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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 entartrage des circuits de refroidissement à eau industriels —

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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 16784-2 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

ISO 16784 consists of the following parts, under the general title *Corrosion of metals and alloys — Corrosion and fouling in industrial cooling water systems*:

— *Part 1: Guidelines for conducting pilot-scale evaluation of corrosion and fouling control additives for open recirculating cooling water systems*

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

Introduction

Due to more stringent environmental requirements and escalating costs of water, there is an industrial need to improve the safety, reliability and cost-effectiveness of open recirculating cooling water systems. Correspondingly, it is 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.

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 part of ISO 16784 applies to corrosion and fouling in industrial cooling water systems

This part of ISO 16784 describes a method for preliminary evaluation of 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 part of ISO 16784 does not include heat exchangers with cooling water on the shell-side (i.e. external to the tubes).

2 Normative references

The following referenced documents are indispensable for the application 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 3696:1987, *Water for analytical laboratory use — Specification and test methods*

ISO 8407:1991, *Corrosion of metals and alloys — Removal of corrosion products from corrosion test specimens*

ISO 8501-1:1988, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 11463:1995, *Corrosion of metals and alloys — Evaluation of pitting corrosion*

3 Terms, abbreviations and definitions

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

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

NOTE 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
Cfu
colony forming units which are a unit of measure for the amount of bacteria in cooling water

3.4
cooling tower
tower used for evaporative cooling of circulating cooling water, normally constructed of wood, plastic, galvanized metal or ceramic materials

3.5
cooling water treatment
adjustment of cooling water chemistry by which corrosion and fouling can be controlled

3.6
cycles 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

3.7
heat rejection capacity
amount of heat that can be rejected by a cooling-tower system

3.8
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

3.9
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

3.10
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 metres (m)

V is the linear velocity, expressed in metres per second (m/s)

ρ is the fluid density, expressed in kilograms per cubic metre (kg/m^3)

η is the fluid viscosity, expressed in kilograms per metre per second (kg/m/s)

3.11
surface temperature
temperature of the interface between the cooling water film and the heat-transfer surface, whether the surface be the tube wall or the outside of a fouling deposit

3.12
TOC
total organic carbon

3.13

tower fill

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

3.14

wall shear stress

shear stress of the fluid film immediately adjacent to the tube wall

NOTE The wall shear stress is expressed in N/m^2.

3.15

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

A test assembly of metallic test tubes is submitted under heat-transfer conditions to the circulation of cooling water for a specified period. This may 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, e.g. 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 Reagents and materials

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, which may be adopted. The first is to use the make-up water as used in the specific cooling system on-site (a variation on this is to use synthetic make-up water), and concentrate it to the required number of cycles in the test system. Annex A includes forms recommended for recording test conditions, compositions of make-up and recirculating water, and test results.

The second approach involves using a synthetic water simulating the 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 will usually contain a higher level of dissolved ionic solids than corresponding natural water, thus making the synthetic water more corrosive.

5.1 Water characteristics

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

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

No.	Component	Value	Units
1	pH		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
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		UFC/ml or UFC/l
25	ATP		RLU

[a] The unit of measurement will depend on the test method.

5.2 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 mother 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 B.1. Alternatively, mother solutions may be prepared as concentrates and subsequently diluted with demineralised water.

6 Apparatus

The core of the test assembly is the heat exchanger section - described further in 6.1 to 6.4. The test assembly comprises two or more metal heat-transfer tubes, made of the relevant alloy used in the on-site heat exchanger, mounted in series (Figure B.1) or in parallel (Annex B.3, Figure B.2). Conduction and convection of electrically generated 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 not to influence the composition of the test water. Glass or plastic [(e.g., poly(vinyl chloride) (PVC), chlorinated poly(vinyl chloride) (CPVC) or poly(vinylidene fluoride) (PVDF)] are 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 (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 may be run by setting a different combination of surface temperature and flow rate for each heat exchange tube. However, it is highly recommended that all of the heat-transfer tubes be of the same metallurgical composition.

6.1 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 will not be fully accurate but will be 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.

6.2 Circulation-rate monitor

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

6.3 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. In essence, blow-down and make-up rates can be monitored by water meters and the evaporation rate deduced. Chemical feed may 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.

6.4 Cooling tower

The design and heat rejection capacity of the cooling tower and tower fill are optional but shall be reported. Deposition of salts in the cooling tower may 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.

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 will have a significant influence on corrosion and fouling. The method of surface preparation shall ensure good repeatability and 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 that is to be tested. The following information is optional for the test procedure, but it is necessary to adopt a standard pre-treatment and preparation procedure for the test tubes.

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

b) Subsequently, blast-clean the test tubes externally with 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 pretreatments, abrasion may not be appropriate.)

c) Clean the test tubes by blowing with compressed air and weigh, to at least an accuracy of 0,01 g, and install them in the tubes of the heat exchanger (6.1). Record the mass of each test tube on a test data sheet.

d) The tubes may be tested with or without pre-treatment. It is frequently considered desirable to test in both conditions, in order to determine quantitatively 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 may 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 measured 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 described in 5.2 so as to achieve the required cooling water quality, the parameters of which 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 so as to achieve the required circulation flow rate (see 6.2). 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 7.1.9). 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 ($t = 0$).

NOTE It is desirable to have set-up the test rig and controls 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 (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 so as to achieve the required circulation flow rate (see 6.2). 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 6.3). Start the dosing device and set the dose level to the prescribed values (see 7.1.9). 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 ($t = 0$).

NOTE It is desirable to have set-up the test rig and controls 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 described in B.3.

7.1.6 Flow rate

The recirculation flow rate measured in the circuit external to the heat-exchange tube section by the flow meter (6.2) 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 ± 1 m/s has been found to be suitable.)

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

The following procedure shall be used as an option to set the flow rate: the cooling water velocity (volumetric flow rate) in the annular space along the test tubes can be calculated by the formula

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

where

ϕ_{circ} is the circulation flow rate, expressed in cubic meters per second ($\text{m}^3\text{/s}$);

v is the average cooling water velocity in the annular space, expressed in metres per second (m/s);

D is the internal diameter of the glass tube, expressed in metres (m);

d is the external diameter of the metal test tube, expressed in metres (m).

7.1.7 Blow-down and half-life

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

The following formula shall be used for the relation between blow-down and half-life of the test system:

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

where

B_d is the blow-down, expressed in litres per hour (l/h);

t_h is the half-life, expressed in hours (h);

V is the water volume of the entire system, expressed in litres (l).

7.1.8 Biocide treatment

If the proposed microbiological control program is suspected to have a possible positive or negative influence on the effectiveness of the inhibitor program being tested, then 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 essentially 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 upon one or more control parameters to be determined during the test.

NOTE 1 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 may also be used with corrosion and scale inhibitors but may be dosed either continually or as shock doses. Some biocides may 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 may result in the composition of the cooling water deviating from the original composition when the test proceeds, e.g. 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 measured 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.

NOTE When important fouling or corrosion changes occur during the test, it may be useful to record this on colour photos.

7.4 Test termination

A test period of (500 ± 10) h, i.e. approximately 21 days, is suggested as a good option for run time of this laboratory test. The test should be continued until an asymptotic fouling (i.e. when the wall temperature attains a quasi-steady value) is reached or 500 h, whichever is less. 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 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.

In case the dosing of chemical treatment additive is prescribed depending on control parameters, also 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 at all, then the test should be stopped. This should be done by agreement between 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 for a period of 24 h at about 105 °C. 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 at 1/3 real size. Study the photo and record; if thought necessary, any details on the fouling.

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) and 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.

Then clean the weighed tubes thoroughly by external treatment with an appropriate solution. Relevant procedures are given in ISO 8407.

Flush the tubes with water, rinse with alcohol, dry with acetone and compressed air, re-weigh to the nearest 0,01 g and 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 at 1/3 real size.

Determine, for each tube, the rise in wall temperature ($T_\mathrm{f} - T_\mathrm{i}$) 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.

NOTE In order for these data to be reliable, the velocity, power and bulk water (from the sump) temperature must remain constant; then a thermal fouling resistance, R_f, can be calculated separately for each wall thermocouple using

$$R_\mathrm{f} = \frac{T_\mathrm{f} - T_\mathrm{i}}{q/A}$$

where

A is the area of heated surface, expressed in square metres (m^2);

q is the energy applied, expressed in watts (W);

T_f is the final wall temperature at the end of the test, expressed in degrees Celsius (°C);

T_i is the initial wall temperature at the beginning of the test, expressed in degrees Celsius (°C).

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

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

8.4 Assessment of results on corrosion

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

By weighing the test tubes before and after the test, the average corrosion rate can be determined.

NOTE Corrosion of metal in aerated aqueous systems is often of the "pitting" type. Measurement of the pitting depth will therefore give information that is very useful in practice, although the pit growth is not linear in time.

Assess the extent of corrosion by determining the following:

- the maximum pitting depth of tubes, by measurement with a needle-type depth gauge for example (see ISO 11463);
- the corrosion rate, in millimetres per year, calculated from the average loss in mass of test tubes, as calculated from the masses before the test and after cleaning; in calculating, take into account the heated surface section over the tube length.

NOTE It is allowed to install weight-loss corrosion coupons or Linear Polarization Resistance (LPR) probes in the system. The results obtained on these can be a part of the assessment of the test results. However, it must be recognized that the corrosion rate in these cases is not determined under heat-transfer conditions (see NACE RP0300-2000).

A graphical representation of the fouling, in $\mathrm{kg/m}^2$, as assessed in accordance with 8.3 and the corrosion rate, in millimetres per year, or the pit depth, in mm, as stated above, is a useful way of comparing the effectiveness of treatment programmes examined in accordance with this test.

9 Test report

The test report shall contain at least the following information:

a) a reference to this International Standard;

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) 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 tower 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, expressed in grams (g), used and the quantity of chemical treatment additive, expressed in milligrams per litre (mg/l), per quantity of blow-down water;

l) 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.

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.

Table A.1 — Test conditions

Tube number	**1**	**2**	**3**	**4**	**5**	**6**
Material						
Exposed tube length (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					
...					

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 11463:1995)						
Pit sizes class (see ISO 11463:1995)						
Pit depth class (see ISO 11463:1995)						

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			