Designation: D4778 – 15

Standard Test Method for Determination of Corrosion and Fouling Tendency of Cooling Water Under Heat Transfer Conditions[1]

This standard is issued under the fixed designation D4778; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method provides directions for fabricating and operating a test apparatus to simultaneously monitor the corrosion and fouling tendency of real and pilot cooling water systems under heat transfer conditions.

1.2 Interpretation of the results of this test method must be left to the investigator. Many variables are involved which may not be easily controlled or fully understood. Variations in design and operating conditions may produce results that are not comparable from unit to unit.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1129 Terminology Relating to Water
D2331 Practices for Preparation and Preliminary Testing of Water-Formed Deposits
D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G16 Guide for Applying Statistics to Analysis of Corrosion Data

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this standard, refer to Terminology D1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *corrosion, n*—the deterioration of the metal by reaction with its environment.

3.2.2 *fouling, n*—deposition of organic matter or inorganic matter, or both, on heat transfer surfaces that result in the loss of heat transfer efficiency.

3.2.3 *heat flux, n*—heat transfer per unit area per unit time.

4. Summary of Test Method

4.1 Water from the system to be tested flows across a heated tube of the desired metallurgy at a constant flow rate and heat flux. Corrosion rate is determined by weight loss while fouling tendency is determined by the deposit weight.

5. Significance and Use

5.1 Deposits on heat transfer surfaces reduce efficiency of the heat exchanger affected. A method for easily determining the corrosion and fouling tendency of a particular water under heat transfer conditions will allow the evaluation of changes in the various system variables such as heat flux, flow velocity, metallurgy, cycles-of-concentration, and treatment schemes on heat exchanger performance.

6. Apparatus (Fig. 1)

6.1 *Test Specimen*—A metal tube of ⅜ or ½ in. (9.5 or 12.5 mm) outside diameter with sufficient inside diameter to snuggly accommodate the cartridge heater. The tube should be cut to a length sufficient to extend ½ in. (12.5 mm) from each end of the test assembly. If both corrosion and deposition are to be determined, metallurgy of the test specimen should match that of the heat exchanger being modeled.

6.2 *Cartridge Heater*—A ¼ or ⅜ in. (6.2 or 9.5 mm) diameter. Heated surface should be 4 to 8 in. (10 to 20 cm) long with a minimum power rating sufficient to provide 110 % of the heat load required (see Eq 7, 8.2.2). The heater should have

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[1] This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.03 on Sampling Water and Water-Formed Deposits, Analysis of Water for Power Generation and Process Use, On-Line Water Analysis, and Surveillance of Water.

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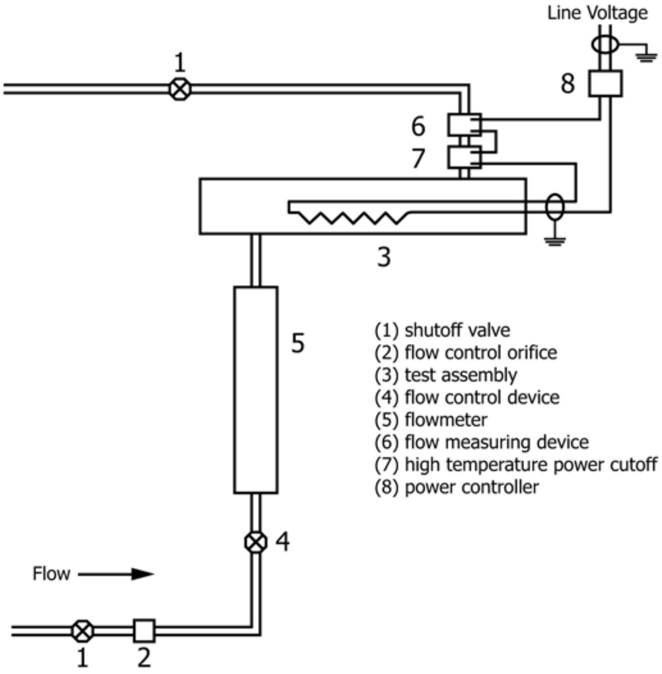
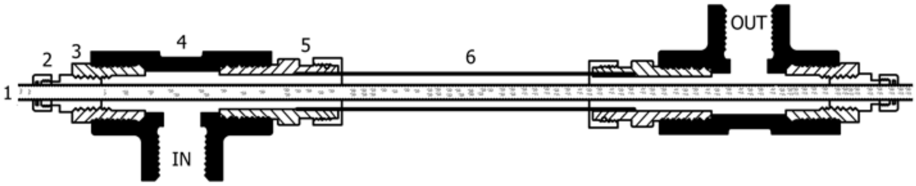
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



NOTE 1—All pipe is threaded 1 in. (25 mm) PVC. Heater should be fused and grounded in accordance with local electrical codes.

FIG. 1 Test Apparatus and Parts List



Parts List:
(1) test specimen

(2) tube fitting; nylon (no metal parts)
(3) reducing bushing, PVC
(4) tee, 1 in. (25 mm) PVC
(5) tube fitting, 1 in. (25 mm) tube by 1 in. (25 mm) male pipe thread stainless steel
(6) acrylic tube, 10 in. (25 cm) long by 1 in. (25 mm) outside Diameter
(7) Cartridge type heater (not shown)

FIG. 2 Test Assembly and Parts List

an unheated section of sufficient length to allow the center of the heated section to be placed consistently in the center of the test specimen.

6.3 *Power Controller*—A device to set and control the power to the heater, such as a variable transformer, is used to adjust the heat flux in order to maintain the surface temperature of the test specimen consistent with the heat exchanger being modeled. The power controller should be rated to maintain at least 120 %, but not more than 400 % of the power required.

6.4 *Flow Control*—A flow meter or a flow control device such as an orifice, or both, is recommended to maintain a consistent flow rate during the test period.

6.5 *Safety Equipment*—A pressure or flow sensor/controller is necessary to cut power to the heater in the event of a flow interruption. A high temperature cutoff is recommended for added protection.

6.6 *Test Assembly*—See Fig. 2.

7. Materials

7.1 *Vapor Phase Inhibitor Paper*—Envelopes constructed of vapor phase inhibitor paper.

8. Procedure

8.1 *Installation of Test Device:*

8.1.1 Placement of the test device with respect to the cooling water system is an important factor in monitoring fouling and corrosion in interpreting the test results. Fouling and corrosion are both affected by temperature. In the case of corrosion, the higher the water temperature, the greater will be the corrosivity of the water. Fouling, however, is a far more complex phenomenon, involving one or more of several types of foulants, namely, particulate matter, precipitates, biomass, corrosion products, and contamination. There are five phases involved in the fouling phenomenon: initiation, attachment, removal, transport, and aging.

8.1.2 Several of the foulants are temperature sensitive. Precipitates, such as calcium carbonate, tend to precipitate more rapidly as temperatures increase. Most biomasses, on the other hand, would agglomerate more rapidly at temperatures between 90 and 105°F (32.2 and 40°C).

8.1.3 The test device may be installed to take its inlet water from one of three locations: cold water supply to a heat exchanger, a heat exchanger outlet, or warm water return to the cooling tower. The choice of location is a function of the type of fouling problem(s) experienced with the particular system. No matter where it is placed, the fouling conditions in the test device should simulate the plant equipment as closely as possible. Specifically, the surface or interface temperature and the shear stress of the water film against the heated surface in the test device should be the same as in the plant equipment being monitored.

8.2 *Determination of Setup Conditions:*

8.2.1 Calculate plant heat exchange conditions as follows:

$$V_p = 0.408(F_p)P/(D^2N) \qquad (1)$$

where:

V = water velocity, ft/s,
$_p$ = process,
F = water flow rate, gal/min,
P = number of passes,
D = inside diameter of tubes in process heat exchanger, in., and
N = number of tubes in process heat exchanger.

$$(q/A)_p = 1910(T_o - T_i)(F_p)/(DLN) \qquad (2)$$

where:

q/A = heat flux on inner tube, Btu/h/ft ^{2},
$_p$ = process,
T = temperature,° F,
$_o$ = outlet water,
$_i$ = inlet water,
F = water flow rate, gal/min,
D = inside diameter of tube in process heat exchanger, in.,
L = length of heater section, ft, and
N = number of tubes in process heat exchanger.

8.2.2 Calculate the test device setup as follows:

$$V_t = [V_p][D/(d_2 - d_1)] \qquad (3)$$

where:

V = water velocity, ft/s,
$_t$ = test device,
$_p$ = process,
D = inside diameter of tube in process heat exchanger, in.,
d_2 = inside diameter of outer tube in test device, in., and
d_1 = outside diameter of inner (heated) tube in test device, in.

$$F_t = 2.45V_t(d_2^{\,2} - d_1^{\,2}) \qquad (4)$$

where:

F = water flow rate, gal/min,
$_t$ = test device,
V = water velocity, ft/s,
d_2 = inside diameter of outer tube in test device, in., and
d_1 = outside diameter of inner (heated) tube in test device, in.

$$W = 9.8(T_s - T_b)V^{0.8}L(1 + 0.096T_b) \ (\text{for } d_1 = 0.50) \qquad (5)$$

where:

W = power supplied to heater, W,
T = temperature, °F,
$_s$ = surface or interface,
$_b$ = bulk water, and
V = water velocity, ft/s,
L = length of heater section, ft, and
d_1 = outside diameter of inner (heated) tube in test device, in.

$$W = 7.94(T_s - T_b)V^{0.8}L(1 + 0.096T_b) \ (\text{for } d_1 = 0.375) \qquad (6)$$

where:

W = power supplied to heater, W,
T = temperature, °F,
$_s$ = surface or interface,
$_b$ = bulk water,
V = water velocity, ft/s,
L = length of heater section, ft, and
d_1 = outside diameter of inner (heated) tube in test device, in.

$$E = (WR)^{0.5} \qquad (7)$$

where:

E = voltage of heater, V,
W = power supplied to heater, W, and
R = resistance of heater, ohm.

8.3 *Preparation of Test Specimen:*

8.3.1 Remove all metal burrs from each end of the tube with a file or emery belt.

8.3.2 Thoroughly degrease the tube inside and out in accordance with Practice G1, and brush to remove adherent grease or metal grit.

8.3.3 Dry with a clean cloth and store in a desiccator until dry.

8.3.4 Weigh the clean dry specimen to the nearest milligram.

8.3.5 Store the weighed specimen in a suitable manner (protective atmosphere) to prevent atmospheric corrosion during storage and in transit. Vapor phase inhibitor paper is suitable for this purpose.

8.4 *Assembly of Test Apparatus:*

8.4.1 Install earth ground to test apparatus and secure in accordance with local electrical codes.

8.4.2 Remove test specimen from protective atmosphere.

8.4.3 Insert cartridge heater into test specimen to prescribed depth.

Note 1—If the fit is not snug, hot spots may occur and the heater life may be significantly shortened.

8.4.4 Assemble test specimen/cartridge heater into test apparatus using nylon fittings such as Swagelok. Connect heater leads to voltage control device.

8.4.5 Flush inlet water line for 10 min to remove any foreign matter.

8.4.6 Connect inlet and outlet water lines.

8.4.7 Turn water on and adjust flow to that calculated in Eq 4, 8.2.2.

8.4.8 Connect power controller to power source. Turn on power.

8.5 *Operation:*

8.5.1 A minimum test period of 14 days is recommended. A period of 30 to 60 days is preferable in order to more accurately evaluate corrosion and deposition.

8.5.2 Maintain flow and power as constant as possible during the test period, making frequent small adjustments rather than infrequent, but large adjustments when and if fluctuations do occur. Keep a log of all changes and adjustments.

8.6 *Analysis:*

8.6.1 At the end of the test period, turn off power and disconnect power controller from power source. Then slowly shutdown water flow.

8.6.2 Carefully drain water from test apparatus to prevent disruption of deposit film.

8.6.3 Remove the test specimen from the apparatus without disturbing deposit film. Note the deposit characteristics such as volume, thickness, color, and appearance. Photograph the deposit where possible.

Note 2—If there is any delay in transporting the test specimen to the laboratory where the analysis will be performed, then it should be placed in a protective atmosphere in the interim period.

8.6.4 Dry the specimen in a desiccator to constant weight. Weigh to the nearest milligram.

Note 3—Deposit may flake off during drying. Place a long sheet of paper under the specimen to collect any fallen deposit and add the weight of this deposit to the test specimen weight.

8.6.5 If the deposit is to be analyzed for composition, remove as much of it as possible with a plastic knife and add to it the deposit collected in 8.6.4. Chemical analysis of the deposit may be performed in accordance with Practices D2331, but this step is optional.

8.6.6 Clean the test specimen as well as possible with a plastic knife. Remove oily deposits in accordance with Practice G1. Remove remaining loose deposits from the specimen by wiping with a soft cloth or bristle brush. If the test specimen is clean, proceed to 8.7. If adherent deposits remain, remove the deposits in accordance with Practice G1.

8.6.6.1 Dry with paper towels followed by warm air drying.

8.6.6.2 Subject a weighed blank coupon of the same metallurgy to the identical cleaning procedure used for the test specimen and reweigh to determine the blank correction factor to be applied to the weight losses.

8.7 After drying, reweigh a clean tube to the nearest milligram.

9. Calculation

9.1 Calculate the deposit weight by subtracting the weight of cleaned test specimen from the weight of specimen with deposit as follows:

$$W_d = W_2 - W_1 \tag{8}$$

where:

W_d = weight gain due to deposition, mg,
W_2 = weight of test specimen with deposit, mg, and
W_1 = initial weight of test specimen, mg.

9.2 Calculate the metal weight loss by subtracting the weight of the cleaned test specimen from the initial specimen weight and correcting for the change in weight of a blank after cleaning as follows:

$$W_c = W_1\left[1 - \left(W_4 - W_5\right)/W_4\right] - W_2 \tag{9}$$

where:

W_c = weight loss due to corrosion, mg,
W_1 = initial weight of test specimen, mg,
W_4 = initial weight of blank specimen, mg,
W_5 = weight of cleaned blank specimen, mg, and
W_2 = weight of test specimen with deposit, mg.

9.3 Calculate the average corrosion rate for the test specimen as follows:

$$X_c = \left(7.09\,W_c\right)/\left(d_1 L_e Z t\right) \tag{10}$$

where:

X_c = average corrosion rate, mills/yr,
W_c = weight loss due to corrosion, mg,
d_1 = outside diameter of test specimen, in.,
L_e = total length of exposed test specimen, in.,
t = exposure time, days, and
Z = density of metal (see Table 1), g/cm ^{3}.

9.4 Calculate the average rate of fouling for the test specimen as follows:

$$X_d = \left(0.0493\,W_d\right)/\left(d_1 L_h t\right) \tag{11}$$

where:

X_d = average rate of fouling, mg/cm ^{2}/day,
W_d = weight gain due to deposition, mg,
d_1 = outside diameter of test specimen, in.,
L_h = length of heated section, in., and
t = exposure time, days.

TABLE 1 Density of Metal

Metallurgy	Z
Admiralty brass	8.52
Copper	8.94
Carbon steel	7.86
304 stainless steel	7.94

10. Precision and Bias

10.1 The precision and bias of this test method are as specified in Practice G1. The precision and bias statement contained in Practice G1 is repeated in Appendix X1 for the benefit of the reader.

10.2 Because this standard is for a continuous sampling method, it is exempt from the requirement of a round-robin test in accordance with Practice D2777, paragraph 1.3.3.

11. Quality Control

11.1 The test specimens should come from a reliable and consistent source. The alloy must meet ASTM specifications.

11.2 All handling steps of the test specimens before and after service must be very consistent and repeatable. The specimens should not be handled with bare fingers. This can affect the results by transferring oils from the fingers to portions of the specimen. This can prevent consistent contact of the cooling water with all portions of the coupon surface.

11.3 The test is designed to be conducted at a single flow rate. However, process conditions may impact flow rate. Changes in process conditions can result in periods of low flow or even periods of no flow (stagnant conditions). Periods of low flow or stagnant conditions should be noted in the report.

11.4 After removal, the specimen should be air dried before being placed back in the envelope.

11.5 The accuracy of the analytical balance should be checked by weighing a calibrated weight.

12. Keywords

12.1 cooling water; corrosion; deposits; fouling; heat transfer

APPENDIX

(Nonmandatory Information)

X1. PRECISION AND BIAS STATEMENT FROM PRACTICE G1

X1.1 The factors that can produce errors in mass loss measurement include improper balance calibration and standardization. Generally, modern analytical balances can determine mass values to ±0.2 mg with ease and balances are available that can obtain mass values to ±0.02 mg. In general, mass measurements are not the limiting factor. However, inadequate corrosion product removal or overcleaning will affect precision.

X1.2 The determination of specimen area is usually the least precise step in corrosion rate determinations. The precision of calipers and other length measuring devices can vary widely. However, it is not generally necessary to achieve better that ±1 % for area measurements for corrosion rate purposes.

X1.3 The exposure time can usually be controlled to better than ±1 % in most laboratory procedures. However, in field exposures, corrosive conditions can vary significantly and the estimation of how long corrosive conditions existed can present significant opportunities for error. Furthermore, corrosion processes are not necessarily linear with time, so the rate values may not be predictive in the future deterioration, but only are indications of the past exposure.

X1.4 Regression analysis on results, as are shown in Fig. 1 (of Practice G1) can be used to obtain specific information on precision. See Guide G16 for more information on statistical analysis.

X1.5 Bias can result from inadequate corrosion product removal or metal removal caused by overcleaning. The use of repetitive cleaning steps, as shown in Fig. 1 (of Practice G1), can minimize both of these errors.

X1.6 Corrosion penetration estimations based on mass loss can seriously underestimate the corrosion penetration caused by localized processes such as pitting, cracking, crevice corrosion, and so forth.