, or $\leq 2,2$ kV for class 1 only (see [Annex F](#));
- nominal discharge current (8/20 μ s): 100 kA;
- lightning impulse current, I_{imp} , (10/350 μ s): 100 kA (class H), 50 kA (class N);
- rated short-duration power frequency withstand voltage (50 Hz): < 250 V;
- rated discharge current (50 Hz): ≥ 100 A / 0,5 s;

- certification according to Directive 94/9/EC “on equipment and protective systems intended for use in potentially explosive atmospheres (ATEX)”;
- proved in accordance with EN 50164-3.

7.5 Coating

7.5.1 General

Pipelines subject to cathodic protection should be installed with an external coating. The coating selection shall be approved by pipeline operator.

NOTE 1 The coating provides the primary prevention against corrosion. It reduces protection current demand, improves current distribution, extends the protected area, and reduces interference to other foreign structures.

The pipeline coating should be applied in a factory, or under factory conditions, on pipe lengths under specified conditions for surface preparation, coating application and inspection. After the welding of pipe lengths during the construction of the pipeline, girth weld areas should be coated with a compatible field joint coating.

NOTE 2 Field joints and fittings coated on site are applied under more demanding conditions and can be a weak point in the general corrosion protection system if not selected and applied correctly.

After the laying of the pipeline, coating defect surveys (see [Annex D](#)) should be carried out in order to evaluate the coating conditions.

7.5.2 Factory-applied coatings

Coatings shall be applied in accordance with

- ISO 21809-1 for polyolefin coatings (3-layer PE or 3-layer PP),
- ISO 21809-2 for fusion-bonded epoxy coatings,
- ISO 21809-4 for polyethylene coatings (2-layer PE), or
- other equivalent standards.

7.5.3 Field joint coatings

ISO 21809-3, EN 10329, or other equivalent standards should be used for the selection and application of field joint coatings.

NOTE Field joint coatings are generally either pre-shaped materials such as cold-applied tapes or heat-shrinkable sleeves or materials applied in the form of powders or liquids.

7.5.4 Coating for trenchless pipelines

Trenchless pipelines (e.g. by horizontal drilling) should be protected with external coatings with additional resistance to mechanical damage. Additional requirements for such coatings may include

- increased thickness, and
- increased mechanical resistance characteristics.

The trenchless installation should be tested for coating damage evaluation before it is tied in to the main section of the pipeline.

NOTE During trenchless installation, it is possible that some coatings will experience surface abrasion damage and this can lead to an increased level of moisture absorption. This will affect the coating electrical resistance and hence the current density requirements.

The acceptance criteria for the coating test should be determined before the installation of the pipeline.

In the absence of any specific requirement, the coating conditions can be evaluated by comparing the current density required to protect the trenchless section with the optimized design values given in [Table 3](#) (see [8.4.3](#)). Known values of current should be injected into the pipe from a temporary groundbed and the current density calculated for the section. If the current density required to achieve cathodic protection is greater than the recommended values in [Table 3](#), the trenchless pipe coating should be considered as unsatisfactory and should be remedied.

[D.4.3](#) defines an acceptable procedure for the test of the coating. Other methods can also be used.

7.5.5 Air to electrolyte interface

For an air to electrolyte interface, a high-performance coating should be used. Specific characteristics for the coating selection may include

- mechanical strength,
- UV stability, and
- adhesion.

7.5.6 Compatibility of coatings and wraps with cathodic protection

Disbondment can cause cathodic protection current shielding by preventing access of the cathodic current to the steel surface exposed to a corrosive electrolyte due to lack of continuity and/or high resistivity of the electrolyte present underneath the disbondment, renewal of corrosive species, or presence of SRB.

The selected coatings shall be compatible with the application of cathodic protection. Compatibility should be verified through cathodic disbondment tests in accordance with the applicable coating standards.

Non-bonded polyethylene wraps should be avoided as they cause shielding of the cathodic protection current and can be detrimental to the protection.

7.5.7 Thermal insulation

Thermal insulation systems are coating systems that include a layer to provide thermal insulation. This can be a dedicated layer in addition to a corrosion-protection layer or it can be a layer such as polyurethane or rubber that provides both corrosion protection and thermal insulation.

Because of the overall coating thickness and the high resistance of the different coating and insulation layers, cathodic protection is unlikely to be effective. The requirement for and the type of cathodic protection for thermally-insulated pipelines shall be evaluated considering the following.

- a) Thermally-insulating materials, such as polyurethane foam, have a high electrical resistance. Even if they become waterlogged, they are likely to shield the cathodic protection current and prevent the protection of the underlying steel pipe. Alternative corrosion control methods should be considered in such cases.
- b) The installation of a cathodic protection system solely to protect an insulated pipeline is normally difficult to justify, unless there is concern that the thermal insulation can suffer significant mechanical damage by third party action that leads to direct exposure of the pipe to the electrolyte.
- c) The intrinsically high resistance to earth of a thermally insulated pipeline precludes the discharge of any induced voltages, for example from adjacent power lines, to earth through the coating. Unless the pipeline has been directly earthed close to the point of the induced voltage, pipeline voltages can change over considerable distances, which can cause corrosion and/or become a safety hazard to personnel who make direct contact with the pipeline.

Cathodic protection potentials measured on thermally insulated pipelines are usually not indicative of the potentials at the metal-to-electrolyte interface beneath the coating. These potentials should not be used for assessing the effectiveness of the cathodic protection. Other methods should be used to verify the integrity of the pipeline at these locations.

7.5.8 Reinforced concrete weight coating

Steel reinforced concrete can be used to increase the weight of a pipeline particularly in wet areas such as marshes. Contact between the rebar of the weight coating and the pipeline shall be avoided. Isolation of the rebar from the pipeline shall be checked by measurements during application of the weight coating (in accordance with ISO 21809-5 or equivalent standard) and during pipeline operation.

7.6 Selection of pipe trench backfill material

In order to avoid the risk of coating damage or shielding effects and to achieve electrical continuity between the pipe and the electrolyte, it can be necessary to add materials to the trench such as washed sand or fine soil. Adding these materials is referred to as padding.

Imported or processed backfill is not usually necessary for coating damage protection when rock jacket coating systems are used.

7.7 Buried casings for pipelines

7.7.1 General

Casings may have a detrimental impact on the cathodic protection of the carrier pipes. Their use should be avoided where possible.

Carrier pipe within casings should have a high-quality coating for protection against corrosion.

The following measures should be implemented when the use of casings is unavoidable:

- coating of the carrier pipe;
- installation of isolating spacers in the annular space between the carrier and casings;
- sealing at the ends of the casing.

In practice, it is almost impossible to achieve a water-tight seal and a suitable filler material may be injected into the annular space. The filler material should either inhibit corrosion (e.g. visco-elastic compounds, inhibited wax) or be designed to allow cathodic protection current to reach the carrier pipe (e.g. concrete, alkaline grout).

Vent pipes shall be considered when building a casing in order to detect a leak of transported fluid. They may also be used to inject fillers for maintenance when necessary.

7.7.2 Casings that shield cathodic protection current

External corrosion protection of the carrier pipe inside sleeves which shield cathodic protection current should be achieved by

- the use of galvanic anodes provided there is an electrolyte,
- filling the annular space with appropriate material with adequate long-term corrosion protection properties,
- if galvanic anodes are used: there shall be no contact between the casing (if metallic) and the galvanic anodes, and
- consideration shall be given to the possibility of the anode corrosion products bridging the spacers.

NOTE Casings that shield cathodic protection current include plastic, coated concrete, low conductive concrete, and coated steel casings.

7.7.3 Casings that pass cathodic protection current

For casings passing cathodic protection current, the external cathodic protection of the carrier pipe can be effective in protecting the carrier pipe inside the sleeve provided there is no contact between the carrier pipe and the casing, and that there is enough electrolyte in the annular space. Without any electrolyte in the annular space, atmospheric corrosion can occur at coating defects.

NOTE Casings that pass cathodic protection current include:

- bare or poorly coated steel pipes;
- uncoated concrete pipes that are sufficiently conductive;
- well coated casings connected to a local earthing which will allow the cathodic protection current to flow.

If cathodic protection of the casing is required (e.g. because of national or local regulations), the casing should be resistively bonded to the carrier pipeline, with the resistance value adjusted to ensure that the casing is always anodic to the carrier pipeline.

7.8 Equipment for the reduction of a.c. interference

There are two basic types of a.c. interference on buried pipelines:

- short-term interference caused by a.c. high voltage power line failure and operational changes (ohmic and inductive effects; see EN 50443);
- long-term interference caused by induction during operation (inductive effect, see EN 15280 and EN 50443).

Mitigation of these effects can require the addition of earthing systems. These earthing systems may be constructed using a wide variety of electrodes (e.g. galvanized steel, zinc, magnesium) provided that these have no adverse effect on the effectiveness of the cathodic protection.

To avoid adverse effects on the cathodic protection, additional earthing systems should be connected to the pipeline via appropriate devices (e.g. d.c. decoupling devices).

7.9 Equipment for the mitigation of d.c. interference

d.c. stray currents can have an adverse impact on the effectiveness of the applied cathodic protection and can require installation of additional equipment to ensure effective external corrosion protection (see EN 50162 and EN 50122-2).

NOTE The following solutions can provide mitigation of d.c. interference:

- installation of a drainage station; drainage stations are usually connected after the commissioning of the cathodic protection system but it is prudent to install all of the equipment during construction;
- installation of isolating joint;
- improvement of the cathodic protection level in anodic d.c. stray current areas.

8 Basic requirements for cathodic protection design

8.1 General

Sizing of cathodic protection systems can be done either by calculations or on the basis of the pipeline operator experience for similar configurations.