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Corrosion of metals and alloys — Corrosion and fouling in industrial cooling water systems —

Part 2: Evaluation of the performance of cooling water treatment programmes using a pilot-scale test rig

Corrosion des métaux et alliages — Corrosion et encrassement des circuits de refroidissement à eau industriels —

Partie 2: Évaluation des performances des programmes de traitement de l'eau de refroidissement sur banc d'essai pilote

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 262, *Metallic and other inorganic coatings, including for corrosion protection and corrosion testing of metals and alloys*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 16784-2:2006), which has been technically revised.

The main changes are as follows:

— the Introduction has been modified;

— the Scope has been modified;

— Normative references have been added;

— the Terms and definitions have been updated;

— Clause 4 has been modified to include principles on the simulation process of cooling water treatments;

— the title of Clause 5 has been changed from “Reagents and materials” to “Water for test”;

— the apparatus has been modified: the components and their descriptions have been added;

— the assessment of results has been modified to be divided into three aspects: corrosion phenomena and type of corrosion, pitting corrosion and corrosion rate;

— the bibliography has been modified.

A list of all parts in the ISO 16784 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

There is an industrial need to improve the safety, reliability and cost-effectiveness of open recirculating cooling water systems. This is due to the rise in stringent environmental requirements as well as the rise in the costs of water. It is therefore important to establish a standard framework for evaluating the performance of cooling water treatment programmes. The aim is to provide users of cooling systems and vendors of treatment materials for those systems with a procedure to make consistent evaluations of cooling water treatment programmes on a pilot scale.

With the continuous development of circulating water treatment technology, some new circulating water treatment technologies, such as reverse osmosis treatment and electrochemical treatment, have become an important part of cooling water treatment schemes.

This document has been revised and updated to add a new test device along with more detailed descriptions of the components. The simulation device uses steam to heat the heat exchange tube, which solves the problem of uneven heating caused by electric heating and is closer to the actual operating conditions on site.

Corrosion of metals and alloys — Corrosion and fouling in industrial cooling water systems —

Part 2:
Evaluation of the performance of cooling water treatment programmes using a pilot-scale test rig

1 Scope

This document specifies the principles, reagents and materials, test apparatus, test methods, evaluation of results and requirements for test reports using pilot tests for industrial cooling water systems.

This document specifies a method to evaluate the performance of treatment programmes for open recirculating cooling water systems. It is based primarily on laboratory testing, but the heat exchanger testing facility can also be used for on-site evaluation. This document does not include heat exchangers with cooling water on the shell-side (i.e. external to the tubes).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3696, *Water for analytical laboratory use — Specification and test methods*

ISO 8044, *Corrosion of Metals and Alloys — Basic Terms and Definitions*

ISO 8407, *Corrosion of metals and alloys — Removal of corrosion products from corrosion test specimens*

ISO 16784-1, *Industrial cooling water systems — Testing and performance — Part 1: Guidelines for conducting pilot-scale evaluation of corrosion and fouling control additives for open recirculating cooling water systems*

ISO 11463, *Corrosion of metals and alloys — Guidelines for the evaluation of pitting corrosion*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
adenosine tri-phosphate
ATP
active chemical present in living bacteria

Note 1 to entry: ATP concentrations can be indirectly measured and are used as an indicator for the presence of biology in cooling water.

3.2
blow-down
discharge of water from the cooling water circuit expressed as a discharge rate

3.3
cooling tower
tower used for evaporative cooling of circulating cooling water, normally constructed of wood, plastic, galvanized metal or ceramic material

3.4
cooling water treatment
adjustment of cooling water chemistry by which corrosion and fouling can be controlled

3.5
cycle of concentration
ratio of the concentration of specific ions in the circulating cooling water to the concentration of the same ions in the make-up water

3.6
heat rejection capacity
amount of heat that can be rejected by a cooling-tower system

3.7
half-life
time needed to reduce the initial concentration of a non-degradable and/or non-precipitable compound to 50 % of its concentration in the cooling water

3.8
make-up water
total water mass per time unit, which is added to the system to compensate for the loss of water due to evaporation, blow-down, leakage and drift loss

3.9
Reynolds number
dimensionless form, $\frac{LV\rho}{\eta}$, which is proportional to the ratio of inertial force to viscous force in a flow system

where:

L is the characteristic dimension of the flow system, expressed in m;

V is the linear velocity, expressed in m/s;

ρ is the fluid density, expressed in kg/m^3;

η is the fluid viscosity, expressed in kg/m/s.

3.10
surface temperature
temperature of the interface between the cooling water film and the heat-transfer surface, whether the surface is the tube wall or the outside of a fouling deposit

3.11
film fill
portion of a cooling tower, which constitutes its primary heat-transfer surface and over which water flows as evaporation occurs

3.12
wall temperature
temperature sensed by a thermocouple placed between the heater element and the inside of the heat-transfer tube wall, preferably as close to the tube wall as possible

4 Principle

Model the circulating cooling water treatment process under specified experimental conditions. The metal pipe samples are placed in circulating cooling water for heat exchange. Evaluate the performance of the cooling water treatment scheme based on factors such as cooling water flow rate, water quality, material flow intensity, heat transfer, the temperature of the cooling water inlet and outlet, concentration ratio, pH, conductivity, concentration of water treatment additives and other critical technological parameters.

A test assembly of metallic test tubes is submitted under heat-transfer conditions to the circulation of cooling water for a specified period. This can be connected directly to the cooling water system on-site, to be representative of service conditions. For laboratory testing, the cooling water composition is designed to reflect the chemistry for the service application but modified with the appropriate treatment programme under investigation. The adoption of synthetic chemistry in laboratory tests can be effective for comparative purposes, for example screening, but will not be representative of service conditions. The effect of the cooling water circulation and the treatment programme on the corrosion and fouling of the test tubes is assessed using a number of measurement parameters.

5 Water for test

5.1 General

The cooling water composition of the test should reflect the likely service application. For laboratory testing using synthetic water, only reagents of recognized analytical grade and only water complying with the minimum requirements of grade 3 of ISO 3696 shall be used.

There are two main operating environments. The first is to use the make-up water used in the specific cooling system on-site (or to use synthetic make-up water) and concentrate it to the required number of cycles in the test system. Annex A includes recommended forms for recording test conditions (see Table A.1, Table A.2, Table A.3), compositions of make-up and recirculating water (see Table A.4) and test results (see Table A.5, Table A.6, Table A.7). Annex B includes measurement and test methods.

The second approach involves using a synthetic water simulating on-site circulating water for the required number of cycles. The use of synthetic circulating water obviates the need to concentrate the synthetic water to obtain the desired cycles of concentration. This approach simplifies the test by avoiding the use of the pilot cooling tower.

Synthetic circulating water usually contains a higher level of dissolved ionic solids than corresponding natural water, thus making the synthetic water more corrosive.

5.2 Water characteristics

The natural or synthetic water(s) used should be characterized as specified in Table 1. Table 1 should be used to record compositions of both the circulating water and the make-up water, if used. Turbidity, total silica, bacteria and adenosine tri-phosphate (ATP) shall only be measured for on-site waters.

Table 1 — Composition of make-up and circulating cooling water

No.	Component	Value	Units
1	pH, 25 °C		pH units
2	Conductivity		µS/cm
3	Total hardness		[a]
4	Alkalinity – p		[a]
5	Alkalinity – m		[a]
6	Ca^{2+}		mg/l
7	Mg^{2+}		mg/l

[a] Depending on the test method, the unit of measurement is either mmol/L or mg/L.

Table 1 *(continued)*

No.	Component	Value	Units
8	Na^+		mg/l
9	K^+		mg/l
10	NH_4^+		mg/l
11	Fe^{2+}		mg/l
12	Cu^{2+}		mg/l
13	Al^{3+}		mg/l
14	CO_3^{2-}		mg/l
15	HCO_3^-		mg/l
16	Cl^-		mg/l
17	SO_4^{2-}		mg/l
18	NO_3^-		mg/l
19	PO_4^{3-}		mg/l
20	SiO_2		mg/l
21	Cl_2		mg/l
22	Turbidity		FTU or NTU
23	Suspended solids		mg/l
24	Bacteria		Cfu/ml or Cfu/l
25	ATP		RLU

[a] Depending on the test method, the unit of measurement is either mmol/L or mg/L.

5.3 Preparation of synthetic test waters using mother solutions

Synthetic test waters are normally prepared in the laboratory at the time of use by mixing mother or stock solutions. One mother solution contains the alkalinity. The other stock solution contains the hardness and other salts required in the test water. The composition of these two solutions is calculated so that, when the solutions are mixed in the proper proportion, they prepare either the circulating test water or an appropriate make-up water. Typical mother solutions are shown in Table B.1. Alternatively, mother solutions can be prepared as concentrates and subsequently diluted with demineralised water.

6 Apparatus

6.1 Heat exchanger section

The core of the test assembly is the heat exchanger section, which is specified further in 6.2 to 6.7. The inner wall of the heat exchange tube should have no pitting, crack, rust or other obvious defects. The length should be determined according to the need. The test assembly comprises two or more metal heat-transfer tubes, made of the relevant alloy used in the on-site heat exchanger. The heating mode can be steam heat exchange (see Figure B.1) or electric, mounted either in series (see Figure B.2) or in parallel (see Figure B.3). Conduction and convection of heat occurs through the heat-transfer tube wall into the circulating cooling water. The materials of construction of the test assembly shall be chosen so as to not influence the composition of the test water. Glass or plastic (e.g. polyvinyl chloride, chlorinated polyvinyl chloride or polyvinylidene fluoride) is commonly used.

From the cooling water reservoir, the cooling water is pumped through the heat exchanger section at a controlled flow rate. If the heat transfer tubes are mounted in series, only one flow rate controller is required. If they are mounted in parallel, one flow rate controller is required for each heat exchange tube. Through partial evaporation of water in a cooling tower (see 6.4), the heat absorbed is subsequently released to the environment. Alternatively, if a cooling tower is not required to concentrate make-up water, a closed cooling loop to extract heat is used. In order to determine corrosion rates on non-heat-transfer surfaces, corrosion coupons (flush mounted probes) of the relevant metals in the system should be used.

If the heat exchange tubes are mounted in parallel, simultaneous tests can be run by setting a different combination of surface temperature and flow rate for each heat exchange tube. However, the heat-transfer tubes should be of the same metallurgical composition.

6.2 Temperature measurement

The wall temperature of the metal tubes should be measured by a thermocouple placed between the heater element and the inside of the heat-transfer tube wall, preferably as close to the tube wall as possible. Because of temperature gradients, this measurement is not fully accurate but it is indicative. More accurate determination would require three thermocouples mounted at varying distances from the tube wall, with the temperature gradient used to determine the temperature at the wall.

6.3 Circulation-rate monitor

The circulation rate can be measured using a flow meter in the flow line, either preceding or following the heat exchange tubes.

6.4 Make-up, evaporation and blow-down measurement

A means for measuring the mass flow of make-up, the amounts of evaporation and blow-down water (including minimum, average and maximum values) shall be established and shall be included in the test report. Blow-down and make-up rates can be monitored by water meters and the evaporation rate deduced. Chemical feed can be based on blow-down or make-up. Blow-down is normally controlled using the conductivity of the circulating water. Make-up is controlled by a level controller in the cooling-tower basin.

6.5 Cooling tower

The design and heat rejection capacity of the cooling tower and film fill are optional but shall be reported. The design of the cooling tower shall meet the design parameter requirements specified in ISO 16784-1. Deposition of salts in the cooling tower can occur depending on the system design. An example of the apparatus is described in B.2. A visual inspection of the inside of the cooling tower at the end of the test is advised.

The determination of the volume of the cooling tank is typically computed in accordance with a third to a fifth times the consumption of circulating cooling water per h. The liquid level should be constant; it can be automatically controlled and water added.

Cooling tower size should be determined according to local air temperature, humidity and process temperature difference. The packing can be polypropylene porous ball.

The fan is recommended to be a fully closed axial flow anti-moisture fan. The water pump is generally an anticorrosion pump.

6.6 Heating system

Electric heating or steam heating can be used. The heating rod should be made of corrosion-resistant metal materials. The heating power can be determined according to the need. When the atmospheric pressure saturated steam system is used, the electric steam furnace made of corrosion resistant metal material should be used. The material of steam condenser and connecting pipeline should also be corrosion resistant metal material.

6.7 Water treatment equipment simulation device

The water treatment equipment simulation devices should be an integral part of the pilot equipment. It can include simulated lime softening units, ion exchange units, reverse osmosis desalination units, electrochemical treatment units, and electromagnetic treatment units, which will have a significant impact on water quality. Synthetic water may also be used to replace the effluent from these simulators when they are not available in certain situations.

6.8 On-line detection device

In addition to the flow and temperature monitoring devices mentioned above, during the test, other automatic control devices are used to control the parameters and process the data, such as corrosion rate meter, pH value, conductivity value, etc.

7 Test method

7.1 Procedure

7.1.1 Cleaning of the test assembly

Before starting a test, the test assembly shall be cleaned in order to prevent contamination with products from a possible previous test or undesirable microbiological fouling.

The following cleaning solutions are suggested: first, flushing with water, then flushing out with an appropriate solution, such as hypochlorite solution in the case of slime formation, sulfamic acid or citric acid and EDTA solution in the case of iron and/or calcium deposits. If an acid solution is used, the system should be flushed with water, neutralized and then flushed again with water until the pH is neutral.

7.1.2 Test tube preparation and pre-treatment

Measure and record the length of the test tubes on a test data sheet.

The surface state of the metal tubes under test has a significant influence on corrosion and fouling. The method of surface preparation shall ensure good repeatability. The surface shall be free of artefacts from the preparation process. The surface preparation method used should adhere to the supplier's instructions for the product under test. A standard pre-treatment and preparation procedure shall be carried out on the test tubes. The following information is optional for the test procedure:

a) Degrease the test tubes internally and externally with acetone.

b) Then, blast-clean the test tubes externally with an abrasive to preparation grade Sa3 in accordance with ISO 8501-1 and to a roughness, *Ra*, of approximately 2,5 µm. Alternatively, abrade using SiC paper of grade P400. For some metals with certain pre-treatments, abrasion is not appropriate.

c) Clean the test tubes by blowing with compressed air and weigh, to at least an accuracy of 0,01 g. Put them in the tubes of the heat exchanger (see 6.2). Record the mass of each test tube on a test data sheet.

d) The tubes can be tested with or without pre-treatment. The test should be carried out in both conditions to determine the value of pre-treatment. Pre-treatment is accomplished by continuous circulation of the pre-film solution, specified by the water treatment vendor through the test tubes at room temperature for a minimum of 48 h and a maximum of 72 h, with a circulation flow rate of at least 0,6 m/s and without heating.

Pre-treatment of the test tubes can be carried out in the test assembly itself, or in a separate circuit connected to the test assembly.

7.1.3 System water content

The total water volume of the cooling water reservoir, heat exchangers and piping of the system shall be calculated and reported.

7.1.4 Procedure to fill the cooling water system

7.1.4.1 Using synthetic circulating test water made from mother solutions (no cooling tower)

Mix mother solutions as specified in 5.3 to achieve the required cooling water quality. The parameters are given in Table 1. Fill the cooling water reservoir with the synthetic water and the solution of chemical treatment additives in accordance with the supplier's instructions.

Start the circulation pump and adjust it to achieve the required circulation flow rate (see 6.3). Drain off at least five times the water content of the heat exchanger section from the system to ensure removal of artefacts from surface pre-treatment. Start the dosing device and set the dose level to the prescribed values (see 7.2). Then allow the cooling water to circulate normally, set the heater to the selected value of heat input, and balance this with the heat extracted in the cooling circuit. Once this has been achieved, record the time as the starting time of the test (t = 0). The test rig and controls should be set up to establish the required steady state-conditions using dummy heat-exchanger test tubes before starting a proper test run.

7.1.4.2 Using make-up water (cooling tower required)

In this case, the make-up water (made either by mixing synthetic mother solutions or using make-up water obtained on-site) is concentrated by evaporation in the model cooling tower to achieve the required composition before the start of the test period.

Fill the cooling water reservoir with the make-up water and the solution of chemical treatment additives in accordance with the supplier's instructions. Start the circulation pump and adjust it to achieve the required circulation flow rate (see 6.3). Drain off at least five times the water content of the heat exchanger section from the system prior to this water reaching the cooling tower to ensure removal of artefacts from surface pre-treatment.

Set the heater to the selected value of heat input and monitor the conductivity of the water until the correct cycles of concentration are obtained. Then, start the blow-down pump and adjust to the appropriate blow-down rate (see 6.4). Start the dosing device and set the dose level to the prescribed values (see 7.2). Then, allow the cooling water to circulate normally, set the heater to the selected value of heat input and record the time as the starting time of the test (t = 0). The test rig and controls should be set up to establish the required steady-state conditions using dummy heat-exchanger test tubes before starting a proper test run.

7.1.5 Heating the test tubes

The duty of the heating elements and the heat flux used should be chosen to represent particular service conditions. A suitable apparatus is shown in B.2.

7.1.6 Flow rate

The recirculation flow rate measured in the circuit external to the heat-exchange tube section by the flow meter (see 6.3) shall be set high enough so that no overheating of test tubes occurs but not too high so that excessive turbulent water flow occurs within the tubes. A flow rate of 0,6 ± 0,1 m/s is suitable.

The flow rate and Reynolds number along the test surface shall be determined.

The following procedure shall be used to set the flow rate. The cooling water velocity (volumetric flow rate) in the annular space along the test tubes can be calculated by Formula (1):

$$\phi_{\text{circ}} = \frac{\pi \cdot v \cdot \left(D^2 - d^2\right)}{4} \quad (1)$$

where

ϕ_{circ}	is the circulation flow rate, expressed in m^3/s;
v	is the average cooling water velocity in the annular space, expressed in m/s;
D	is the internal diameter of the glass tube, expressed in m;
d	is the external diameter of the metal test tube, expressed in m.

7.1.7 Blow-down and half-life

The blow-down shall be measured and controlled. The half-life time of the system shall be determined.

Formula (2) shall be used to determine the relationship between the blow-down and the half-life of the test system:

$$t_h = \ln 2 \cdot V / B_d \quad (2)$$

where

B_d	is the blow-down, expressed in l/h;
t_h	is the half-life, expressed in h;
V	is the water volume of the entire system, expressed in l.

7.1.8 Biocide treatment

If it is possible that the proposed microbiological control program has an influence on the effectiveness of the inhibitor program under test, the dosing of chemicals for microbiological control should be undertaken in accordance with the manufacturer's instructions or appropriate standards for microbiological growth inhibition.

7.1.9 Make-up water for cooling-tower use

During the test, the volume of the cooling water in the system shall remain constant to ensure that the cooling water quality remains constant throughout the test. This is best achieved by automating make-up and blow-down. The cooling water volume is maintained at the required level by using either the actual site supply water or synthetic make-up water.

When using synthetic make-up water, the concentrations of the dissolved salts are divided by the cycles of concentration of the tested cooling water. Both synthetic water and actual site make-up water are dosed in a volume controlled by the level-control device, which ensures that the liquid level in the cooling water basin remains constant.

Dissolved chemical treatment additives are dosed in accordance with the supplier's instructions. The dose should be given as a fixed quantity of chemical treatment additive per unit of time, or as a variable quantity depending on one or more control parameters to be determined during the test.

NOTE Higher doses of corrosion inhibitors are often used at the start of a test to pre-film metal surfaces (refer to the manufacturer's instructions).

Biocides can also be used with corrosion and scale inhibitors but may be dosed either continually or as shock doses. Some biocides can interfere with the action of corrosion and scale inhibitors and, therefore, dosing of biocides should follow, as closely as is practical, the manufacturer's instructions and on-site practice.

During the test, the method of dosing shall remain the same. This can result in the composition of the cooling water deviating from the original composition when the test proceeds, for example, as the result of deposition of $CaCO_3$ and stripping of CO_2 across the cooling tower, which is the proper simulation of an operating cooling-tower system.

7.2 Determination of analytical and control parameters

During the test, the pH and conductivity should be recorded regularly alongside the concentration of water treatment additives. Other information should be gathered as appropriate (see Table 1).

Continuously record the temperatures of the water entering and leaving the heat-exchanger section, as well as the wall temperatures of each tube.

7.3 Test data reporting

All relevant data and measurement results should be reported on a test data sheet. An example is given in Annex A. When important fouling or corrosion changes occur during the test, it can be useful to record this in colour photos.

7.4 Test termination

The test period for this laboratory test should be (500 ± 10) h, i.e. approximately 21 days. The test should be terminated if an asymptotic fouling (i.e. when the wall temperature attains a quasi-steady value) is reached even if the test period is less than 500 h. Switch off the power to the heaters and allow the water to cool down to room temperature. Take a water sample for analysis and drain the system and remove the test tubes for evaluation.

8 Assessment of results

8.1 Recording of cooling water quality

For each of the analytical parameters, record the highest, lowest and mean of all the values measured on a test data sheet. An example of a test data sheet is given in Annex A.

If the dosing of chemical treatment additives is prescribed depending on control parameters, record the minimum and maximum target values for these control parameters on a test data sheet.

If, during the test, the values found for the analytical parameters are consistently outside the tolerance for their target values as recommended by the supplier and agreed between the interested parties, or when these target values cannot be achieved or maintained, the test should be stopped. This should be agreed upon by the interested parties.

8.2 Treatment of the test tubes

Carefully remove all test tubes from the test assembly while they are still wet. Photograph the wet tubes, rinse with distilled water, then carefully place them in a drying oven at about 105 °C for a period of 24 h. Collect any deposits that have been dislodged from the tubes in the process.

8.3 Assessment of results on deposition and fouling

Store half of the test tubes for reference purposes. After drying, carefully weigh, to the nearest 0,01 g, the other half of the test tubes including any adhering or collected loose fouling products.

Take a photograph (photo 1) of the weighed test tubes and make a print showing the tubes at least a third of the real size. Study the photo and record any details on the fouling, if necessary.

Scrape the deposits from one test tube using a blunt plastic knife. Determine the loss in mass of the scraped-off deposits at 600 °C and at 900 °C (loss on ignition). Perform a semi-quantitative analysis on the ash residue remaining by X-ray fluorescence (XRF) or an equivalent method. Record the results (loss in mass on ignition and content of MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, Cl, K_2O, CaO, Cr_2O_3, MnO, Fe_2O_3, NiO, CuO, ZnO, MoO_3, as needed) on a test data sheet. An example of a data sheet is given in Annex A.

Clean the weighed tubes thoroughly by external treatment with an appropriate solution in accordance with the relevant procedures given in ISO 8407.

Flush the tubes with water, rinse with alcohol, dry with acetone and compressed air and re-weigh to the nearest 0,01 g. Record the loss in mass before and after cleaning as the mass of the fouling for each tube.

Take another photograph (photo 2) of the weighed tubes and again make a print showing the tubes at least a third of the real size.

Determine, for each tube, the rise in wall temperature ($T_f - T_i$) over the total test period. Determine, for each tube, the average temperature rise over the temperature sensors and the maximum temperature rise and record these on a test data sheet.

In order for these data to be reliable, the velocity, power and bulk water (from the sump) temperature shall remain constant. A thermal fouling resistance, R_f, can then be calculated separately for each wall thermocouple using Formula (3):

$$R_f = \frac{T_f - T_i}{q/A} \quad (3)$$

where

A	is the area of heated surface, expressed in m^2;
q	is the energy applied, expressed in W;
T_f	is the final wall temperature at the end of the test, expressed in °C;
T_i	is the initial wall temperature at the beginning of the test, expressed in °C.

To obtain an average fouling resistance for each heater, the calculated R_f values can be averaged.

Assess the fouling quantitatively by calculating the average mass of deposit per heated surface area in kg/m^2. When calculating the heated surface area, use the heated section of the tube length.

8.4 Assessment of results on corrosion

8.4.1 Corrosion phenomena and type of corrosion

Assess the corrosion phenomena by visual inspection and describe the type of corrosion. Where appropriate, describe the type(s) (e.g. uniform, pitting or patchy corrosion), distribution and maximum depth of local corrosion on the weighed tubes.

8.4.2 Pitting corrosion

Evaluate the pitting corrosion of the specimens with a 3D microscope or in accordance with ISO 11463. Record the amount, area, depth and distribution of pitting.

If an online pitting measurement device is used, the measured data and results shall be reported.

8.4.3 Corrosion rate

The corrosion rate, in mm per year, is calculated from the average loss in mass of test tubes, which is calculated from the masses before the test and after cleaning. When calculating, take into account the heated surface section over the tube length.

Weight-loss corrosion coupons or Linear Polarization Resistance probes may be installed in the system. The results obtained on these can be a part of the assessment of the test results. The corrosion rate in these cases shall not be determined under heat-transfer conditions.

To compare the effectiveness of treatment programmes examined under this test, a graphical representation can be made of the fouling in g/m^2, which is assessed in accordance with 8.3, and either the corrosion rate in mm per year or the pit depth in mm.

9 Test report

The test report shall contain at least the following information:

a) a reference to this document, i.e. ISO 16784-2;

b) all details necessary to identify the product tested;

c) the type of water tested, i.e. simulated-site circulating water or synthetic water;

d) the metal type of the test tubes;

e) the method of heating the test tubes and of measuring the changes in temperature in the test tube; the tube arrangement and whether in series or parallel; total exposed length and total heated length of the test tube; the cooling water flow path along and/or through the test tube;

f) the type and number of heat exchangers and test tubes, including duty and local heat flux;

g) the mass flow of make-up, evaporation and blow-down, including minimum, average and maximum values;

h) the design and duty of the cooling tower and film fill;

i) the control parameters of the cooling water quality during the test: special attention should be given to deviations of the water quality during the run time of the test;

j) the requirements necessary to complement this test as detailed by the supplier of the product under test;

k) the total dosage/quantity of chemical treatment additive used, expressed in g, and the quantity of chemical treatment additive, expressed in mg/l, per quantity of blow-down water;

l) the chemicals, equipment and test methods used to inhibit or activate biofilm formation, including biocide demand, dosing amount and frequency, bacterial counts and/or ATP measurements;

m) an accurate description of the corrosion and fouling, e.g. general corrosion, pitting, patchy corrosion, composition of deposit and biomass, if any;

n) the starting and ending date of the test;

o) any deviations from the procedure;

p) any unusual features observed.

Annex A
(informative)

Test data sheet on the performance of cooling water treatment programmes

Data sheets to present the performance of the cooling water treatment programme tested are given in Tables A.1 to A.7.

Table A.1 — Test conditions

	Tube number					
	1	2	3	4	5	6
Material						
Exposed tube length (cm)						
Outer diameter (cm)						
Inner diameter (cm)						
Thickness (cm)						
Circulation flow rate (l/h)						
Water velocity (m/s)						
Heat flux (kW/m^2)						
Inlet/outlet temperature (°C)						
System volume (l)						
Half-life time (h)						
Make-up (l/h)						
Blow-down (l/h)						
Concentration factor						

Table A.2 — Pre-treatment

Method of passivation	Pre-filming with product Pre-film volume

Table A.3 — Method of treatment

Code and dosage of product 1 (mg/l)	
Code and dosage of product 2 (mg/l)	
pH-value	
M-alkalinity (mmol/l)	
P-alkalinity (mmol/l)	

Table A.4 — Analysis of cooling water

	Make-up	Cooling water			
		Target value	Measured		
			High	Low	Average
Calcium (Ca^{2+}) (mg/l)					
Magnesium (Mg^{2+}) (mg/l)					
pH-value					
M-alkalinity (mmol/l)					
Chloride (Cl^{-}) (mg/l)					
Orthophosphate (PO_4) (mg/l)					
Iron (Fe), total (mg/l)					
Conductivity (µS/cm)					
Turbidity					
Sulfate ion (SO_4^{2-}) (mg/l)					
etc.					

Table A.5 — Corrosion results

	Tube number					
	1	2	3	4	5	6
Loss in mass						
a) Mass of test tube (g)						
b) Mass of test tube (g) after the test						
c) Mass of test tube (g) after cleaning						
Loss in mass (g) [a)–c)]						
Corrosion						
Corrosion rate (mm per year) of heated surface						
Pitting corrosion class density (see ISO 11463)						
Pit sizes class (see ISO 11463)						
Pit depth class (see ISO 11463)						

Table A.6 — Fouling results

	Tube number					
	1	2	3	4	5	6
Mass of deposit (g) Table A.5: [b)–c)]						
Mass of deposit per heated surface (g/m^2) Table A.5: [b)–c)]/heated surface						
Average rise in temperature (Δ °C)						
Highest rise in temperature (Δ °C)						
U-coefficient, start						
U-coefficient, end						
Fouling factor						

Table A.7 — Results of the deposit analysis on a test tube

Element/compound	Content in % (mass fraction), semi-quantitative analysis	Element, compound	Content in % (mass fraction), semi-quantitative analysis
MgO		Cr_2O_3	
Al_2O_3		MnO	
SiO_2		Fe_2O_3	
P_2O_5		NiO	
SO_3		CuO	
Cl		ZnO	
K_2O		MoO_3	
CaO			
Loss in mass at 600 °C			
Loss in mass at 900 °C			
Crystalline compounds detected			

Annex B
(informative)

Further information on measurement and test methods

B.1 Mother solutions

Typical mother solutions for standard cooling water are listed in Table B.1

Table B.1 — Typical mother solutions for standard cooling water

Mother solution number	Quantities of substances in 5 l of water	Auxiliary solution
1	147 g $CaCl_2 \cdot 2H_2O$ 29 g NaCl 33 g $MgCl_2 \cdot H_2O$ 50 ml auxiliary solution A	A: 100 mg $ZnCl_2$ 500 mg NaBr 1 400 mg NH_4Cl in 1 l of water
2	84 g $NaHCO_3$ 10,5 g Na_2CO_3	
3	43 g Na_2SO_4 3 g KNO_3 50 ml auxiliary solution B	B: 4,0 g $Al_2\ (SO_4)\ _3 \cdot 18H_2O$ in 1 l of water
4	5 g $Na_2SiO_3 \cdot 9H_2O$ 50 ml auxiliary solution C	C: 8,2 g K_2HPO_4 in 1 l of water
5	0,5 g kaolin	
6	3,0 g C_2H_5OH (ethanol)	

The mother solutions and solutions prepared from the mother solutions shall remain clear upon preparation. Precipitation shall not occur prior to testing.

B.2 Apparatus

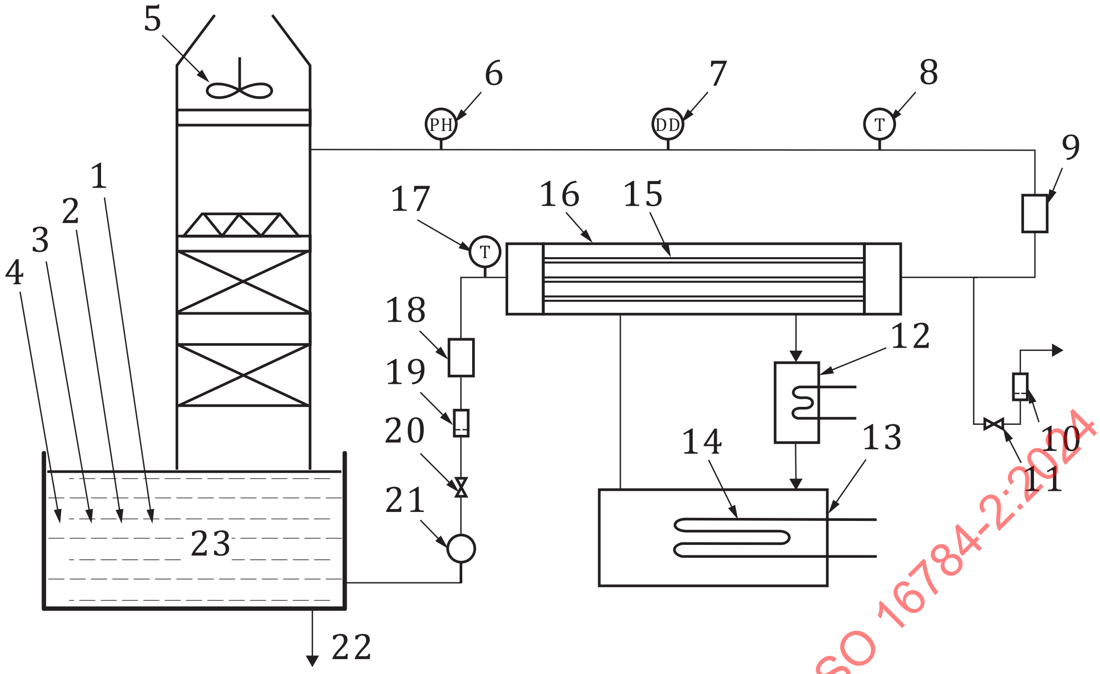
B.2.1 Cooling-tower set-up

The cooling-tower system consists of a plastic-coated sump of 60 l. The tower is equipped with a fan. The cooling tower should have a duty comparable with the duty of the heater assembly. A drift eliminator is included in the tower to prevent drift losses. Deposition of salts in the cooling tower shall be countered to the maximum extent by providing the cooling tower with splash-type fill. Film-forming fill should not be used.

NOTE A splash-type fill refers to a fill section in the cooling tower at which the water, as it falls, sprays out in very small droplets so that no drying out takes place anywhere on the fill. This type of fill is therefore not very sensitive to deposition of salts. A film-forming fill is a fill type in which the cooling water, as it falls, flows down over corrugated walls in an ever-thinner film, so that areas can dry out locally. A film-forming fill is therefore much more sensitive to salt deposition.

To enable visual inspection of the inside of the cooling tower during the test, at least one side of the tower shall be made of a transparent material.

It is permitted to use an extra cooler in addition to the cooling tower, in order to cool down part of the heat generated in the test assembly. The total heat load removed by this cooler shall, however, not exceed 3 kW.



Key

1 supplemental water
2 hypochlorite
3 inhibitors
4 acid
5 fan
6 pH meter
7 conductivity meter
8 outlet temperature measuring element
9 hanging cylinder
10 blowdown flowmeter
11 blowdown valve
12 steam cooler
13 electric steam furnace
14 electric heater
15 test tube
16 simulation heat exchanger
17 inlet temperature measuring element
18 entrance hanging piece barrel
19 circulating flowmeter
20 regulating valve
21 circulating pump
22 sewage
23 cooling water tank

Figure B.1 — Diagram of dynamic simulation cooling tower test device for steam heating