International
Standard

ISO 16784-1

Second edition
2024-12

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

Part 1:

Guidelines and requirements for conducting pilot-scale evaluation of corrosion and fouling control additives for open recirculating cooling water systems

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

Partie 1: Lignes directrices et exigences pour l'évaluation pilote des additifs anti-corrosion et anti-encrassement pour circuits de refroidissement à eau à recirculation ouverts

Reference number
ISO 16784-1:2024(en)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

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.

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).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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 16784-1:2006), which has been technically revised.

The main changes are as follows:

- the Introduction has been modified;
- normative references have been added;
- Clause 3 has been modified;
- Clause 4 has been modified: the title was changed from "Types of testing" to "General requirements and recommendations" and the latest requirements on environmental protection have been added;
- Clauses 7 and 8 have been combined and content related to new water treatment methods has been added.
- 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

A lot of changes have taken place in the development environment of global industrial enterprises, including advances in related technologies. As the industry grows and competition intensifies, while at the same time more stringent pollution requirements are introduced and water becomes more scarce, businesses have to operate in a safer, greener and more economical way. In many cases, cooling water quality is declining, which leads to higher concentration rates, more corrosion and more susceptibility to scaling.

Cooling water treatment technologies have developed and their use is expanding. Water pollution caused by additives used in cooling system has attracted public attention, and green environmental protection additives have become a new trend in development. Factories need to achieve zero waste water discharge. Cooling water treatments are effective measures for maintaining the best operating efficiency, protect the economic life of equipment, suppress corrosion and prevent scaling, microbial pollution and deposition on various heat transfer surfaces.

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

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

1 Scope

This document specifies general requirements and parameters for the pilot test evaluation of corrosion and scaling control additives in open recirculating cooling water systems. This document covers parameters including test unit design, operation, water quality and contamination. It also covers the design and operation of pilot test devices as well as parameters to be evaluated in pilot test units.

This document covers the criteria that are used in pilot scale testing programmes for selecting water treatment programmes for specific recirculating cooling water systems.

This document is only applicable to open recirculating cooling water systems. It does not apply to closed cooling systems and once-through cooling water systems.

This document applies only to systems that incorporate shell and tube heat exchangers with standard uncoated smooth tubes and cooling water on the tube side. This document does not apply to heat exchangers with shell-side water, plate and frame and/or spiral heat exchangers and other heat exchange devices. However, when the test conditions are properly set up to model the surface temperature and shear stress in more complex heat transfer devices, the test results can predict the results of operating heat exchangers of that design.

The test criteria established in this document are not intended to govern the type of bench and pilot scale testing normally carried out by water treatment companies as part of their proprietary product development programmes. However, water treatment companies can choose to use the criteria in this document as guidelines in the development of their own product development test procedures.

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 8044, *Corrosion of metals and alloys — Basic terms and definitions*

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 terminology 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
fouling
deposition of any material on a heat transfer surface

3.2
surface-to-volume ratio
S/V ratio
ratio of the total surface area of metal exposed to water in the cooling system to the total volume of water in the system

4 General requirements and recommendations

4.1 Selection of test methods

4.1.1 Laboratory and off-site testing

Laboratory testing, or testing at alternative off-site locations, can in some cases be necessary for selecting cooling water chemical treatment programmes. This type of testing can be used for new construction start-up programmes, when operating systems are not available, or for evaluating alternative treatment programmes. In such cases, the evaluation should include site-specific design criteria and environmental regulations that affect the cooling water system. Site-specific water supplies should be used whenever possible. All criteria in this document relating to water compositions, water treatment methods (as described in Annex A), test unit configuration, heat exchanger design and operating conditions should be followed insofar as possible.

No laboratory or off-site testing programme can completely duplicate plant conditions. Site-specific factors (e.g. process leaks, microbiological growth, corrosion products, airborne contamination) can affect the operation of cooling water systems and the performance of chemical treatment programmes in ways that override the results of laboratory or off-site testing programmes.

4.1.2 On-site testing

Whenever possible, water treatment programmes should be evaluated on site, using plant water supplies and actual design and operating conditions, particularly those that cannot be duplicated in the laboratory.

4.1.3 Online testing

Whenever possible, all off-site, laboratory and on-site pilot scale testing should be validated by monitoring actual performance results online. Pilot units can be adapted for online work by using a side stream from the plant circulating cooling water as feedwater, bypassing the pilot unit cooling tower. Such online testing validates offline or laboratory tests. Cooling systems can be evaluated online; however, the data collected will be the result of the combination of any existing treatment and all additional chemicals that were added for the evaluation period. Online testing in this way can optimize the treatment programme to meet specific plant requirements. For example, small quantities of a treatment chemical can be added just ahead of the test heat exchanger to measure the effects of increasing additive dosage, or the possible synergistic effects of a new chemical added to the existing treatment programme.

4.2 Cost analysis

Cost analysis of the selected additives should be evaluated according to ISO 22449-2.

5 Test unit design parameters

5.1 General

When designing a pilot-scale evaluation programme for water treatment products, the mechanical design and operation of each cooling water system shall be evaluated. It can be impractical to simulate a specific critical plant heat load or water flow pattern exactly. Contamination cannot develop in the same way in a pilot cooling tower as in the plant systems. Compromises can therefore be necessary. Plant design and operations shall be followed in all such circumstances. Deviations shall be noted in the test reports.

In addition to adding corrosion and scaling control additives to circulating cooling water, some water treatment methods are also commonly used for circulating cooling water treatment, including:

- the lime softening method;
- the ion exchange method;
- the reverse osmosis desalting method;
- the electrochemical treatment method;
- the electromagnetic method;
- bypass filtration methods.

These methods are discussed in 5.4. Specific attention shall be given to the impact of using these methods on additive selection in the design of the pilot unit.

For efficiency, pilot test research can be done on two or more identical test units at the same time.

5.2 Construction materials

5.2.1 Cooling towers

Small cooling tower basins can be made of uncoated, plastic-coated, galvanized low-carbon or stainless steel. Large tower basins are usually concrete. Splash fill can be wood, ceramic or plastic. It is not important that the pilot cooling tower duplicates the design of the plant towers. However, if the plant system contains galvanized steel, galvanized steel should be included as a non-heat-transfer test material in the pilot system.

5.2.2 Film fill

If the plant cooling towers contain film fill, a section of this fill (if available) should be used in the pilot tower. Film fill consists of closely packed layers of lightweight plastic material, normally PVC, arranged in a honeycomb-like structure. This maximizes the surface area over which water flows, and thereby improves evaporation efficiency. However, the increased surface area also encourages deposit formation in the fill.

Deposits can consist of mineral scales formed by the evaporation of water, microbiological deposits and corrosion products and silt carried into the tower. Biofilms tend to act as a glue that encourages other deposits to adhere to the fill. Because the space between adjacent layers of fill is often quite small, deposited material can bridge the fill and block water flow. This is a serious problem, because film fill cannot be cleaned chemically unless water can flow through all parts of the fill.

Mechanical cleaning, including water lancing, often damages the lightweight fill material. In addition, the weight of a significant deposit in the film fill can mechanically damage it. Hence, one performance requirement of any cooling water chemical treatment programme intended for use in a film-fill cooling tower shall be to prevent bridging of the fill.

The condition of the film fill in an operating cooling tower can be monitored using a fill test box. This is a section of fill, a cube with sides of 0,6 m, enclosed in a supporting box that is open at the top and bottom. The box is exposed to droplets of condensation that fall below the fill in the cooling tower, in an accessible location. If the fill surfaces feel slippery, or if there is a visible deposit layer, this indicates fouling conditions in the fill.

A fill test box is a very useful qualitative monitoring tool in an operating cooling tower. However, it can be impractical in a pilot cooling tower due to space and size limitations. It is best to design the pilot cooling tower so that the actual tower fill can be accessed conveniently for visual and physical inspection.

5.2.3 Non-heat-transfer metal surfaces

Circulating water lines can be lined with carbon steel, copper, brass, fiberglass, polyethylene or cement. Unless process-side conditions dictate otherwise, heat exchanger shells are usually made of carbon steel. Bimetallic corrosion shall be avoided.

All corrosion-prone metals that are present in the operating system should be included as non-heat-transfer test coupons in the pilot study. This is important for two reasons. First, localized corrosion of piping systems can lead to unexpected failures. Second, corrosion product deposits can accumulate on heat-transfer surfaces, which can lead to under-deposit corrosion and losses in efficiency. Water treatment chemicals can only provide corrosion protection when the chemicals can reach the metal surfaces. Unprotected metal areas beneath deposits thus become potential sites for under-deposit corrosion.

5.2.4 Heat exchangers

Heat exchanger design is generally focused on process-side requirements and on the actual process involved (liquid cooling, gas cooling or condensing). Process heat exchangers are designed to control the temperature of a process fluid under the most severe expected conditions. That is, the warmest cooling water and the maximum production rate.

Heat exchangers are designed with a built-in fouling factor that allows the unit to produce the desired process temperature control with some loss of efficiency due to either water- or process-side fouling of the tubes. For these reasons, process heat exchangers are often oversized. To achieve the desired process-side outlet temperature control, operators throttle the water flow in response to ambient conditions, production demands and the degree of fouling in the heat exchanger. Reducing the water flow rate through the tubes increases the surface temperature and allows suspended solids to settle on the tube surfaces and mineral scale deposits to form. This leads to losses in heat-transfer efficiency and increased opportunities for corrosion of the tubes. See also 9.3.1.

NOTE The terms "fouling factor" and "fouling thermal resistance" refer to the measured resistance to heat transfer caused by a deposit on a heat-transfer surface. The fouling factor is also used in heat-exchanger design to increase the heat-exchanger surface area to compensate for thermal inefficiency caused by a deposit on the heat-transfer surface. The term "fouling factor" is commonly used for both. However, "fouling thermal efficiency" can be substituted for the measured fouling factor.

One very important function of the chemical water treatment programme is to minimize corrosion and deposit formation of all kinds on heat exchanger surfaces. In designing a pilot-scale testing programme, one critical set of parameters involves the configuration of the heat-transfer section. Heat-transfer tubes can be made of carbon steel, copper, copper alloys or stainless steels. If required in petrochemical plants or other locations with severe process-side conditions, heat-transfer tubes can include a wide variety of other alloys and a few non-metallic materials.

Care should be taken when selecting the heat exchanger to be modelled. The most appropriate heat exchanger has a combination of the highest surface temperature and the lowest velocity, within reason. Some judgment is required in the selection process.

Petrochemical plants sometimes include vertically oriented shell-and-tube heat exchangers. Because of process requirements, water is often on the shell side in such exchangers. Shell-side water creates particularly severe corrosion and fouling problems that cannot be satisfactorily simulated in the type of pilot-scale equipment covered by this document. This is especially true of vertical shell-side water heat exchangers.

Many plant heat exchangers include multi-tube and multi-pass designs. Such designs are difficult to simulate in a pilot-scale unit. This document refers to single-tube, single-pass designs with parameters selected to simulate the conditions under study in the plant exchanger.

5.3 Measuring instrument

Online testing instruments shall be used to test the changes of parameters during the experiment, including but not limited to: temperature, pressure, flow rate, conductivity, pH, online corrosion rate test instrument.

5.4 Other simulation devices

There are a number of water treatment methods for recycling water, which can result in different water qualities. These methods include:

- the lime softening method,
- the ion exchange method,
- the reverse osmosis desalting method,
- the electrochemical treatment method,
- the electromagnetic method.

The simulators of different water treatment methods should be simulated as part of the pilot-scale equipment when pilot-scale experiments are carried out.

When the simulation devices are not available in some cases, artificial synthetic water can be used to replace the effluent of these devices.

6 Operating parameters

6.1 General

For any given heat exchanger design, the kinetics of fouling and corrosion are controlled by three parameters: surface temperature, water velocity and residence time, in addition to water quality. It is not possible to duplicate all the characteristics of an operating heat exchanger in a small pilot-scale unit, so compromises shall be made in controlling each of these parameters.

6.2 Surface temperature

The surface temperature of the heat-transfer surface controls the rate of temperature-driven corrosion and fouling reactions. The surface temperature, in turn, is a function of the heat flux, metallurgy, water flow and the degree of water- and process-side fouling of the tubes.

During testing of water treatment programmes under the most severe conditions that can realistically exist in a specific plant, the surface temperature of the heated tube sections in the pilot unit should match the highest surface temperature in the operating heat exchanger. This temperature can be estimated from measured water- and process-side flows and temperatures as well as the design data for the heat exchanger.

6.3 Water velocity

Water velocity through the heat exchanger tubes determines the rate of transfer of dissolved and suspended matter between the bulk cooling water and the water film in contact with the tube wall. These materials can include scaling ions (e.g. calcium and carbonate), dissolved ions (the corrosive species in most cooling water systems), foulants, including suspended solids, and the chemical additives designed to control fouling and corrosion.

Increasing water velocity normally helps to control both fouling and corrosion. Flow rates between about 1,0 m/s and 2,5 m/s are common. Excessive velocity can cause flow-assisted corrosion, depending on the tube metallurgy. Lower velocities can be required to closely simulate specific plant heat exchangers operating with velocities lower than 1 m/s.

6.4 Residence time

In reference to heat exchangers, residence time is the time that water is exposed to the heat-transfer surfaces in a specific exchanger during each cycle through the cooling system. This cannot be exactly duplicated in a small pilot unit. However, the effect of residence time per unit of heat-transfer length is simulated by matching surface temperature and flow velocity to field conditions as closely as possible.

7 Water quality and contamination

7.1 General

This clause discusses the effects of the quality and availability of make-up water for open cooling water system operation, performance and control, emphasizing problems that shall be considered when designing specific pilot cooling water test facilities. The quality of the available make-up water can vary seasonally, can be drawn from several different sources and can be reused after being treated by the different processing units , as described in 5.1. Such variations should be considered.

7.2 Natural versus synthetic water supplies

For practical reasons, most water treatment product development work is performed in the laboratory, using waters that have been synthesized to resemble typical natural waters. However, the closer a product development project comes to actual field use, the more important it is to test on-site, using actual field water supplies.

Laboratory waters cannot duplicate the organic content of natural waters. Simple organic compounds are sometimes added in the laboratory to compensate for this, but without much success. Natural lignins and tannins and process contaminants are site-specific. These materials can have important effects, especially on the tendency of a water to precipitate mineral scales. Similarly, microbiological contamination from water and airborne sources cannot be duplicated in the laboratory.

For convenience, laboratory waters are synthesized by dissolving various salts to form stock or mother solutions, which are then mixed as needed to form test waters. Waters made in this way have higher contents of dissolved solids, and therefore higher conductivities, than natural waters that obtain their mineral contents by slow dissolution of oxides and carbonates. For this reason, synthetic waters are generally more corrosive than the corresponding natural supplies. This can significantly affect product performance, especially if the intended application is in a soft water supply that has a low content of dissolved-solids.

Natural waters are sometimes shipped to laboratories for cooling water testing. This can be a partial solution to the problems described in this subclause. However, alkalinity relationships, pH and the microbiological community in the water all change on standing. Even drummed natural waters are often not fair representations of field conditions.

7.3 Water from different sources

7.3.1 Fresh water

Soft, medium and hard water supplies create specific problems when cycled in cooling tower systems. These problems shall be solved by water treatment programmes matched to the chemistry of the circulating water. Water quality and availability vary widely. Mineral content, organic matter, other contaminants and cycles of concentration all affect water treatment operations.

7.3.2 Seawater and brackish water

High levels of dissolved solids make these water supplies corrosive and require specially formulated treatment programmes. Alkalinity and hardness are often low, so mineral scaling can be less significant than in some fresh water supplies. Seawater is normally used in once-through systems, but brackish water can be concentrated to conserve water and minimize blowdown. Microbiological contamination shall be considered in pilot testing with these waters. Metals shall match site conditions.

7.3.3 Recycle/reuse water

Use of secondary treated sewage effluent as cooling tower make-up is an effective way to conserve fresh water and minimize wastewater discharge. Special problems introduced by these water sources include ammonia, high levels of phosphate, other inorganic salts and biological oxygen demand (BOD) and chemical oxygen demand (COD). These waters are particularly unstable and cannot be transported to a laboratory for reliable testing, as described in ISO 22449-1.

Use of in-plant recycled wastewater as cooling tower make-up is an effective way to conserve fresh water and minimize wastewater discharge. Special problems introduced by these water sources include a wide variety of inorganic and organic constituents and BOD and COD. This depends on the plant processes from which the wastewater is received as well as the processes through which it is treated.

7.3.4 Dual and combined make-up systems

Some plants use two very different make-up water sources, for example, recycled water and a municipal supply, or a surface water and a ground (well) water. Supplies can be used concurrently, or one may be a backup for the other. This creates a variable circulating water composition that cannot easily be simulated. In such cases, on-site pilot-scale testing is the only practical way to evaluate cooling water additives.

7.4 Contamination

7.4.1 General

Contamination of the circulating cooling water with airborne solids and gases, microbiological matter and process materials can severely affect system performance and operating efficiency. Contaminants can create fouling and corrosion problems that can seriously degrade the performance of cooling water chemical additives. In most cases, system contaminants cannot be tested off site. It is very important, therefore, to recognize the presence of contaminants in the system for which additives are being evaluated. The test protocol shall include these contaminants and evaluate their effects on additive performance.

7.4.2 Process leaks

Process leaks are common in industrial plants. Hydrogen sulfide, ammonia, oil in oil refineries, a wide variety of organic and inorganic chemicals in chemical plants, coke fines and mill scale in steel mills, etc., all create water treatment problems that shall be managed by the water treatment programme. Contaminants can interact with normal constituents of the water with suspended solids and with the water treatment chemicals to create secondary fouling and corrosion problems. These problems are site-specific and very difficult to simulate in a laboratory.

7.4.3 Biological matter

Biological contamination from the make-up water, process leaks and airborne sources shall be considered in designing water treatment programmes. Loss of heat transfer, flow restrictions and microbiologically induced under-deposit corrosion shall all be considered. Microbiological matter is often the glue that binds other deposits to metal surfaces. Microbiological control is therefore an essential part of any water treatment programme. These problems are especially difficult to simulate because they are site-specific and because the microbiological sources are unstable and not reproducible in a laboratory even if they can be transported.

7.4.4 Airborne solids and gases

For obvious reasons, the air in a controlled laboratory environment cannot be the same as the air blowing through a cooling tower in an operating plant. In an oil refinery, for example, ammonia and hydrogen sulfide gases can affect pH control and microbiological activity. Dirt, coke fines and other airborne material add suspended solids. Exhaust fans can blow kitchen fumes into commercial heating, ventilating and air conditioning (HVAC) cooling towers. These and similar contaminants can have major effects on the performance of cooling water treatment programmes. Identification of specific airborne contamination is a vital part of any pilot test programme, and this contamination cannot easily be simulated in a laboratory.

8 Parameters to be evaluated in pilot test units

8.1 Corrosion

8.1.1 General

Corrosion is a principal determinant of the economic life of water-handling equipment. Economic life, in turn, is a key design parameter for equipment used in cooling water systems. Operating systems can contain several different materials of construction. The corrosion criteria to be evaluated for each of the critical metallurgies should be determined. Water treatment programmes shall be selected to protect metals exposed to water in the system that can be expected to corrode. The pilot testing programme shall include corrosion measurements on each of these metals, including on both heat-transfer and non-heat-transfer surfaces.

8.1.2 Criteria for corrosion evaluations

The criteria used for evaluating corrosion inhibitor performance are industry-dependent. For example, a carbon steel corrosion rate of 0,075 mm/a is considered unusually low in many steel mills. In an oil refinery, this same corrosion rate can be in the normal range, while it is unacceptably high in a clean HVAC system. Thus, a corrosion inhibitor programme required for good performance in an HVAC system can be “overkill” and not cost-effective in a steel mill. The pilot test parameters shall match both the industry type and the specific plant site.

8.1.3 Types of corrosion damage

Serious corrosion damage in open cooling water systems is usually the result of localized attack, including pitting, crevice attack, etc. Damage from general surface corrosion, in the absence of major upsets such as acid leakage into the water, is unusual. Evaluation should therefore include both localized and general corrosion on all metals to be protected.

8.1.4 Microbiologically influenced corrosion

Microbiologically influence corrosion (MIC) occurs in an environment developed by certain types of microorganisms that make the materials susceptible to attack. These organisms can generate organic and inorganic acids as part of their metabolic processes, and this can lead to rapid pitting attack on steel and other metals. MIC is especially difficult to study in pilot-scale test units because the deposits that harbour the microorganisms do not form readily under these conditions. MIC is best studied in the field. If a specific system under evaluation is shown to be subject to MIC, the chemical treatment programme shall include methods for removing deposits and killing microorganisms in these deposits. If this is not done, chemical treatment programmes that are effective in a pilot unit can perform badly in the field.

8.1.5 Methods for evaluating corrosion in pilot-scale test units

8.1.5.1 Heat-transfer specimens

Heat-transfer specimens in the pilot test unit should be used for both corrosion and fouling evaluations. The test specimens should be easy to remove so that they can be photographed and weighed. Corrosion patterns should be noted, and pit depths measured when appropriate.

8.1.5.2 Corrosion coupons

Corrosion coupons provide a measure of the average corrosion rate over the period of exposure. They also accumulate deposits and can show the presence of under-deposit corrosion. Corrosion coupons should be handled and evaluated according to ISO 11845. Corrosion coupons, while useful for evaluating system corrosiveness, fail to replicate the hydrodynamic and thermal conditions of heat exchanger tubes. Corrosion coupon data should be considered indicative only.

8.1.5.3 Online measurements of general corrosion

Linear polarization resistance (LPR) instruments measure the corrosion current flowing between two electrodes exposed in the cooling water, with a small applied voltage. (Both two-electrode and three-electrode LPR systems are available; electrodes can also be used as corrosion coupons.) From this current, the instrument calculates an “instantaneous” corrosion rate, i.e., the rate at the moment of measurement. Such data are useful for showing the effects of additives and dosage changes and changes in process variables such as pH. Combined with coupon results, LPR data can be useful in identifying the corrosive species in specific systems and studying the performance of corrosion inhibitors. Such devices can be calibrated against corrosion coupon studies performed over the same exposure period. Care should be taken to perform several such studies to validate the calibration. Similar data can be generated using galvanostatic methods.

More recent techniques, such as electrochemical noise, can be adopted but need to be validated for the application.

8.2 Fouling

8.2.1 General comment

Fouling reduces heat exchanger performance by insulating the heat-transfer surface from the water. Fouling also increases the pressure drop through the heat exchanger, thus restricting water flow. Fouling of the tube surface determines the efficiency with which heat is transferred through a heat exchanger. Fouling creates potential sites for under-deposit corrosion, including MIC. Possible process-side fouling shall be considered when evaluating the performance of water treatment programmes in specific-field heat exchangers. The vast majority of heat exchangers are designed with an allowance for fouling, as explained in 5.2.4. Thus, any evaluation of a cooling water treatment programme should include provisions for quantifying fouling. Measured fouling shall be compared against the design allowance for the heat exchanger, taking into account any deviation of test parameters from actual operating and design conditions. Corrosion coupons should be evaluated according to 8.1.5.2.

8.2.2 Types of water-side fouling

Water-side foulants include mineral scales such as calcium carbonate and calcium phosphate, corrosion products, microbiological material, general waterborne and airborne solids, and, in some cases, process contaminants. The specific mix of foulants in an operating system can affect the choice of fouling inhibitors included in the water treatment programme.

8.2.3 Pilot-scale methods for evaluating fouling (see also ISO 16784-2)

8.2.3.1 Heat-transfer methods

The central focus of a pilot-scale cooling water test unit is usually a heated tube surface that simulates a field heat exchanger. In one design, the tube is heated electrically from the inside. Water flows through the annular space between the outside of the tube and a surrounding glass or plastic tube. Thus, the outer surface of the heated tube simulates the inner surface of a “tube-side” heat exchanger. Another design uses an external heater with water flowing within the tube. In either case, the tube should be commercial heat exchanger tubing matched as closely as possible to the field system. The tube should be usable without extensive machining or other treatment.

Fouling should be evaluated throughout the test by measuring heat-transfer coefficients and fouling factors. At the conclusion of a pilot test, fouling of the heated tube surface can be evaluated by visual examination of the tube surface (including a photographic record), by the weight of the deposit removed from the surface and by analyses of the deposits. It is important to be able to assemble the unit easily and to disassemble it without disturbing deposits on the tube surface.

8.2.3.2 Non-heat-transfer methods

Fouling of non-heat-transfer surfaces can also be important in operating cooling systems. Deposits can restrict water flow in small-diameter tubes and create sites for under-deposit corrosion. Inspections of corrosion coupons and coupon racks provide visual evidence of deposit formation. Coupons made from corrosion-resistant stiff wire mesh (e.g. nichrome, stainless steel and titanium) can be used to accumulate suspended solids and microbiological deposits.

Pressure drop across a length of small-diameter tubing can provide a measure of fouling. It is particularly sensitive to microbiological fouling and is most appropriately used to measure this type of fouling. If desired, such a device can be incorporated as an optional part of a pilot-scale testing unit.

8.3 Water treatment additives

8.3.1 Combination testing

Pilot-scale test facilities should be designed to allow feeding and control of water treatment additives combined into practical programmes as recommended by the suppliers. Testing of individual components can produce results that are not typical of field conditions. Different combinations of additives can produce equivalent good performance but can require different sets of operating parameters. Therefore, it is possible that testing different programmes under identical conditions does not produce the best results that can be obtained from any programme.

8.3.2 Compatibility of additives

The components of any treatment programme shall be compatible with one another and with the system. Cationic biocides can precipitate with anionic surfactants. Oxidizing biocides can enhance the activity of some non-oxidizing biocides, but can destroy some scale and corrosion inhibitors, especially when their concentration is high. Some corrosion inhibitors are effective at recommended dosages but can precipitate and cause fouling and localized corrosion if overdosed or used outside the recommended pH range.

9 Design of pilot-scale performance testing facilities

9.1 Objectives

A method to evaluate the performance of cooling water treatment programmes using a pilot-scale rig is given in ISO 16784-2, in which all factors affecting additive evaluation should be considered as far as possible. Development of additives to control specific water treatment problems and mechanisms is not covered by either part of ISO 16784. The objective of pilot plant testing according to this document should be to assess the performance of formulated water treatment programmes under site-specific field conditions. When the objective is to solve an existing problem in an operating cooling system, that can be done most effectively with an online monitor of fouling, corrosion and chemical parameters operating on the existing cooling system. This is undertaken initially by incrementally adding to the existing treatment chemistry. Subsequently, the existing treatment programme can be changed by incorporating the new chemistry.

9.2 The importance of simulating specific process and application environments

Specific water treatment processes shall be simulated when conducting pilot-scale evaluation of corrosion and fouling control additives.

Care should be taken to simulate fouling and corrosion conditions in heat exchangers, which are critical from a water treatment standpoint, as opposed to specific process bottlenecks. The latter can be the result of design shortcomings or process problems, rather than water chemistry. Realistic test conditions are critically important. Both over- and under-stressing the water treatment programme can decrease the utility of the test results and make the test results misleading.

9.3 Compromises in pilot-scale performance testing

9.3.1 Heat source, heat duty and temperature

9.3.1.1 Heat source

Most pilot-scale performance test devices substitute electrically heated heat-transfer surfaces for process heat exchangers, but steam heat transfer is more similar to field conditions. These two kinds of heat sources are often used. These devices are subject to some limitations. They are steady-state devices, which eliminate all process-side variables, such as heat transfer through a process film, process side fouling, and variations in heat duty as production rates vary. Thus, the test device has a constant heat duty regardless of the waterside fouling. In actual operation, the heat duty of a heat exchanger would be reduced as the water-side fouling deposit thickens.

9.3.1.2 Heat duty

The heat duty and heat flux of a pilot-scale performance test device are substantially different from those of a process heat exchanger being modelled. The differences are the result of both size and geometry. The test device is much smaller than the process heat exchanger.

9.3.1.3 Test geometry

An annular geometry can be substituted for internal tubular flow. The heat flux in the test device is greater in order to obtain the same heat-transfer surface temperature as the outlet of the process heat exchanger. The water velocity can be different from that in the process heat exchanger, in order to replicate the shear stress of the water film against the heat-transfer surface. When an annular geometry is used, the equivalent diameter of the annular space, and that of the internal tubes in the process heat exchanger, can be significantly different.

9.3.1.4 Temperature profile

It is very difficult to simulate the water temperature profile in a large operating cooling circuit with a pilot unit. The conditions of the pilot unit should be adjusted, as closely as possible, to simulate the conditions that are under study. Possible compromises include corrosion rate versus bulk water temperature, relative surface areas and localized chemistry.

9.3.1.5 Statistical analyses

In order to analyse test results statistically, either a device consisting of multiple parallel tubes or a series of tests on a single tube device is required. Statistical analysis is not normally required under field conditions.

9.3.1.6 Protocol and report

The test protocol and test reports should include specific design and operating data for both the plant heat exchanger and the test unit, so that this information can be part of the water treatment decision process. The test report should include calculations demonstrating the hydrodynamic similarity of the test unit to the exchanger being simulated. Differences, if any, should be described and discussed.

9.3.2 Water chemistry

9.3.2.1 On-site versus off-site water

Whenever possible, pilot-scale testing should be performed on site using plant water supplies. A second and less satisfactory option is to ship plant water to an off-site laboratory for testing. For practical reasons, this method is frequently used. In such cases, it is important to remember that the water chemistry, particularly the alkalinity relationships and the microbiological content of the water, changes in transit and storage, so that these properties of the water are not correctly assessed in the off-site tests.