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EAST AFRICAN STANDARD

Protection of metallic materials against corrosion — Guidance on the assessment of corrosion likelihood in closed water circulation systems

EAST AFRICAN COMMUNITY

Foreword

Development of the East African Standards has been necessitated by the need for harmonizing requirements governing quality of products and services in East Africa. It is envisaged that through harmonized standardization, trade barriers which are encountered when goods and services are exchanged within the Community will be removed.

In order to meet the above objectives, the EAC Partner States have enacted an East African Standardization, Quality Assurance, Metrology and Test Act, 2006 (EAC SQMT Act, 2006) to make provisions for ensuring standardization, quality assurance, metrology and testing of products produced or originating in a third country and traded in the Community in order to facilitate industrial development and trade as well as helping to protect the health and safety of society and the environment in the Community.

East African Standards are formulated in accordance with the procedures established by the East African Standards Committee. The East African Standards Committee is established under the provisions of Article 4 of the EAC SQMT Act, 2006. The Committee is composed of representatives of the National Standards Bodies in Partner States, together with the representatives from the private sectors and consumer organizations. Draft East African Standards are circulated to stakeholders through the National Standards Bodies in the Partner States. The comments received are discussed and incorporated before finalization of standards, in accordance with the procedures of the Community.

Article 15(1) of the EAC SQMT Act, 2006 provides that "Within six months of the declaration of an East African Standard, the Partner States shall adopt, without deviation from the approved text of the standard, the East African Standard as a national standard and withdraw any existing national standard with similar scope and purpose".

East African Standards are subject to review, to keep pace with technological advances. Users of the East African Standards are therefore expected to ensure that they always have the latest versions of the standards they are implementing.

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Introduction

This standard results mainly from investigations into and experience gained on the corrosion of metallic materials normally present in water circulation systems in buildings (unalloyed and low alloyed steels, cast iron, aluminium, copper and copper alloys, stainless steels).

Because of the complex interactions between the various influencing factors, which can alter during service life due either to normal operation changes in service conditions or accidental events, the extent of corrosion can only be expressed in terms of likelihood. This Standard therefore is a guidance document and does not set explicit rules for the use of metallic materials in water systems.

A correct evaluation of the corrosion likelihood therefore needs a corrosion expert (or at least a person with technical training in the corrosion field) and knowledge of the technology and operating conditions of the system considered.

Though incidences of severe damage because of corrosion (and/or scaling) are generally rare, certain basic precautions should be taken in order to maintain a long-term, trouble-free service. This Standard should therefore be considered as a guidance document. On the basis of the information provided herein, decisions can be made during design, installation and service life to minimize the likelihood of corrosion damage occurring.

In the preparation of this East African Standard, the following source was consulted extensively:

BS EN 14868:2005, *Protection of metallic materials against corrosion — Guidance on the assessment of corrosion likelihood in closed water circulation systems*

Assistance derived from this source and others inadvertently not mentioned is hereby acknowledged.

BRITISH STANDARD

**BS EN
14868:2005**

Protection of metallic materials against corrosion — Guidance on the assessment of corrosion likelihood in closed water circulation systems

The European Standard EN 14868:2005 has the status of a British Standard

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BSi
British Standards

National foreword

This British Standard is the official English language version of EN 14868:2005.

The UK participation in its preparation was entrusted to Technical Committee ISE/NFE/8, Corrosion of metals and alloys, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled "International Standards Correspondence Index", or by using the "Search" facility of the *BSI Electronic Catalogue* or of British Standards Online.

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English Version

**Protection of metallic materials against corrosion - Guidance on
the assessment of corrosion likelihood in closed water
circulation systems**

Protection des matériaux métalliques contre la corrosion -
Recommandations pour l'évaluation du risque de corrosion
dans les systèmes fermés à recirculation d'eau

Korrosionsschutz metallischer Werkstoffe - Leitfaden für
die Ermittlung der Korrosionswahrscheinlichkeit in
geschlossenen Wasser-Zirkulationssystemen

This European Standard was approved by CEN on 8 July 2005.

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 Central Secretariat 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 Central Secretariat has the same status as the official versions.

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Foreword

This European Standard (EN 14868:2005) has been prepared by Technical Committee CEN/TC 262 "Metallic and other inorganic coatings", 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 February 2006, and conflicting national standards shall be withdrawn at the latest by February 2006.

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

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Introduction

This European Standard results mainly from investigations into and experience gained on the corrosion of metallic materials normally present in water circulation systems in buildings (unalloyed and low alloyed steels, cast iron, aluminium, copper and copper alloys, stainless steels).

Because of the complex interactions between the various influencing factors, which can alter during service life due either to normal operation changes in service conditions or accidental events, the extent of corrosion can only be expressed in terms of likelihood. This European Standard therefore is a guidance document and does not set explicit rules for the use of metallic materials in water systems.

A correct evaluation of the corrosion likelihood therefore needs a corrosion expert (or at least a person with technical training in the corrosion field) and knowledge of the technology and operating conditions of the system considered.

Though incidences of severe damage because of corrosion (and/or scaling) are generally rare, certain basic precautions should be taken in order to maintain a long-term, trouble-free service. This European Standard should therefore be considered as a guidance document. On the basis of the information provided herein, decisions can be made during design, installation and service life to minimize the likelihood of corrosion damage occurring.

1 Scope

This European Standard gives a review of influencing factors on the corrosion likelihood of metallic components (pipes, tanks, vessels, heat exchangers, pumps etc.) in water circulation systems in buildings.

The water circulation systems considered are:

- heating systems (up to 110 °C service water temperature);
- cooling and chilling systems;

which are filled with potable water or water of similar composition according to the Directive 98/83/EC.

NOTE 1 Sanitary hot water systems with a re-circulation loop are not considered in this European Standard as they are not really closed system, because the water is continually renewed. The corrosion likelihood of these systems is discussed in EN 12502 Parts 1 to 5 [1], [2], [3], [4], [5].

NOTE 2 Cooling systems with open atmospheric towers are not considered in this European Standard because fresh water is generally added to the system periodically to compensate for losses by evaporation or blow-down.

NOTE 3 Heating systems in buildings, connected to district heating systems without an intervening heat exchanger, are not considered in this European Standard. However, local heating systems, where several buildings are heated by one boiler plant, are included.

2 Normative references

The following referenced documents are indispensable for the application of this European Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12502-1:2004 *Protection of metallic materials against corrosion - Guidance on the assessment of corrosion likelihood in water distribution and storage systems - Part 1: General*

EN ISO 8044:1999 *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 given in EN ISO 8044:1999, EN 12502-1:2004 and the following apply.

3.1

ferrous materials

cast iron, unalloyed and low alloyed steel (excluding stainless steel)

3.2

sludge formation

build-up of non-adherent particulate corrosion products which can be suspended and/or deposited in the system

3.3

scaling

formation of relatively thick layers of calcium carbonate and/or corrosion products, especially on heat transfer surfaces

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4 Symbols and abbreviations

- $c(\text{Cl}^-)$ Concentration of chloride ions in mmol l^{-1}
 $c(\text{HCO}_3^-)$ Concentration of hydrogen carbonate ions in mmol l^{-1}
 $c(\text{SO}_4^{2-})$ Concentration of sulphate ions in mmol l^{-1}
 $c(\text{NO}_3^-)$ Concentration of nitrate ions in mmol l^{-1}

5 Types of corrosion

When evaluating the corrosion likelihood in water circulation systems almost all types of corrosion should be taken into consideration.

The following types of corrosion can occur in the systems under consideration:

- uniform corrosion;
- localised corrosion:
 - pitting corrosion;
 - bimetallic corrosion;
 - crevice corrosion;
 - deposit corrosion;
 - water-line corrosion;
 - selective corrosion (de-alloying);
 - erosion corrosion;
 - cavitation corrosion;
 - stress corrosion cracking;
 - microbial corrosion.

These types of corrosion can lead to different kinds of corrosion damage:

- leakage;
- constriction of flow;
- reduction of efficiency;
- boiler noise;
- seizure of movable components and other detrimental effects.

6 Role of oxygen

6.1 General

In the systems under consideration, the corrosion processes are mainly determined by the extent of oxygen ingress into the system. Generally, oxygen reduction is the driving force for anodic metal dissolution reactions. If the ingress of oxygen can be prevented, the rate of corrosion will be minimised to the extent that corrosion damages will normally not occur.

Oxygen can enter the system in different ways:

- as dissolved oxygen in the filling and any make-up water;
- from the atmosphere into the water within an open expansion vessel or some so-called de-aeration units and with some kinds of pressurisation systems (e.g. compressor or pump pressurisation systems);
- from the atmosphere in the case of negative pressure (e.g. through gaskets, O-rings on valves or some automatic air vents);
- from the atmosphere by diffusion through organic materials (e.g. plastic pipes without barrier, rubber hoses or rubber membranes of air-filled expansion vessels and some so-called de-aeration systems);
- as dissolved oxygen in drinking water in the case of defective secondary heat exchangers for domestic hot water, where the pressure in the domestic hot water is greater than in the primary heating water;
- from air pockets remaining in the system after refilling during maintenance or modification.

Corrosion becomes negligible after consumption of the oxygen initially present in the filling water provided that the water is not renewed and no air entry is possible. The main concern with a closed system is therefore to maintain water and air tightness. However, in some systems, especially large complex ones, maintaining complete air tightness can be impractical.

6.2 Influence of design and operating conditions on oxygen ingress

With respect to oxygen ingress, two cases should be considered:

- **Case I:** systems with no significant oxygen ingress;
- **Case II:** systems with continuous or intermittent oxygen ingress.

Case I is defined by the fact that practically no oxygen ingress is possible during service. Oxygen dissolved in the initial fill water is quickly used up in forming corrosion products, which in most cases does not lead to impairment of the system.

Case II is characterised by the fact that oxygen ingress is possible during service either occasionally, regularly or continuously.

Systems designed to represent Case I can become Case II during service depending on operating conditions.

Examples of Case I are as follows:

- a. Systems with a closed expansion vessel, which are correctly designed, installed and maintained.
- b. Open vented heating systems under conditions where only negligible amounts of oxygen are introduced into the circulating water.

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Examples of Case II are as follows:

- c. Open vented systems where during service the re-circulating water is regularly enriched with oxygen.
- d. Systems with closed expansion vessels in situations where:
 - volume of the expansion vessel is too small;
 - gas pressure within the dry expansion vessel is not correctly adjusted to match the water pressure;
 - gas pressure decreases during service;
 - water volume decreases because of water loss (e.g. from valves and pumps).

Such circumstances can result in negative pressure in the system during cooling phases (e.g. overnight), leading to oxygen ingress through O-rings or gaskets and automatic air vents.

- e. Systems with continuous oxygen ingress by diffusion through the walls of organic materials, e.g. plastic pipes, rubber hoses.

NOTE Refilling of a system does not normally lead to significant oxygen ingress. However, if the circulation water is regularly renewed because of losses in the system and excessive amounts of fresh water are added (more than 2 times initial fill volume) oxygen ingress will almost certainly lead to significant impairment of the system.

7 Microbial corrosion

Micro-organisms (algae, yeasts, fungi, bacteria etc.) can exist in debris left in the system after construction or can enter the system with the initial filling water or via open header tank during operation. In Case II systems, this can lead to bio-fouling problems and can also give rise to microbial corrosion irrespective of metallic materials used in the system.

Although corrosion is favoured at moderate temperatures, not even the high temperatures in heat exchangers are always sufficient to kill all micro-organisms and some bacteria are thermophiles. Favourable conditions (nutrients, inorganic ions and organic contaminants, possibly also from some water treatment additives) favour growth of microbiological organisms. Bacterial growth is also favoured by stagnant conditions, especially under deposits, in dead legs or crevices formed during manufacturing operations. Their metabolism produces organic acids, which promote initiation and acceleration of localised corrosion cells. The most well known case is anaerobic bacteria, especially sulphate reducing bacteria, developing under deposits.

In addition, in Case II systems, aerobic bacteria in the bulk water can oxidize ferrous (Fe^{2+}) to ferric (Fe^{3+}) ions leading to an enhanced uniform corrosion.

8 Corrosion damage in Case I conditions

8.1 Ferrous materials

8.1.1 Leakage

Leakage caused by corrosion generally does not occur under Case I conditions.

8.1.2 Constriction of flow

In the normal course of events, corrosion of iron does not lead to sludge formation to the extent that it constricts flow. However, in special cases, where the ratio of water volume to surface area of iron is very high (i.e. with large buffering vessels or large surfaces of non-oxygen consuming materials such as plastic or

stainless steel) the oxygen content of filling water can give rise to the build-up of non-adherent sludge composed of corrosion products (see 9.1.2).

8.1.3 Reduction of efficiency

In systems containing waters of relatively low pH (< about 8) increased concentration of iron(II) ions can lead to enhanced formation of magnetite (Fe_3O_4) according to equation (A.5), Annex A.1, on the hot walls of heat transfer surfaces. This scale, which can be associated with lime scale, reduces boiler efficiency irrespective of the boiler material. However, in the majority of systems the pH of the re-circulating water rises quickly above 8,0 and this corrosion damage does not occur.

The deposition of iron corrosion products on the inside surfaces of plastic pipes, formed according to (A.4), Annex A.1, can also lead to the reduction of heat transfer efficiency by decreasing water flow.

8.1.4 Boiler noise

On directly heated heat transfer surfaces, unevenly distributed scale (e.g. iron oxides and calcium carbonate) can lead to boiler noise because of nucleate boiling, particularly in the case of small, high efficiency heat exchangers.

8.2 Copper and copper alloys

8.2.1 Leakage

Generally no leakage caused by pitting corrosion happens with copper and copper alloys.

Leakage caused by stress corrosion cracking of brass can occur when a critical level of tensile stress together with a sufficient concentration of nitrite and/or ammonia is present. Critical tensile stresses can be induced during construction, for example by over-tightening threads or use of male tapered threads with female parallel threads. Nitrites and/or ammonia are normally not present in potable water in concentrations sufficient to induce stress corrosion. However, nitrates in water are reduced in oxygen-free conditions in re-circulating systems and in critical areas, for example in crevices or under deposits.

8.2.2 Constriction of flow

There is generally no constriction of flow caused by corrosion of copper and copper alloys under Case I conditions.

8.2.3 Reduction of efficiency

There is generally no reduction of efficiency caused by corrosion of copper and copper alloys under Case I conditions.

Nevertheless, corrosion of other materials in the system can lead to a reduction of efficiency, see 8.1.3 and 8.3.3.

8.2.4 Boiler noise

There is generally no boiler noise caused by corrosion of copper and copper alloys under Case I conditions.

Nevertheless, corrosion of other materials in the system can lead to boiler noise, see 8.1.4 and 8.3.4.

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8.3 Aluminium

8.3.1 Leakage

Leakage caused by non-uniform corrosion will not occur if potable water without further treatment is used as filling water.

Only in very soft waters with low buffer capacity, in cases of self alkalization or when alkaline products are added, which raise the pH value above 8,5 (e.g. some alkaline inhibitors for protection of ferrous materials), is corrosion likely because of the formation of aluminates and evolution of hydrogen. In such situations, leakage is usually caused by erosion corrosion in areas of turbulent flow.

In special cases, where the ratio of water volume to surface area of aluminium is very high (i.e. with large buffering vessels or large surfaces of non-oxygen consuming materials such as plastic or stainless steel) the oxygen content of filling water in combination with a high chloride content can lead to pitting corrosion and leakage.

8.3.2 Constriction of flow

Constriction of flow because of aluminium corrosion will not occur if potable water without further treatment is used.

If the water is treated with alkaline products (see 8.3.1), corrosion can lead to the formation of aluminates, which can be transformed to solid corrosion products on hot walls of heat exchangers. In extreme cases, this effect can lead to total blockage of a heat exchanger. Furthermore, the evolution of hydrogen can induce the formation of gas pockets, which can in turn constrict flow.

8.3.3 Reduction of efficiency

Reduction of efficiency solely caused by aluminium corrosion will not occur if potable water without further treatment is used as filling water.

If the water is treated with alkaline products (see 8.3.1) corrosion can lead to the formation of aluminates, which can be transformed to solid corrosion products on hot walls of heat exchangers. As with lime scale formation, the build-up of aluminium oxide scale increases thermal resistance of the wall which, in turn, decreases heat transfer and hence reduces boiler efficiency, irrespective of the boiler material. The poorly soluble nature of aluminium corrosion products formed on AlSi-alloys in most acids effectively prevents restoration of desired boiler efficiency by chemical cleaning.

8.3.4 Boiler noise

Boiler noise caused by the formation of corrosion products will not occur if potable water without further treatment is used as filling water.

If the water is treated with alkaline products (see 8.3.1), unevenly distributed aluminium oxide scale formed on directly heated heat transfer surfaces can lead to boiler noise particularly in the case of small, high efficiency heat exchangers. The poorly soluble nature of aluminium corrosion products formed on AlSi-alloys in most acids effectively prevents elimination of boiler noise by chemical cleaning.

8.4 Stainless steel

8.4.1 Leakage

There is generally no leakage caused by corrosion of stainless steels under Case I conditions.

8.4.2 Constriction of flow

There is generally no constriction of flow caused by corrosion of stainless steels under Case I conditions.

8.4.3 Reduction of efficiency

There is generally no reduction of efficiency caused by corrosion of stainless steels under Case I conditions.

Nevertheless, corrosion of other materials in the system can lead to a reduction of efficiency, see 8.1.3 and 8.3.3.

8.4.4 Boiler Noise

There is generally no boiler noise caused by corrosion of stainless steels under Case I conditions.

Nevertheless, corrosion of other materials in the system can lead to boiler noise, see 8.1.4 and 8.3.4.

9 Corrosion damages in Case II systems

9.1 Ferrous materials

9.1.1 Leakage

Under exceptional circumstances, perforation of radiators, steel boilers and tubes can occur. Any such perforations are usually associated with localised corrosion cells. The anodic parts of these corrosion cells are located mainly under deposits, in crevices and at three-phase boundaries, i.e. metal-water-air (water-line corrosion). In radiators, localised corrosion takes place preferentially at the bottom or at welded points. Localised corrosion can also occur because of residual flux deposited in steel radiators.

The critical conditions with regard to initiation and stabilisation of corrosion cells are encountered in situations where a heating system has been drained (e.g. after pressure testing or for frost damage prevention) owing to the unavoidable effects of residual water.

NOTE When using water-antifreeze mixtures for a limited period of time, it is recommended the pH of the refilled circulation water is controlled and adjusted, because organic reactions with antifreeze residues can lead to a decrease of pH and an increase of corrosion likelihood.

In the case of cast iron heat exchangers, severe scaling can lead to thermal overload increasing the risk of crack formation.

9.1.2 Constriction of flow

Constriction of flow can occur because of the accumulation of solid corrosion products or gases.

The solid corrosion products essentially comprise poorly soluble black sludge, which can be formed according to equations (A.4) or (A.5), Annex A.1. This sludge will settle in areas of low flow. In radiators, this can lead to the formation of cold spots if vertical water ways become blocked. Because of its magnetic properties, magnetite can accumulate on ferrous components which, in areas of small cross section (e.g. metallic

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connections to rubber hoses), can lead to blockage. Sludge formation can be exacerbated because of flocculation by aluminium species in the water.

In the case of plastic pipes or rubber hoses, oxygen permeation leads to the formation of poorly soluble, orange/brown hydrated iron(III) oxide (FeOOH) species on the inside surfaces. This process can result in relatively thick corrosion product layers, and large flakes can become detached and cause blockages downstream. Any such flakes on plastic pipework surfaces are characterised by a smooth, bright appearance and a matt appearance on the water side.

The presence of gas in radiators can prevent water circulation predominantly in radiators fixed in the higher parts of an installation. This gas consists mainly of nitrogen but can contain significant amounts of hydrogen from reactions (A.5) and (A.6), Annex A.1.

9.1.3 Reduction of efficiency

The mechanism of reduction of efficiency in Case II systems is similar to Case I systems (see 8.1.3), but can be enhanced due the higher amount of corrosion products in circulation. In situations where untreated fresh water is regularly introduced into a system, additional lime scale formation will further enhance the reduction of efficiency.

9.1.4 Boiler noise

The conditions with respect to boiler noise are similar to those described in 8.1.4. As with reduction in efficiency, in situations where fresh water is regularly introduced into a system, additional lime scale formation will increase the likelihood of boiler noise.

9.1.5 Seizure of movable components and other detrimental effects

Seizure of movable components (e.g. pumps, valves, energy meters) can occur from deposition of suspended magnetite. This effect can be enhanced by the magnetic properties of the ferrous substrate, as can be seen in energy meters with rotating magnets.

In cast iron pumps used in systems incorporating non-barrier plastic pipes or rubber hoses, seizure can also occur because of the direct formation of corrosion products on the iron surfaces.

Cast iron pump housing can occasionally suffer cavitation damages if the pump characteristics are not appropriate for the system or if uninhibited acidic cleaners are used.

Wear of pump shafts, bearings and seals can also occur from circulation of solid corrosion products.

9.2 Copper and copper alloys

9.2.1 General

There are generally no significant corrosion damages with copper and its alloys under Case II conditions.

However, there are two main exceptions:

- in the presence of ammonia and critical tensile stresses;
- in the presence of deposits (e.g. iron corrosion products) on copper surfaces without protective layers.

9.2.2 Leakage

In general, copper and its alloys have good corrosion resistance in systems with continuous or intermittent oxygen ingress. However, the deposition of other materials (i.e. water borne debris such as corrosion products from other metallic components, silt, fluxes etc.) on fresh copper surfaces without protective layers can lead to the development of localised corrosion cells similar to those described in 9.1.1 for ferrous materials.

Under certain conditions which give rise to the presence of ammonia and/or nitrites, stress corrosion cracking of brass components can occur along the lines described in 8.2.

In certain large systems where sodium sulphite is used as an oxygen scavenger, corrosion damage from the formation of thick copper(I) sulphide layers can occur. This can manifest itself in the form of perforation of pipework or failure of joints containing phosphorus-bearing brazing alloys.

Extreme cases of dezincification of brass components can lead to leakage.

9.2.3 Constriction of flow

Copper generally poses no problems in terms of constriction of flow in these systems.

Dezincification of alpha/beta duplex brasses can result in the formation of zinc hydroxy-carbonate deposits which can become detached and accumulate in small orifice valves, etc., resulting in constricted flow or blockage. However, the risk of any such occurrence can be obviated by the use of immune or dezincification resistant copper alloys.

9.2.4 Reduction of efficiency

With the exception of copper(I) sulphide formation described in 9.2.2, there are generally no problems in terms of reduction of efficiency from the formation of copper corrosion products.

9.2.5 Boiler noise

With the exception of copper(I) sulphide formation described in 9.2.2, there are generally no problems in terms of boiler noise from the formation of copper corrosion products.

9.2.6 Seizure of movable components and other detrimental effects

Seizure of movable components can occur as a result of the deposition of zinc hydroxy-carbonate arising from dezincification of brass components.

9.3 Aluminium

9.3.1 General

In Case II systems, aluminium components can suffer corrosion damages, the severity of which depends primarily on conditions related to water and material quality.

9.3.2 Leakage

Leakage on heat exchangers and radiators can occur because of erosion corrosion and pitting corrosion.

Erosion corrosion is more likely to occur in systems filled with waters with pH-values below 6 or above 8,5 and/or in the presence of water borne debris.

The likelihood of pitting corrosion of aluminium is increased if the system water has a high chloride content (more than about 6 mmol l^{-1} (200 mg/l)) deriving from filling and/or flux residues. Chloride concentration in the system can increase over time because of evaporation from open expansion vessels and the consequent need for make-up water.

Pitting of aluminium is likely to occur from bimetallic corrosion when it is in direct contact with copper (either as components or swarf) or if copper ions are present in the water. These ions electrodeposit preferentially on aluminium surfaces forming spots of metallic copper with very high cathodic activity.

Leakage can also occur because of the inappropriate use of acidic or alkaline cleaning agents.

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Where debris and sludge settle out on aluminium surfaces, especially magnetite from other parts of the system, under-deposit corrosion can occur leading to leakage. This is because of the effects of differential aeration and production of acidic conditions under the deposit.

9.3.3 Constriction of flow

Under the adverse circumstances described in 9.3.2, voluminous aluminium corrosion products can lead to constriction of flow or blockage in small diameter waterways inside heat exchangers and/or other components.

9.3.4 Reduction of efficiency

The reduction of efficiency in Case II systems is similar to Case I systems (see 8.3.3).

9.3.5 Boiler noise

Unevenly distributed aluminium oxide scale formed on directly heated heat transfer surfaces can lead to boiler noise particularly in the case of small, high efficiency heat exchangers. The insoluble nature of aluminium oxide in most acids effectively prevents elimination of boiler noise by chemical cleaning.

9.3.6 Seizure of movable components and other detrimental effects

If significant amounts of voluminous aluminium corrosion products are formed and transported around the system, seizure and wear of components (e.g. valves, pumps) can occur.

9.4 Stainless steel

9.4.1 General

In Case II systems, stainless steels do not normally suffer from corrosion damages. However, adverse circumstances, usually related to high chloride contents, can cause corrosion leading to leakage. The likelihood of these damages is much reduced when molybdenum containing stainless steels or duplex austenitic-ferritic stainless steels is used.

9.4.2 Leakage

Leakage on heat exchangers and components can occur because of pitting corrosion, crevice corrosion and stress corrosion cracking.

The likelihood of pitting corrosion increases with increasing chloride content and temperature of the water. For non-molybdenum bearing stainless steels this can occur with chloride contents in waters as low as $1,5 \text{ mmol l}^{-1}$ (50 mg l^{-1}). Molybdenum bearing stainless steels as well as duplex austenitic-ferritic stainless steels are usually immune to pitting corrosion in these systems.

Pitting corrosion within narrow crevices can occur at even lower chloride level and is even possible with molybdenum bearing stainless steels in systems filled with a water with high chloride content. Crevices can be pre-existing, e.g. at joints, or can be formed under water borne deposits, e.g. sand or corrosion products.

Stress corrosion cracking can occur in waters with high chloride contents caused by residual or induced tensile stresses. Residual stresses can be generated by the manufacture of threaded components or corrugated tubes. Induced tensile or cyclic stresses can occur during operation. In the waters under consideration, stress corrosion cracks only appear at the base of pits or within narrow crevices. Therefore stress corrosion cracking is more likely to occur in non-molybdenum bearing stainless steels.

The likelihood of inter-granular corrosion in heat affected zones of welded components is negligible in the systems under consideration.

9.4.3 Constriction of flow

There is no constriction of flow with stainless steels in the systems under consideration.

9.4.4 Reduction of efficiency

No significant reduction of efficiency from corrosion of stainless steel will occur in the systems under consideration.

9.4.5 Boiler noise

There is no boiler noise from corrosion of stainless steels in the systems under consideration.

9.4.6 Seizure of movable components and other detrimental effects

Seizure of stainless steel movable components is possible in exceptional circumstances where these components undergo pitting or crevice corrosion.

10 Corrosion protection methods**10.1 General**

The primary cause of corrosion problems in water circulation systems is ingress of oxygen from air or fresh water. Therefore, design, commissioning, operation and maintenance of systems are important in terms of minimising corrosion likelihood.

10.2 Design**10.2.1 General**

Care should be taken to avoid direct contact between dissimilar metals (especially copper and aluminium) by the appropriate use of insulation materials. It is important to ensure that all sections of metallic pipework and boiler are connected to the common earth for health and safety reasons. This will also prevent the possibility of stray current corrosion occurring.

The use of galvanised steel in heating systems is not recommended because of formation of hydrogen gas bubbles.

Where plastic pipework is used on under-floor heating systems the use of non-barrier pipes is disadvantageous because of the steady ingress of oxygen and requires further corrosion protection measures.

Systems should be designed so that flow rates are not high enough to cause serious flow noise. Such flow rates increase the likelihood for erosion corrosion.

10.2.2 Systems with closed expansion vessels

Systems should be designed in such a way that negative pressure cannot occur at any point in the system. This is achieved by correct sizing of the expansion vessel in order to ensure that it is large enough to accommodate the expansion in water volume during heating.

10.2.3 Systems with open expansion vessels

Systems should be designed so that there is a sufficient static head of pressure and the circulator is correctly sized and located. This is to prevent pumping-over or excessive fluctuation of the water level in the open expansion vessel (see-sawing). Pumping-over occurs when on heating, water is continually fed into the expansion vessel from a separate vent and expansion pipe.

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10.3 Commissioning

10.3.1 General

If pressure testing is carried out with water, the system should be kept completely filled afterwards.

The gas pressure in closed expansion vessels should be checked and if necessary adjusted before installation. Optimum performance is given when the gas pressure in the dry expansion vessel is adjusted to the static water pressure in the re-circulating system, which is generally determined by the difference between the highest point of the system and the location of the expansion vessel ($10 \text{ m} \approx 0,1 \text{ MPa}$).

The water pressure in the system shall at all times be higher than the atmospheric pressure. It is therefore recommended that the water pressure of the cold system be adjusted to at least $0,05 \text{ MPa}$ above the gas pressure of the dry expansion vessel.

As part of the commissioning of a re-circulating water system, manufacturers of components (e.g. boilers, pumps) can recommend chemical cleaning with proprietary cleaners designed for such systems, in order to reduce the likelihood of corrosion damages occurring over both the short and long term. Proper chemical cleaning followed by thorough flushing at least two times with fresh water will remove swarf, excess flux, oils and greases and initial limescale deposits on heat exchanger surfaces. The use of chemical cleaners should be carried out in accordance with the manufacturer's instructions.

As filling water normally tap water is used. With regard to all kinds of localised corrosion, the use of desalinated water is advantageous as corrosion cells cannot stabilise without the presence of salts, which can form acids by hydrolysis. However, if oxygen is present, the use of deionised water will need addition of small amounts of alkali to prevent corrosion damage by uniform corrosion (sludge formation) in the system.

With regard to circulating water composition, a slight alkalisation to a pH-value above 8 is necessary to prevent formation of iron oxide scale on heat transfer areas caused by higher amounts of soluble iron compounds in the circulation water. In order not to raise the pH-value too much thereby risking damaging components made from aluminium, use of a proprietary formulation which buffers the water to pH 8 to 8,5 is preferable instead of a strong alkali, such as caustic soda, NaOH.

In systems prone to freezing conditions, antifreeze shall be added to give the required level of frost protection. With glycol-based antifreezes, oxygen ingress can lead to the microbially influenced formation of organic acids, thereby increasing corrosion likelihood. Therefore inhibited, buffered antifreezes are preferable to untreated glycols, especially for long term application (e.g. in weekend houses). The use of glycol-based antifreezes for short term applications (e.g. freeze protection for one winter period within the building phase) can lead to corrosion problems after insufficient draining of the system.

It is useful to make a log of the dates and details of any commissioning operation including the identity and dosage of any chemicals added.

10.3.2 Corrosion inhibitors

Chemical inhibitors can be used under Case II conditions to prevent corrosion damages. However, inhibitors should not be used as a substitute for physical solutions to prevent oxygen ingress. They work by adsorbing or precipitating on the metal surfaces thereby reducing the anodic and/or cathodic reaction rates. They also often contain chemicals which buffer the pH of the system water and can neutralise any residual acids. Since re-circulating heating and cooling systems contain a variety of metals including steel, cast iron, copper and copper alloys and aluminium, the corrosion inhibitor if used should be compatible with all the relevant metals in the system. Care should also be taken to ensure that the inhibitor chosen is compatible with all the non-metallic materials in the system, including plastic pipework, rubber hoses, membranes, seals, O-rings, etc.

Inhibitors which function purely by anodic action can increase the likelihood for pitting attack in restricted areas, such as in crevices or under debris. Therefore, the use of inhibitor blends which contain both cathodic and anodic inhibitors is preferred. It is favourable to use products with low toxicity and environmental impacts.

If corrosion and scale inhibitors are used, it is preferable to add these immediately after chemical cleaning and flushing. Care should be taken to follow the manufacturer's instructions for dosage rates and in carrying out checks on this during the lifetime of the system.

The inhibitor shall be able to function in the particular water quality used in the system. If the water used has a high calcium content, precipitation of calcium salts should not occur during heating.

Some corrosion inhibitors can favour the growth of micro-organisms, especially when open-header tanks are used. Biocides are often added to inhibitor formulations to prevent this or they can be added separately. Biocides on their own can be aggressive to some metals.

The use of oxygen scavengers such as sodium sulphite or hydrazine, which are often used in boilers, is not recommended in closed re-circulating systems.

10.4 Operation and maintenance

10.4.1 General

The re-circulating system should be checked at least once per year or when components of the system are changed to maintain correct and efficient operation. Reference should be made to the log and the log updated.

In terms of corrosion protection the checks include:

- measurement and, if necessary, adjustment of gas pressure in the expansion vessel (preferably by filling with nitrogen);
- determination and, if necessary, adjustment of inhibitor concentration according to manufacturer's instructions;
- control and, if necessary, adjustment of the water pressure in the circulation system at least every three months recording in the log the amount of water added;
- inspection of the radiators for gas build-up and/or cold spots;
- Inspection and cleaning (if necessary) of any open expansion vessel.

If gas is detected in radiators, it should be checked for hydrogen by using appropriate equipment. A negative test result usually indicates that the gas is nitrogen (from air ingress) and checks should therefore be made for system tightness.

The presence of an odour can be indicative of microbial activity (see Clause 7). In either case, the system should be cleaned and flushed prior to treating the water with appropriate inhibitors and/or biocides.

When checking for gas it is useful to obtain a water sample. Discolouration of the water is indicative of significant corrosion in the system. For a system containing iron components, a reddish discolouration indicates high levels of oxygen ingress and hence warrants further investigation.

10.4.2 Cleaning of operational systems

Cleaning in operation of systems which contain sludge (iron oxides) and/or limescale helps to restore system efficiency and increases the effectiveness of subsequently added corrosion inhibitors. The effectiveness of the cleaning operation can be increased by use of powered flushing (in which the system circulator is replaced by a more powerful pump) and cyclonic or magnetic filters, which should be regularly maintained.

After the cleaner is circulated for an appropriate period of time, it should be drained prior to thorough flushing with fresh water.

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If acids are used during cleaning, it is important to check that the water in the system has a neutral or near neutral pH after flushing. Neutralising chemicals are usually added before the flushing stage.

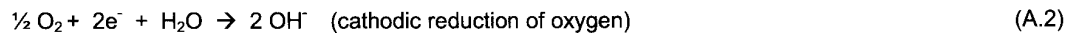
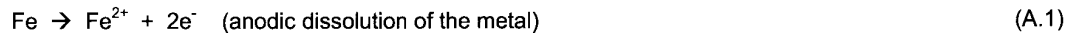
It is not advisable to use hydrochloric acid for cleaning processes because of the risk of initiation of pitting corrosion.

Annex A (informative)

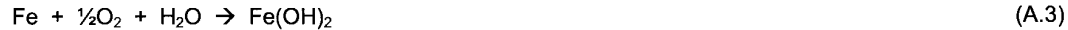
Important corrosion reactions in the systems under consideration

A.1 Ferrous materials

In the case of iron corrosion, it is essential to consider the following simplified reactions:



The total reaction is



$\text{Fe}(\text{OH})_2$ (iron(2) hydroxide) reacts further building up the final corrosion product Fe_3O_4 (magnetite) in the following two ways:

— with excess of oxygen



— or according to the Schikorr-reaction:



NOTE 1 Even if oxygen is totally absent, the water itself can be reduced to hydrogen gas; the kinetics of this reaction are usually very slow.



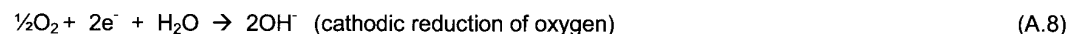
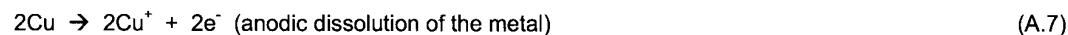
The corrosion products can occur in the form of tubercles above a pit, the well-known black sludge or as protective layer on the steel surface. In the case of high oxygen ingress, also hydrated $\gamma\text{-Fe}_2\text{O}_3$ can be formed, which has little protective effects.

Other electrochemical reactions can take place which influence and enhance the type and rate of corrosion. These reactions are mentioned in the relevant sections.

NOTE 2 In reality, the situation is more complex with the final corrosion products being comprised of a mixture of the limiting phases Fe_3O_4 and $\gamma\text{-Fe}_2\text{O}_3$ (hydrated maghemites).

A.2 Copper and copper alloys

In the case of copper, corrosion should only be considered in the presence of oxygen. The following reactions can occur:



The total reaction is



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Besides Copper(1)-Ions can be oxidised according to:



in combination with Equation (8) to:



The protective layer normally consists of Cu_2O in contact with the metallic copper followed by a layer of CuO .

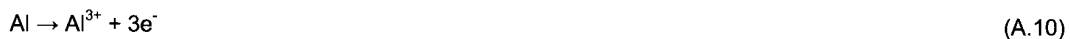
Corrosion products can occur in the form of very small green tubercles above pits, acting also as protective layer on the copper surface.

Other electrochemical reactions can take place which influence and enhance the type and rate of corrosion. These reactions are mentioned in the relevant sections.

A.3 Aluminium

Aluminium is only stable in the oxidation state 0 and III. Because of its amphoteric character, aluminium is unstable in acidic and alkaline solutions. Therefore the following reactions will occur:

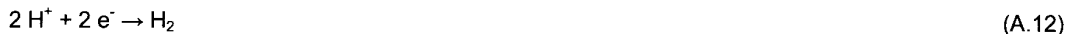
— Acidic and neutral; anodic partial reaction:



— Alkaline; anodic partial reaction:



— Acidic; cathodic partial reaction:



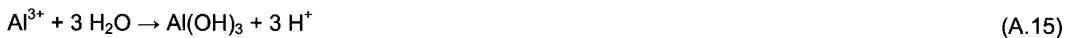
— Neutral and alkaline; cathodic partial reaction in the presence of oxygen:



— Alkaline; cathodic partial reaction in the absence of oxygen:



In neutral solutions ($4,5 < \text{pH} < 8,5$), the Al^{3+} -ion will react to aluminium hydroxide in the following reaction:



In acidic solutions ($\text{pH} < 4,5$), aluminium hydroxide is soluble according to the following reaction:



Whereas it is soluble in alkaline solutions ($\text{pH} > 8,5$),- corresponding to:



On aluminium, the passivating surface layer of aluminium oxide-hydroxide is formed spontaneously in air (with oxygen and humidity). In neutral heating water without additives (normally drinking water), this passivating layer is stable and protects against corrosion. In closed systems the passivating surface layer grows to an ultimate thickness (Case I conditions), whereas in open systems (Case II, see 9.3) in the presence of oxygen, the corrosion reaction will not stop until the system is damaged.

A.4 Stainless steels

The corrosion resistance of stainless steels is based on the fact that these materials have a very thin protective layer. This passive layer is immediately built up, when stainless steel surfaces come into contact with water or even moisture of the air.

The quality of this passive layer and thus the corrosion resistance of the material in different environments depends on the chromium and molybdenum content of the material.

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