
**General principles of cathodic protection
in sea water**

Principes généraux de la protection cathodique en eau de mer

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Foreword

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

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

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

ISO 12473 was prepared by the European Committee for Standardization (CEN) (as EN 12473) and was adopted, under a special “fast-track procedure”, by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*, in parallel with its approval by the ISO member bodies.

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Foreword

This European Standard has been prepared 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of an identical text or by endorsement, at the latest by July 2000, and conflicting national standards shall be withdrawn at the latest by July 2000.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Annex A of this European standard is normative.

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1 Scope

This European Standard covers the general principles of cathodic protection including the criteria for protection, environmental and design considerations and secondary effects of cathodic protection and is intended as an introduction to other European Standards in the general series "Cathodic Protection of Steel Structures in Sea Water".

This European Standard provides a link between the theoretical aspects and the practical applications of cathodic protection as contained in the European Standards:

prEN 12474:1997, *Cathodic protection for submarine pipelines.*

EN 12495:2000, *Cathodic protection for fixed steel offshore structures.*

prEN 12496:1997, *Galvanic anodes for cathodic protection in sea water and saline mud.*

prEN 13173:1998, *Cathodic protection for steel offshore floating structures.*

This group of European Standards does not cover cathodic protection of steel in concrete whether immersed or atmospherically exposed. These aspects are covered by prEN 12696-1:1997 and prEN 12696-2.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN ISO 8044, *Corrosion of metals and alloys – Basic terms and definitions (ISO 8044:1999).*

3 Terms and definitions

For the purposes of this European Standard the terms and definitions in EN ISO 8044 and the following apply:

3.1

acidity

presence of an excess of hydrogen ions over hydroxyl ions ($\text{pH} < 7$)

3.2

alkalinity

presence of an excess of hydroxyl ions over hydrogen ions ($\text{pH} > 7$)

3.3

anaerobic condition

absence of free oxygen in the electrolyte

3.4

anodic area

that part of a metal surface which acts as an anode

3.5

bond

metal conductor, usually of copper, connecting two points with the intention of making the points equipotential

3.6

calcareous deposits

minerals precipitated on the steel cathode because of the increased alkalinity caused by cathodic protection

3.7 calomel reference electrode
reference electrode consisting of mercury and mercurous chloride in a saturated solution of potassium chloride

3.8 cathodic area
that part of a metal surface which acts as a cathode

3.9 cathodic disbonding
failure of adhesion between a coating and a metallic surface that is directly attributable to the application of cathodic protection

3.10 cathodic protection system
entire installation, including active and passive elements, that provides cathodic protection

3.11 cell
complete electrolytic system comprising of a cathode and an anode in electrical contact and with an intervening electrolyte

3.12 coating breakdown factor
coating breakdown factor is the anticipated reduction in cathodic current density due to the application of an electrically insulating coating when compared to that of bare steel

3.13 coating defect
discontinuity in the protective coating

3.14 coating resistance
electrical resistance between a coated metal and the electrolyte. It is determined largely by the size and number of coating defects and coating pores and is, therefore, indicative of the condition of the coating

3.15 conductor
substance in which electric current flows

3.16 continuity bond
bond designed and installed specifically to ensure electrical continuity of a structure

3.17 copper/copper sulphate reference electrode
reference electrode consisting of copper in a saturated solution of copper sulphate

3.18 corrosion interference
increase or decrease in the rate of corrosion, or the tendency towards corrosion, of an immersed structure caused by the interception of part of the cathodic protection current applied to another immersed structure

3.19 depolarization
removal of factors resisting the flow of current in a cell

3.20 dielectric shield
alkali resistant organic coating applied to the structure being protected in the immediate vicinity of an impressed current anode to enhance the spread of cathodic protection and minimize the risk of hydrogen damage to the protected structure in the vicinity of the anode

3.21**drainage bond**

bond to achieve electric drainage

3.22**driving potential**

difference between the structure/electrolyte potential and the anode/electrolyte potential

3.23**electrical resistance of coating**

see coating resistance

3.24**electronegative**

qualification applied to a metallic electrode to indicate that its potential is negative with respect to another metallic electrode in the system

3.25**electro-osmosis**

passage of a liquid through a porous medium under the influence of a potential difference

3.26**environmentally assisted cracking**

brittle fracture of a normally ductile material in which the corrosive effect of the environment is a contributory factor

3.27**galvanic action**

spontaneous electrochemical reaction which occurs in a system comprising a cathode and an anode in electrical contact and with an intervening electrolyte, resulting in corrosion of the anode

3.28**groundbed**

system of immersed electrodes connected to the positive terminal of an independent source of direct current and used to direct the cathodic protection current onto the structure being protected

3.29**holiday**

see coating defect

3.30**impressed current anode**

anode in an impressed current installation

3.31**insulated flange**

flanged joint between adjacent lengths of pipe in which the nuts and bolts are electrically insulated from one or both of the flanges and the gasket is non-conducting, so that there is an electrical discontinuity in the pipeline at that point

3.32**ion**

atom, or group of atoms, carrying a charge of positive or negative electricity

3.33**isolating joint**

electrically discontinuous joint or coupling between two lengths of pipe, inserted in order to provide electrical discontinuity between them

**3.34
over polarization**

when the structure to electrolyte potentials are more negative than those recommended for satisfactory cathodic protection. Over polarization provides no useful function and may even cause damage to the structure by excessive production of gases which may cause embrittlement or protective coating damage

**3.35
polarization**

change in the potential of an electrode as the result of current flow to or from that electrode

**3.36
potential gradient**

difference in potential between two separate points in the same electric field

**3.37
protected structure**

structure to which cathodic protection is effectively applied

**3.38
protection current**

current made to flow into a metallic structure from its electrolytic environment in order to effect cathodic protection of the structure

**3.39
resistivity (of an electrolyte)**

resistivity is the resistance of an electrolyte of unit cross section and unit length. It is expressed in ohm(s) metres (Ω m). The resistivity depends, amongst other things, upon the amount of dissolved salts in the electrolyte

**3.40
scale precipitation**

formation of insoluble chemical compounds on the surface of a cathodically protected structure. These are referred to as calcareous deposits (see 3.6)

**3.41
silver/silver chloride reference electrode**

reference electrode consisting of silver, coated with silver chloride, in an electrolyte containing chloride ions

**3.42
slow strain rate test**

this test involves the slow tensile loading of a specimen of a circular cross section under conditions of constant strain rate with the gauge area exposed to the test environment

**3.43
standard hydrogen electrode**

reference electrode consisting of an electro-positive metal, such as platinum, in an electrolyte containing hydrogen ions at unit activity and saturated with hydrogen gas at one standard atmosphere

**3.44
structure to electrolyte potential**

difference in potential between a structure and a specified reference electrode in contact with the electrolyte at a point sufficiently close to, but without actually touching the structure, to avoid error due to the voltage drop associated with any current flowing in the electrolyte

**3.45
sulphate reducing bacteria**

group of bacteria found in most soils and natural waters, but active only in conditions of near neutrality and freedom from oxygen. They reduce sulphates in their environment, with the production of sulphides and accelerate the corrosion of structural materials

3.46 telluric currents

electrical currents induced by time varying changes in the earth's magnetic field. These currents flow generally in the earth or in the oceans. They are able to flow in metallic conductors laid in the soil or in the sea

3.47 transformer rectifier

transformer rectifier is a device that transforms the alternating voltage to a suitable value and then rectifies it to direct current. Direct current derived in this way is used as a power source for impressed current cathodic protection systems

4 Corrosion principles of buried or immersed metals

4.1 The nature of metallic corrosion

When a metal corrodes in contact with an electrolyte neutral atoms pass into solution by forming positively charged ions and excess electrons are left in the metal. The process for iron may be expressed as

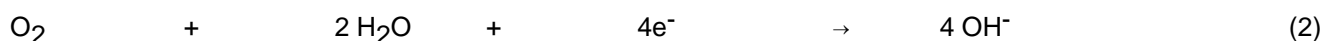


Thus corrosion is accompanied by the flow of an electric current from metal to electrolyte due to the movement of positive ions into the electrolyte and of electrons into the metal. Any area to which current flows is referred to as an anodic area and the reaction is called an anodic reaction. The metallic ions may react with negative ions in the electrolyte to give insoluble corrosion products (for example, rust in the case of steel). Such reactions do not materially affect the corrosion process except where insoluble corrosion products stifle further corrosion attack.

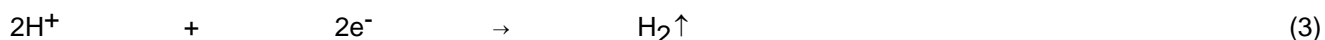
For the corrosion reaction to proceed the overall electric neutrality has to be maintained. Therefore, the movement of electrons into the metal and positive ions into the electrolyte at the anodic areas has to be counterbalanced by the consumption of electrons at other areas, known as cathodic areas.

Various reactions can occur at cathodic areas and these are known as cathodic reactions.

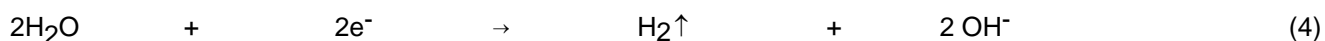
The following equations show the most common reactions that occur at cathodes:



oxygen water electrons hydroxyl ions



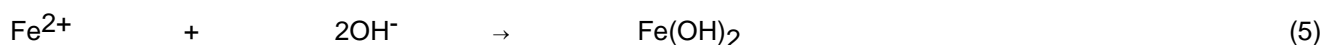
hydrogen ions electrons hydrogen gas



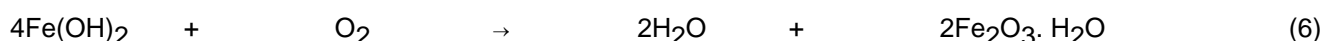
The first of these reactions occurs in the presence of dissolved oxygen and near-neutral conditions.

The second is favoured by acidity (excess of hydrogen ions) while the third is dominant at pH values greater than neutral.

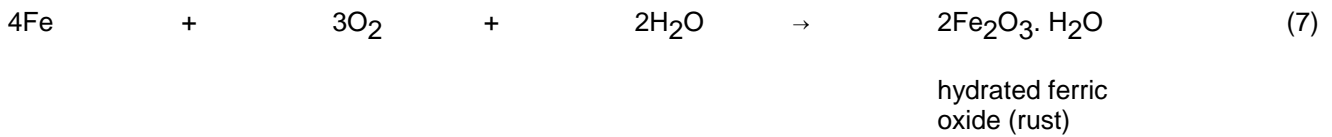
In aerated near neutral conditions, the iron ions produced at the anode react with the hydroxyl ions formed at the cathodic sites to produce ferrous hydroxide.



The ferrous hydroxide is readily oxidised by dissolved oxygen to form hydrated ferric oxide $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$:

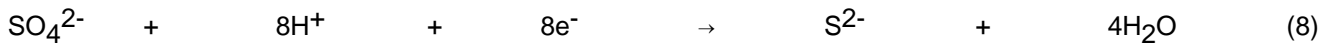


Thus the overall reaction which proceeds through a series of intermediate steps may be written as:



In practice the rate of corrosion is often determined by the rate at which the cathodic reaction can be sustained.

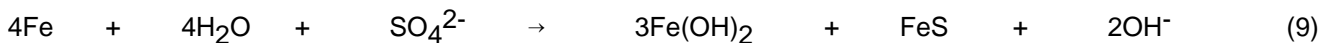
In near neutral anaerobic waterlogged environments sulphate reducing bacteria may give rise to a further type of cathodic reaction in the corrosion of iron and steel. These microbes reduce dissolved sulphates to sulphides possibly through the reaction



and the corrosion is characterised by the fact that it occurs

- a) in the absence of air; and
- b) sulphides are present in the corrosion products.

From the composition of the actual products formed it is probable that the corrosion mechanism involves cathodic depolarisation which may be represented by the simplified equation (9);



Stimulation of the cathodic reaction depends on the bacteria possessing an enzyme (hydrogenase) to enable them to oxidise hydrogen found at the cathodic sites.

The sulphide ions produced by the reduction of sulphate can sometimes stimulate the anodic process of iron dissolution.

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4.2 Polarisation

Where corrosion occurs, the potential difference between the two electrochemical reactions on the surface provides the driving force for the reaction. As a result, both electrode reactions are changed from their equilibrium condition causing a net anodic reaction to occur in one case and a net cathodic reaction in the other. The two potentials approach one another because all or part of the potential difference is used in driving the individual reactions. For corrosion to occur spontaneously, not only does there have to be a difference between the two reaction potentials, but the potential of the cathodic process has to be more positive than that for the anodic process.

These circumstances are represented schematically in figure 1, which is a plot of electrode potential, E , against the logarithm of the reaction rate. Because anodic and cathodic reactions release and consume electrons, respectively, the anodic and cathodic reaction rates are represented by an electrical current, I . For simplicity, both reaction rates are plotted on the same axis, the direction of the current is ignored and only the magnitude is used to represent rate.

E_C is the equilibrium potential for the cathodic reaction where there is no net cathodic reaction rate. The negative changing curve from E_C shows that, as the potential becomes more negative, the cathodic reaction rate increases. Conversely, E_A is the equilibrium potential for the anodic reaction [eg equation (1)] and again at E_A there is no net anodic reaction. The positive changing curve from E_A shows that, as the potential becomes more positive, the anodic reaction rate increases.