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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

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

Partie 1: Lignes directrices pour l'évaluation pilote des additifs anticorrosion et antitartre pour circuits de refroidissement à eau à recirculation ouverts

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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 16784-1 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

Environmental requirements, water shortages, and business pressures have forced industrial plants and power stations to operate with longer production runs, reduced maintenance outages, fewer operating personnel, and increased stress on cooling water systems. Similarly, commercial refrigeration (heating, ventilating, and air conditioning [HVAC]) systems have experienced increased heat loads and requirements for a long-term, continuous, cooling water supply to computer facilities, large retail establishments, campuses, and office complexes.

Under these increasingly severe conditions, cooling water chemical treatment programmes are expected to maintain optimum operating efficiency and, at the same time, protect the economic life of the equipment by inhibiting corrosion, mineral scaling, microbiological fouling, and miscellaneous deposition on heat-transfer surfaces.

Cooling system design and operating characteristics vary widely, within individual plants, from site to site, and worldwide. Thus, selection and optimization of water treatment programmes must be a site-specific process. In most systems, optimized cooling water chemical treatment is the key to successful long-term operations. The subject of this part of ISO 16784 is, therefore, the establishment of criteria for the pilot-scale evaluation of the performance of cooling water additives under field-specific operating conditions.

This part of ISO 16784 is intended for use by cooling system owners/operators, water treatment companies and others who must evaluate the performance of cooling water additives under field-specific operating conditions.

This part of ISO 16784 was developed on the basis of NACE RP0300 [4].

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

1 Scope

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

This part of ISO 16784 covers the criteria that must be defined and implemented in a pilot-scale testing programme to select water treatment programmes for use in specific recirculating cooling water systems.

This part of ISO 16784 covers only open recirculating cooling water systems. Closed cooling systems and once-through cooling water systems are specifically excluded.

This part of ISO 16784 applies only to systems incorporating shell-and-tube heat exchangers with standard uncoated smooth tubes and cooling water on the tube side. Heat exchangers with shell-side water, plate and frame and/or spiral heat exchangers, and other heat exchange devices are specifically excluded. 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 may predict what may occur in an operating heat exchanger of that design.

The test criteria established in this part of ISO 16784 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 may choose to use the criteria in this part of ISO 16784 as guidelines in the development of their own product-development test procedures.

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 8044:1999, *Corrosion of metals and alloys — Basic terms and definitions*

ISO 16784-2, *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*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 8044:1999 and the following abbreviations and symbols apply.

ASTM: ASTM International

BOD: Biological oxygen demand

COD: Chemical oxygen demand

HVAC: Heating, ventilating, and air conditioning

LPR: Linear polarization resistance

MIC: Microbiologically influenced corrosion

NACE: NACE International

PVC: Polyvinyl chloride

s/V ratio: Surface-to-volume ratio

UNS: Unified Numbering System

4 Types of testing

4.1 Laboratory and off-site testing

4.1.1 Laboratory testing, or testing at alternative off-site locations, may in some cases be necessary for selecting cooling water chemical treatment programmes. This type of testing could 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 part of ISO 16784 relating to water compositions, test unit configuration, heat exchanger design, and operating conditions should be followed insofar as possible.

4.1.2 No laboratory or off-site testing programme can completely duplicate plant conditions. Site-specific factors, such as process leaks, microbiological growth, corrosion products, airborne contamination, etc., may 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.

4.2 On-site testing

4.2.1 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. Criteria for these effects are discussed in 9.1.2.

4.2.2 Specific attention shall be given to site-specific rules and environmental regulations that may affect the types of chemical products that can be used, the allowable amount and composition of blowdown water, and air quality regulations affecting cooling tower discharge.

4.3 On-line testing

Whenever possible, all off-site, laboratory, and on-site pilot-scale testing should be validated by monitoring actual performance results on-line. Pilot units can be adapted for on-line work by using a sidestream from the plant circulating cooling water as feedwater, bypassing the pilot unit cooling tower. Such on-line testing serves to validate the off-line/laboratory tests. Cooling systems may be evaluated on-line; 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. On-line testing in this way can be useful for optimizing the treatment programme to meet specific plant requirements. For example, small quantities of a treatment chemical may 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.

5 Test unit design parameters

5.1 General

Careful evaluation of the mechanical design and operation of each cooling water system is a necessary prerequisite for designing a pilot-scale water treatment product-evaluation programme. It may not be practical to simulate a specific critical plant heat load or water flow pattern exactly. Contamination in a pilot cooling tower may not develop in the same way as in the plant systems; compromises may therefore be necessary. In all such cases, plant design and operations must be followed as closely as possible, and deviations must be noted in the test reports.

5.2 Construction materials

5.2.1 Cooling towers

5.2.1.1 Small cooling tower basins may be made of uncoated, plastic-coated, galvanized low-carbon steel, or stainless steel. Large tower basins are usually concrete. Splash fill may 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 Special requirements for film fill

5.2.2.1 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 must flow, and thereby improves evaporation efficiency. However, the increased surface area also encourages deposit formation in the fill.

5.2.2.2 Deposits may consist of mineral scales formed by evaporation of water, corrosion products and silt carried into the tower, and microbiological deposits. 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 may “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.

5.2.2.3 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.

5.2.2.4 The condition of film fill in an operating cooling tower can be monitored by using a “fill test box.” This is simply a section of fill, roughly a 0,6 m (2 ft) cube, enclosed in a supporting box open at the top and bottom. The box is exposed to the “rain” falling below the fill in the cooling tower, in an accessible location. A slippery feeling on the fill surfaces, or appearance of a visible deposit layer, indicates fouling conditions in the fill.

5.2.2.5 A fill test box is a very useful qualitative monitoring tool in an operating cooling tower, but because of space and size limitations, it may not be practical in a pilot cooling tower. In such cases, 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

5.2.3.1 Circulating water lines may be carbon steel, copper, brass, fiberglass, polyethylene or cement-lined. Unless process-side conditions dictate otherwise, heat exchanger shells are usually made of carbon steel.

5.2.3.2 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: localized corrosion of piping systems can lead to unexpected failures; and corrosion product deposits can accumulate on heat-transfer surfaces, leading to losses in efficiency and opportunities for underdeposit corrosion. 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 underdeposit corrosion.

5.2.4 Heat exchangers

5.1.4.1 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.

5.2.4.2 Heat exchangers are designed with a built-in *fouling factor* [1)] 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 provides more opportunity for suspended solids to settle on the tube surfaces and for mineral scale deposits to form. Both of these effects lead to losses in heat-transfer efficiency and increased opportunities for corrosion of the tubes. See also 9.3.1.

5.2.4.3 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 may be made of carbon steel, copper, copper alloys, or UNS [2)] S30400 and S31600 (types 304 and 316 stainless steels). If required in petrochemical plants or other locations with severe process-side conditions, heat-transfer tubes may include a wide variety of other alloys and a few nonmetallic materials.

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

5.2.4.5 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 part of ISO 16784. This is especially true of vertical shell-side water heat exchangers.

NOTE As stated in the fourth paragraph of the Scope, shell-side heat exchangers are specifically excluded from this part of ISO 16784.

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1) *Fouling factor* or *fouling thermal resistance* refers to the measured resistance to heat transfer caused by a deposit on a heat-transfer surface. *Fouling factor* is also used in heat-exchanger design to increase the heat-exchanger surface area to compensate for the thermal inefficiency expected to occur due to a deposit on the heat-transfer surface. The term *fouling factor* is commonly used for both. However *fouling thermal efficiency* may be substituted for the measured fouling factor.

2) Metals and Alloys in the Unified Numbering System (latest revision), a joint publication of the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers Inc. (SAE), 400 Commonwealth Dr., Warrendale, PA 15096.

5.2.4.6 Many plant heat exchangers include multi-tube and multi-pass designs. Such designs are difficult to simulate in a pilot-scale unit. This part of ISO 16784 refers to single-tube, single-pass designs with parameters selected to simulate the conditions under study in the plant exchanger.

6 Operating parameters

6.1 General

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

6.2 Surface temperature

6.2.1 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.

6.2.2 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, and the design data for the heat exchanger.

6.3 Water velocity

6.3.1 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 bicarbonate), dissolved ions (the corrosive species in most cooling water systems), foulants including suspended solids, and the chemical additives designed to control fouling and corrosion.

6.3.2 Increasing water velocity normally helps to control both fouling and corrosion. Flow rates between about 1,0 m/s and 2,5 m/s (3 and 8 ft/s) are common. Excessive velocity may cause flow-assisted corrosion, depending on the tube metallurgy. Lower velocities may be required to closely simulate specific plant heat exchangers operating with velocities lower than 1 m/s (3 ft/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

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 must be considered when designing specific pilot cooling water test facilities. The quality of the available make-up water may vary seasonally, or may be drawn from several different sources. Such variations should be considered.