
**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**

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

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*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*

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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.

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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

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

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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

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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/m³)

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

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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		$\mu\text{S/cm}$
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.

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6.2 Circulation-rate monitor

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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.