



Standard Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Methods)¹

This standard is issued under the fixed designation D 2688; 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.

^{e1} NOTE—Footnotes were editorially removed in July 1999.

1. Scope

1.1 These test methods cover the determination of the corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. Pitting is a form of localized corrosion: weight loss is a measure of the average corrosion rate. The rate of corrosion of a metal immersed in water is a function of the tendency for the metal to corrode and is also a function of the tendency for water and the materials it contains to promote (or inhibit) corrosion.

1.2 The following two test methods are included:

Test Method	Corrosivity Test of	Sections
A	Internal Metallic Pipes (Coupon)	10 to 18
B	City and Building Distribution Water (1, 2, 3, 4, 5) ²	19 to 30

1.3 *Test Method A* employs flat, rectangular-shaped metal coupons which are mounted on pipe plugs and exposed to the water flowing in metal piping in municipal, building, and industrial water systems.

1.4 *Test Method B* employs removable, tared pipe inserts which are installed in a plastic piping assembly tailored to provide the same surface and flow conditions as in a normal metal piping system. Proper dimensions are provided throughout so that streamline flow (no-flow distortion) results and corrosion and scale formed on the inserts will be the same as that occurring in the metal piping system being tested. Steel, galvanized steel, and soldered copper and copper inserts have been found to provide meaningful corrosion test results by this test method.

1.5 *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.* For a specific hazard statement, see 26.1.1.

¹ These test methods are under the jurisdiction of ASTM Committee D-19 on Water and are the direct responsibility of Subcommittee D19.03 on Sampling of Water and Water-Formed Deposits, and Surveillance of Water.

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

2. Referenced Documents

2.1 ASTM Standards:

- A 120 Specification for Pipe, Steel, Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless, for Ordinary Use³
- D 1129 Terminology Relating to Water⁴
- D 1193 Specification for Reagent Water⁴
- D 2331 Practices for Preparation and Preliminary Testing of Water-Formed Deposits⁵

3. Terminology

3.1 *Definitions:* —For definitions of terms used in these test methods, refer to Terminology D 1129.

4. Significance and Use

4.1 Since the two tendencies are inseparable for a metal to corrode and for water and the materials it contains to promote or inhibit corrosion, the corrosiveness of a material or the corrosivity of water must be determined in relative, rather than absolute, terms. The tendency for a material to corrode is normally determined by measuring its rate of corrosion and comparing it with the corrosion rates of other materials in the same water environment. Conversely, the relative corrosivity of water may be determined by comparing the corrosion rate of a material in the water with the corrosion rates of the same material in other waters. Such tests are useful, for example, for evaluating the effects of corrosion inhibitors on the corrosivity of water. Although these test methods are intended to determine the corrosivity of water, they are equally useful for determining corrosiveness and corrosion rate of materials.

5. Composition of Specimens

5.1 The specimens shall be similar in composition to the piping in the system in which the corrosion test is being made. Welded or seamless pipe shall be used in Test Method B; however, butt-welded piping specimens may be used in Test

³ Discontinued 1988 (Replaced by A 53)—See 1988 *Annual Book of ASTM Standards*, Vol 01.01.

⁴ *Annual Book of ASTM Standards*, Vol 11.01.

⁵ *Annual Book of ASTM Standards*, Vol 11.02.

Method B provided care is taken to pick smooth specimens (excluding butt joints).

6. Effect of Cold Working on Corrosion

6.1 Cold working can be important in causing localized corrosion; however, plastic deformation can be minimized in specimen preparation by following proper machining practices (6) (for example, drilling, reaming, and cutting specimens for Test Method A). While the importance of proper preparation and machining is recognized in the other test methods, it is considered important to retain stressed areas in the piping inserts (Test Method B) since these specimens then have the same properties as the piping system being tested.

7. Types of Corrosion

7.1 *General Corrosion* is characterized by uniform attack of the metal over the entire surface.

7.2 *Pitting* is a form of localized corrosion, the depth, number, size, shape, and distribution of pits being pertinent characteristics. It may be evaluated by counting the number, by noting the size, shape, and distribution, and by measuring the depth of pits in representative areas. Both sides of the coupons must be examined in Test Method A. In Test Method B the specimens must be cut longitudinally before internal examination for pitting can be performed.

7.2.1 A system may be devised for grading pitting (7).

7.3 *Crevice Corrosion* is a pertinent factor to consider in corrosion testing, since active corrosion sites may develop in such locations. Crevices may exist at threads and joints and under deposits, as well as in corrosion specimens. In Test Method A, crevice corrosion may be in evidence where the specimen is fastened to the holder and at coupon markings. Providing a large specimen surface area relative to the crevice area reduces this influence on the overall corrosion results. Light sanding is necessary to remove edges of coupon marking. In Test Method B, areas subject to crevice corrosion are coated with paint.

7.4 *Edge Corrosion*— The increased corrosion that occurs at edges of corrosion specimens, where the metal may be of different composition or structure, must be given attention. In Test Method A, specimens of a high ratio of surface area to edge area reduce this effect. In Test Method B, the edges are painted to prevent fluid contact. If an abnormally high degree of edge corrosion is observed in the case of Test Method A, the effect may be evaluated by measurement of the specimen dimensions previous to and following exposure. Use of a specimen of less thickness may also reduce the edge effect in weight loss.

7.5 *Impingement Attack (Erosion-Corrosion)*, associated with turbulent and high-velocity flow, particularly when soft metals and copper are involved, is characterized by continuous broader-type pits and bright metal from which protective films have been scoured away. Some under-cutting also may be present.

8. Water-Formed Deposits

8.1 Water-formed deposits observed on the specimens may be analyzed by the methods listed in Practices D 2331. The most common constituents will be calcium, magnesium, aluminum, zinc, copper, iron, carbonate, phosphate, sulfate, chloride, and silica.

9. Purity of Reagents

9.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁶ Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

9.2 *Purity of Water*— Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Type III of Specification D 1193.

TEST METHOD A—Coupon

10. Summary of Test Method

10.1 Carefully prepared, weighed metal coupons are installed in contact with flowing cooling water for a measured length of time. After removal from the system, these coupons are examined, cleaned, and reweighed. The corrosivity and fouling characteristics of the water are determined from the difference in weight, the depth and distribution of pits, and the weight and characteristics of the foreign matter on the coupons.

11. Interferences

11.1 Deviation in metal composition or surface preparation of the coupons may influence the precision of the results.

11.2 The presence of different metals in close proximity to the coupon, (within 76 mm (3 in.)), even if they are insulated from the coupon, constitutes a source of error in the results.

11.3 Deviations in the velocity and direction of flow past the coupons may influence the precision of the results.

11.4 Results are directly comparable only for the water temperature to which the coupon is exposed.

11.5 Crevices, deposits, or biological growths may affect local corrosivity; results should therefore be interpreted with caution.

12. Apparatus

12.1 *Coupon Specimens*— Prepare coupons in accordance with Section 14.

⁶ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

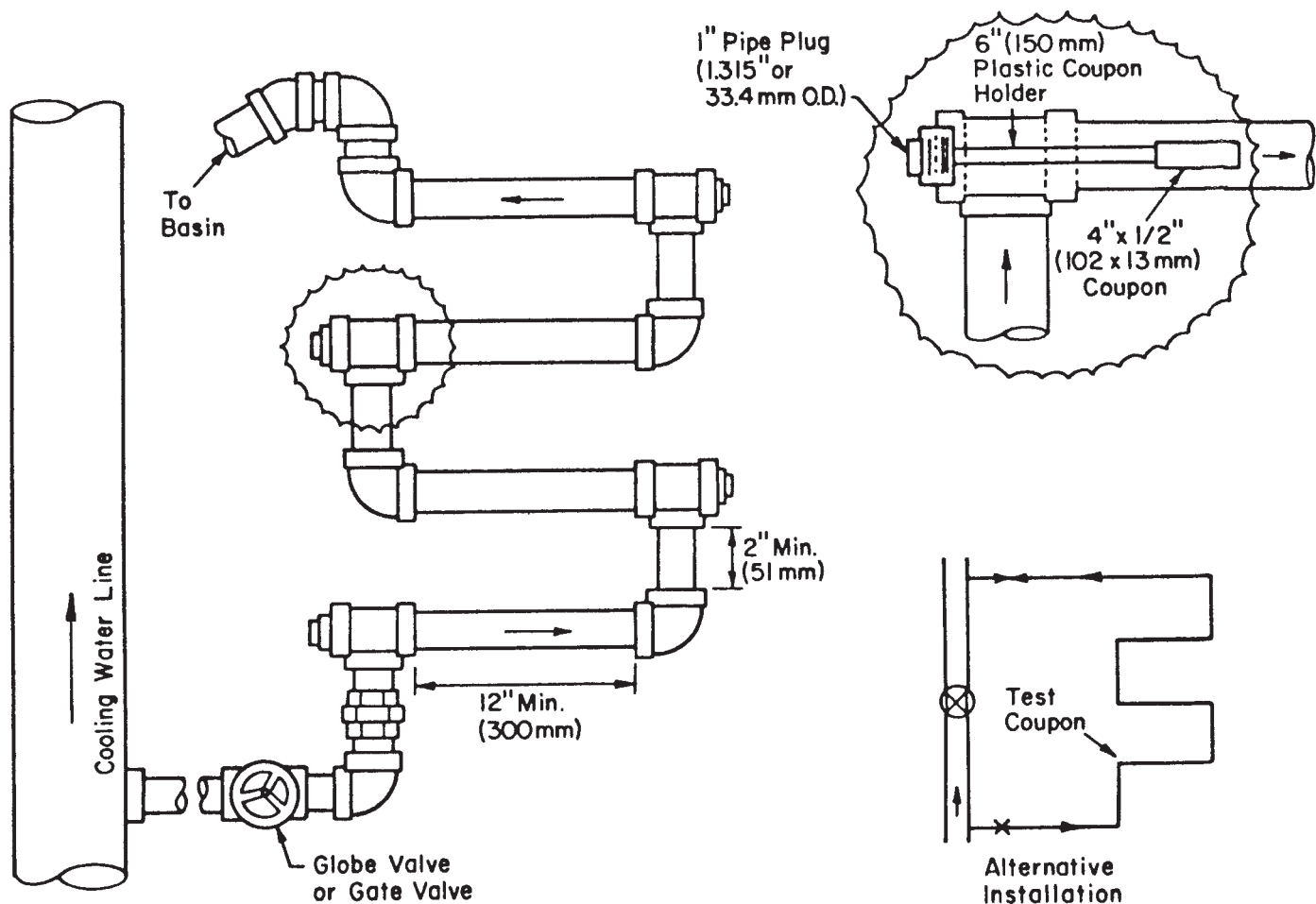


FIG. 1 Installation of Corrosion Coupons

12.2 *Insulating Washer, Screw, and Nut*—Use for attaching the coupon to the phenolic rod. The insulating washer has a sleeve that fits into the coupon hole and around the screw.^{7,8}

12.3 *Phenolic Rod*—Use a 152-mm (6-in.) length of canvas-based 13-mm (0.5-in.) outside diameter phenolic rod, or equivalent, attached at one end to a drilled pipe plug, and having a flat surface and a hole at the other end suitable for attachment of the coupon.⁹

12.4 *Piping Arrangement*, as illustrated in Fig. 1, for installation of coupon specimens. This arrangement has been changed in order that flow passes over the holder end of the

specimens first at two locations and over the specimen first at the other two locations. This enables one to determine whether the turbulence provided by the corrosion testers or the elbows influences the results.

12.5 *Dial Depth Gage*—A gage with a knife-edge base, pointed probe, and dial indicator for measurement of pit depth.

12.6 *Emery Paper*, Number 0.

13. Reagents and Materials

13.1 *Benzene*.

13.2 *Chromic Acid-Phosphoric Acid Solution*—Dissolve 30 g of chromic acid (chromium trioxide, CrO_3) in approximately 500 mL of water and add 36 mL of phosphoric acid (H_3PO_4 35 %). Dilute the resulting solution to 1L.

13.3 *Chromium Trioxide* (CrO_3), anhydrous crystals.

13.4 *Corrosion Inhibitor I*, a liquid material having a flash point of 71°F, which contains amino ketones of rosin, surface active agents, alcohols, and less than 10 % by volume of synergists, for hydrochloric acid.

13.5 *Corrosion Inhibitor II*, a nonflammable liquid containing heterocyclic nitrogen bases (usually in the form of salts), surface active agents, and synergists, for sulfuric acid.

13.6 *Hydrochloric Acid* (1 + 4)—Mix 1 volume of concentrated HCl (sp gr 1.19) with 4 volumes of water.

⁷ Allied Industrial Electronics, 100 N. Western Ave., Chicago, IL 60680, extruded fiber washer for No. 8 screw, Part No. 26D-3226, manufactured by G. C. Electronics, Rockford, IL (as Part No. 6526C), has been found satisfactory for this purpose. The dimensions are as follows: outside diameter 9.5 mm ($\frac{3}{8}$ in.), inside diameter of hole 4.0 mm ($\frac{5}{32}$ in.), total thickness including the raised are approximately 1.5 mm ($\frac{1}{16}$ in.), outside diameter of raised are 6.4 mm ($\frac{1}{4}$ in.), and thickness of raised are approximately 0.4 mm ($\frac{1}{64}$ in.).

⁸ It may be preferred to obtain the complete corrosion tester and coupons from Metal Samples, P.O. Box 8, Mumfords, AL 36268, who construct the rod from TFE-fluorocarbon or nylon, include a screw made from this same material and avoid the necessity of including a washer and nut by providing screw threads in the mounting.

⁹ Phenolic rod meeting the National Electrical Manufacturers Association (NEMA) Grade CE or LE is satisfactory. The pipe plug is marked externally to permit orientation of the coupon as desired.

13.7 *Hydrochloric Acid, Inhibited*—Mixed 357 mL of concentrated HCl (sp gr 1.19) and 5.0 g of inhibitor (see 13.4). Then dilute to 1 L with water.

13.8 *Isopropyl Alcohol*.

13.9 *Methyl Orange Indicator Solution* (0.5 g/L)—Dissolve 0.05 g of methyl orange in water and dilute to 100 mL with water.

13.10 *Nitric Acid-Dichromate Solution*—Mix 224 mL of HNO₃ (sp gr 1.42) with twice the volume of water. Add 22.75 g of sodium dichromate (Na₂Cr₂O₇·H₂O) and dissolve. Dilute the resulting solution to 1 L.

13.11 *Sulfuric Acid, Inhibited*—Slowly add 29 mL of H₂SO₄ (sp gr 1.84) to approximately 500 mL of water. Add and dissolve 0.5 g of Inhibitor II (see 13.5). Dilute the resulting solution to 1 L with water.

13.12 *Trichloroethylene*.

13.13 *Tripoli*—Finely granulated, porous, siliceous rock; amorphous silica (SiO₂), soft, porous, and free of sharp edges or other suitable erosive-type cleaning agent.

13.14 *Vapor Phase Inhibitor Paper*.

14. Coupon Preparation

14.1 In this procedure, coupons are to be made principally from sheet metal; however, in a few cases, as with cast iron or cast bronze, it may be necessary to prepare coupons from castings.

14.2 Use a coupon size of 13 by 76 by 1.6 mm (0.5 by 3.0 by 0.0625 in.) for all sheet metals; and a 13 by 76 by 3 mm (0.5 by 3.0 by 0.125 in.) for cast metals. Other sizes are suitable, providing the total area is about 259 mm² (4 in.²), the principal requirement being to keep the flat area large compared to the edge area.

14.3 *Sheet Metal Coupon Preparation*—Obtain sheet metal of the type desired except for stainless steel; use cold-rolled steel free of rust spots for ferrous metal. Obtain stainless steel with a No. 4 finish.¹⁰

14.3.1 Shear 14-gage sheet metal material to the dimensions of 13 by 75 mm (0.5 by 3.0 in.).

14.3.2 Drill or punch a 5-mm (0.019-in.) hole with its center about 3 mm (1/8 in.) from one end of the coupon.

14.3.3 Deburr all sharp edges on the coupon specimen using a file or emery belt, and deburr the hole with an oversize drill.

14.3.4 Stamp identifying numbers or letters on the coupon area below the mounting hole.

14.4 *Cast Metal Coupon Preparation*—Obtain rough castings of the desired metal, measuring about 19 by 114 by 6 mm (3/4 by 4 1/2 by 1/4 in.) from a commercial foundry or elsewhere.

14.4.1 Surface grind to the dimensions of 13 by 102 by 3 mm (0.5 by 4.0 by 0.125 in.) and a surface roughness of about 124 μin.

14.4.2 Drill a 7-mm (9/32-in.) hole with its center about 8 mm (5/16 in.) from one end of the coupon.

14.4.3 Deburr all sharp edges on the coupon specimen using a file or emery belt, and deburr the hole with an oversize drill.

14.4.4 Stamp identifying numbers or letters on the small coupon area between the edge and the mounting hole.

14.4.5 The approximate weight of metal coupons, g, is as follows:

Steel	10.35
Cast Iron	11.65
Copper	13.33
Zinc	8.7
Lead	16.80

14.5 *Cleaning Ferrous Metal Coupons*—Remove oil by immersion in benzene. Dry. Immerse in a solution containing HCl (1 + 4) for 30 min at room temperature.

14.5.1 Remove acid from the coupon by three rapid successive rinses in separate water baths; the last rinse water bath shall contain methyl orange solution and must be kept neutral (yellow). The first and second bath must be renewed frequently. Rinse successively in isopropyl alcohol and benzene, and dry with a clean cloth. Store in a desiccator.

14.6 *Cleaning Copper, Brass, and CuproNickel Coupons*—Clean, dry, and store coupons exactly as for ferrous coupons (see 14.5).

14.7 *Cleaning Stainless Steel Coupons*—Degrease with benzene, dry with a clean cloth, and passivate by immersing in nitric acid-dichromate solution (see 13.12) at 43 to 49°C (110 to 120°F) for 15 to 30 min; rinse with water, then benzene, dry with a clean cloth, and store in a desiccator.

14.8 *Cleaning Aluminum Coupons*—Degrease with benzene and dry. Immerse in HNO₃ (sp gr 1.42) for a minimum of 3 min at room temperature. Rinse with water twice, once with isopropyl alcohol; and finally with benzene. Dry with a clean towel and store in a desiccator. If coupon is not visibly clean, repeat the procedure using submerged scrubbing with a fiber bristle brush in the water rinse.

14.9 *Cleaning Zinc or Galvanized Steel Coupons*—If the surface is free of oxide, degrease with benzene, dry with a clean towel, and store in a desiccator. If oxide is present, polish with No. 0 emery paper, scrub in isopropyl alcohol using a stiff fiber brush, and rinse in benzene. Dry and store in a desiccator.

14.10 *Cleaning Lead Coupons*—(Specimens shall be handled gently with plastic-tipped tweezers). First, rinse in deionized water, then immerse in glacial acetic acid for 30 s. Rinse off the acid with flowing deionized water for 30 s; immerse in acetone for 15 s; dry by laying on dry towel; store in a desiccator for 1 h before weighing to 0.1 mg.

15. Procedure

15.1 Weigh the clean, dry specimens on an analytical balance to the nearest 0.1 mg.

15.2 After weighing, store the specimens in a desiccator until ready for use. If storing in a desiccator is inconvenient or impractical, use an alternative method for providing a corrosion-free atmosphere.

15.3 Store ferrous metal coupons in separate envelopes made from vapor phase inhibitor-impregnated paper. Store nonferrous metal coupons in sealed plastic envelopes or wrapped in plastic film.

15.4 Attach the coupon to the phenolic rod, using an insulating washer to preclude any contact of coupon with the screw and nut assembly (see Specification A 120). For added

¹⁰ *Metals Handbook*, Vol 1, American Society for Metals, Metals Park, OH 44073, 1961, p. 430.

protection, attach the specimen to the holder using a screw and nut of the same metal composition as the coupon.

15.5 Install the holder and coupon assembly in a suitable line or in a bypass piping arrangement as shown in Fig. 1.

15.6 Adjust the rate of flow of water in the test piping to a rate that gives a flow velocity that corresponds to the normal flow in those parts of the system under prime consideration. Normally, the flow velocity will be in the range from 0.6 to 1.8 m (2 to 6 ft)/s. Check and readjust the flow as necessary to maintain the desired rate.

15.7 Remove specimens from the system at chosen intervals. Since the corrosion will be high initially and then fall to a lower, nearly constant rate, two time series should be chosen.

15.7.1 Use short time intervals for the first time series in order to establish the rate at which passivity occurs. Removal of three or four sets of coupons at 4- to 7-day intervals is recommended.

15.7.2 Use long time intervals for the second time series in order to establish the mean steady-state corrosion rate. Removal of the first coupons after 1 month and the remaining coupons at 1 to 3-month intervals is recommended.

15.8 Protect the specimen if it cannot be examined, cleaned, and reweighed immediately after removal from the system. Dry between paper towels. Store the ferrous metal coupons in separate envelopes made from vapor phase inhibitor-impregnated paper or wrap carefully in plastic film. For nonferrous metal coupons, wrap carefully in plastic film. The interim period between removal of specimens and reweighing should be kept to a minimum and in no case should it exceed 1 week.

15.9 Examine the specimen and record either by photograph or by description the appearance of the specimen, paying particular attention to the amount and nature of any adherent deposit. Chemical analysis of the deposit may be performed, but this step is optional.

15.10 For ferrous coupons, use one of the following alternative procedures for cleaning the coupon prior to reweighing.

15.10.1 Clean the coupons as well as possible with a plastic knife. Remove oily and greasy deposits by soaking in trichloroethylene. Remove remaining loose corrosion products by brushing with a bristle brush. Immerse the specimens in inhibited acid, using either of the following two techniques.

15.10.1.1 Immerse the specimens in inhibited HCl (1 + 1.8) for 30 s at room temperature.

15.10.1.2 Immerse the specimens in inhibited H₂SO₄ (1 + 34) at 71°C (160°F) with a direct current source imposed on the coupon as an anode, and lead as a cathode. The voltage should be 4 to 5 V and the current density 2.5 to 3.0 A per specimen. Keep the specimens in the bath for 3 to 5 min.

15.10.2 Rinse with water after removing specimens from the inhibited acid bath. Rub specimens with granular Na₃PO₄, then with tripoli. Rinse with water. Rinse with isopropyl alcohol. Dry between paper towels followed by warm air drying.

15.11 For copper to copper alloy coupons, use the following procedure for cleaning prior to reweighing. Clean the coupons as well as possible with a plastic knife. Remove oily or greasy deposits by soaking in trichloroethylene. Immerse the coupons

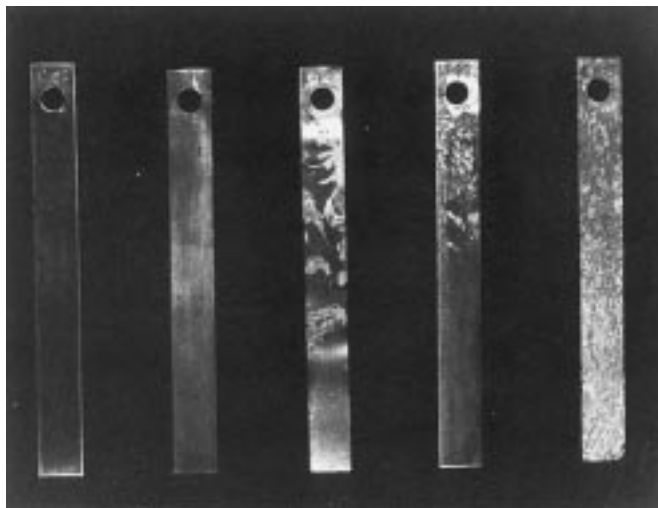


FIG. 2 Recording of Coupon Appearance

in inhibited HCl (1 + 1.8) for 30 s. Rinse coupons with water, rinse with isopropyl alcohol, and finally, rinse with benzene. Dry coupons between paper towels. Place in a desiccator for 1 h.

15.12 For aluminum or aluminum alloy coupons, use the following procedure for cleaning prior to reweighing. Clean the coupons as well as possible with a plastic knife. Remove oily or greasy deposits by soaking in trichloroethylene. Immerse the coupons in chromic acid-phosphoric acid solution (see 13.2) at room temperature for 30 min. Remove and rinse with water, rinse with isopropyl alcohol, and finally, rinse with benzene. Dry between paper towels. Place in a desiccator for 1 h.

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

15.14 Reweigh each coupon to the nearest 0.1 mg.

15.15 If pitting (see 7.2) is apparent on the coupon, measure the depth of the pits in a representative area with the dial depth gage. Record the resultant values as pit depths. The number, size, shape, and distribution of the pits shall also be determined and recorded.

15.16 Record the appearance of the cleaned, weighed coupon as “protected,” “moderate localized,” “moderate pitting,” or “severe pitting,” by comparing the coupon with the illustrations given in Fig. 2.

16. Calculation

16.1 Corrosion rates are normally calculated as an average penetration in mils per year or millimetres per year assuming that localized attack or pitting is not present and that the corrosion is general (8).

16.2 *Calculation of the Corrosion Rate:*

16.2.1 To calculate the corrosion rate (8, 9, 10) in mils per year for each coupon, use Eq 1:

$$\text{Corrosion Rate (mils per year, mpy)} = 22.3 \frac{W}{(dat)} \quad (1)$$

where:

W = weight loss, mg,
 d = density of the metal, g/cm³,
 a = exposed area of coupon, in.², and
 t = time, days.

16.2.2 To calculate the corrosion rate in micrometers per year for each coupon, use Eq 2:

$$\text{Corrosion Rate (micrometers per year, } \mu\text{m/y)} = 3650 W/(dat) \quad (2)$$

where:

W = weight loss, mg,
 d = density of the metal, g/cm³,
 a = exposed area of coupon, cm², and
 t = time, days.

16.3 The specific gravities of various metals (g/cm³) are:

Admiralty brass	8.17
Copper	8.9
Yellow brass	8.02
Aluminum	2.70
Low carbon steel	7.85
Lead	11.34

16.4 Calculate the pitting rate using Eq 3:

$$\text{Pitting rate, mils (mm) per year} = \text{maximum pit depth} \times 365/t \quad (3)$$

where:

t = exposure time, days.

16.5 To convert from mils per year to millimetres per year, multiply by 0.0254.

17. Interpretation of Results

17.1 It should be recognized that the following deviations between the coupons and the corresponding material of construction may lead to the following erroneous interpretations:

- 17.1.1 Deviations in composition or surface preparation,
- 17.1.2 Deviations in velocity and direction of flow, and
- 17.1.3 Deviations in crevices, deposits, or biological growths.

18. Precision and Bias

18.1 Precision is a function of each individual system. Therefore, a general statement regarding this property is not practical at this time.

18.2 This is a comparative type test, for which precision cannot be evaluated. There are many variables, such as velocity, temperature, water quality, and the presence of other metals that may influence the rate of corrosion of the coupons. As well, the composition of the test metal and the different forms of corrosion which can occur, such as general corrosion, pitting, and microbiological type, may affect the results appreciably.

TEST METHOD B—Pipe Inserts in Plastic Pipe (1, 2, 3, 4, 5)

INTRODUCTION

This method of corrosion testing in municipal distribution water systems has been used effectively for many years; however the assembly has been cumbersome and costly to prepare. Recently, several papers (1, 2, 3, 4, 5) have been presented which make the technique more practical, accord-

ingly, the test method has been rewritten to include these improvements. Essentially, the change is from exterior metal piping including a plastic sleeve for housing the inserts in a complete plastic (PVC)¹¹ body. This simplifies the construction and reduces machining costs. The basic unit is now generally a ¾-in. outside diameter (26.7-mm) assembly, rather than 1-in. (33.4-mm). Table 1 provides the dimensions for preparing ½-in. outside diameter (21.3-mm), ¾-in. outside diameter (26.7-mm), and 1-in. outside diameter (33.4-mm) assemblies.

19. Summary of Test Method

19.1 Removable pipe inserts are installed in plastic pipe connected by piping unions and are made part of the pipe system under test. Proper dimensions are provided throughout so that streamline flow (no-flow distortion) is provided in test assemblies in standard steel and galvanized and copper tubing. Interest is now being shown in testing corrosion resistance of other metals, such as lead, for example; however, at present, testing of the corrosion resistance of lead is confined to Test Method A, because the uniform preparation of lead pipe inserts is difficult and may not be reproducible. Soldered copper pipe inserts are presently being tested. Exposed inside surface of the piping is not altered, and the outside surface is painted to prevent corrosive attack since the crevice corrosion occurring there is not indicative of the corrosion desired to be measured. Loss in weight of the insert is a measure of the average corrosion per unit area. Examination of the surface is made to evaluate pitting. This test method may be used to determine the degree of corrosion occurring in a cold or hot distribution water system or cooling water system, to evaluate different methods of chemical treatment, and to determine the proper choice of a corrosion-resistant metal for the system.

20. Apparatus

20.1 *Tester Assembly*— The assembly consists of two inserts, constructed from a representative lot of ¾-in. outside diameter (26.7-mm) standard steel or galvanized pipe (Specification A 120) (reduced 0.030-in. (0.8-mm) in outside diameter by machining Schedule 40 galvanized pipe in order to fit desirably in the assembly) or copper piping. The inserts are held in place by ¾-in. outside diameter (26.7-mm) spacers, as shown in Fig. 3 and Fig. 4, in a 1-in. (33.4-mm) PVC union, socket type, installed in a typical ¾-in. (26.7-mm) service line. Recently, ½-in. (21.3-mm), ¾-in. (26.7-mm), and 1-in. (33.4-mm) testers have also been constructed according to Table 1 and Table 2 and installed in these sized lines. The U.S. Army Construction Research Laboratory (CERL) has developed (Fig. 5)¹¹ a pipe loop system including both Test Methods A and B plus a flow meter and water meter for better measuring the corrosion in a cold and hot water system.

20.2 *Dial Depth Gage*— See 12.5.

20.3 *Ultrasonic Cleaning Equipment*, 150-W, 6-qt (6-L) tank capacity to hold 2-L beaker.

21. Reagents and Materials

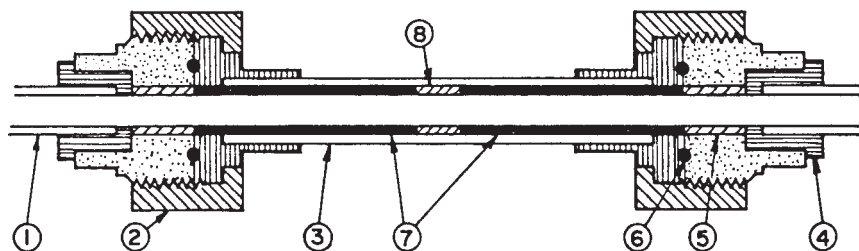
21.1 *Acetone*.

¹¹ PVC piping is specified to be PVC Type I, Grade I, Cell classification-12454-B and CPVC fittings, Type IV, Grade I, Cell classification 23477-B.

TABLE 1 Specifications for ISWS Type Corrosion Specimens

Materials of Construction			Specimen Dimensions			
Pipe size, in.	Class	Metal	Length, in.	Inside diameter, in.	Outside diameter, in.	Area, in. ²
1/2	Schedule 80, pipe	steel	4.00	0.546	0.625	6.86
	Schedule 80, pipe	galvanized	4.00	0.538 ^A	0.625	6.76
	Type L, tube	copper	4.00	0.545	0.625	6.85
3/4	Schedule 40, pipe	steel	4.00	0.824	1.050	10.35
	Schedule 40, pipe	galvanized	4.00	0.816 ^A	1.050	10.25
	Type L, tube	copper	4.00	0.824	1.050	10.35
1	Schedule 40, pipe	steel	4.00	1.049	1.125	13.18
	Schedule 40, pipe	galvanized	4.00	1.037 ^A	1.125	13.03
	Type L, tube	copper	4.00	1.025	1.125	12.88

^A Assumes a zinc coating thickness of 0.004 in.



- ① 3/4" (1.91 cm) PVC Service Line
- ② 1" (2.54 cm) Union, PVC, Socket Type, Sch 80
- ③ 1" (2.54 cm) x 10" (25.4 cm) Pipe Nipple, PVC, Sch 40
- ④ 1" (2.54 cm) x 3/4" (1.91 cm) Reducing Bushing, PVC, Socket
- ⑤ 3/4" (1.91 cm) PVC Spacer, Sch 40, Q.D. Reduced 0.015" (0.038 cm) If Needed, Reducing Union I.D. to Pipe I.D. to Hold Specimen in Place
- ⑥ O-Ring
- ⑦ Corrosion Specimens, 3/4" (1.91 cm) O.D. Reduced 0.030" (0.076 cm) Machined from Sch 40 Galvanized Steel or Steel Pipe
- ⑧ Specimen Separator, 3/4" (1.91 cm) PVC, Sch 40, O.D. Reduced 0.015" (0.038 cm). Length is Adjusted to Provide Flush Fit with Inner Faces of Union.

FIG. 3 Pipe Specimens (CERL)-3/4-in. (1.91-cm)

21.2 *Alicyclic Abietylamines*, formulated (including ethylene oxide adducts of these amines and nonphenyl and 5 % diethylthiourea in isopropanol solution), liquid corrosion inhibitor for sulfamic acid.

21.3 *Substituted Keto-amine Corrosion Inhibitor*¹², for hydrochloric acid.

21.4 *Hydrochloric Acid* (3 + 8), *Inhibited*—Add 465 mL of concentrated hydrochloric acid (HCl, sp gr 1.19) to 1200 mL of water, then add 4 mL of substituted keto-amine corrosion inhibitor (see 21.3), mix well, and dilute to 2 L.

21.5 *Sulfamic Acid*.

21.6 *Sulfamic Acid* (100 g/L), *Inhibited*—Dissolve 10 g of sulfamic acid (HSO₃NH₂) in 90 mL of water and dilute to 100 mL. Add 5 mL of alicyclic abietylamines (see 21.2) and mix.

21.7 *Trichloroethylene*.

21.8 *Passivating Stock Solution*—Dissolve 40 g of sodium nitrite (NaNO₂), 23 g of sodium acid phosphate (NaH₂PO₄), and 20 g of disodium phosphate (Na₂HPO₄) in water, and dilute to 1 L.

21.9 *Passivating Solution, Dilute*—Add 50 mL of passivating stock solution to 350 mL of water.

22. Preparation of Inserts

22.1 After stamping an insert number on the exterior surface with a die, degrease the inserts by immersion in trichloroethylene and air-dry.

¹² Complex substituted keto-amine (50 to 60 %) corrosion inhibitor as Rodine 213 manufactured by Amchem Products Inc., Ambler, PA 19002 has been found satisfactory for this purpose.

Specimen Holder the Same at Both Ends - Both Specimen Holders the Same on Both Sides of Loop

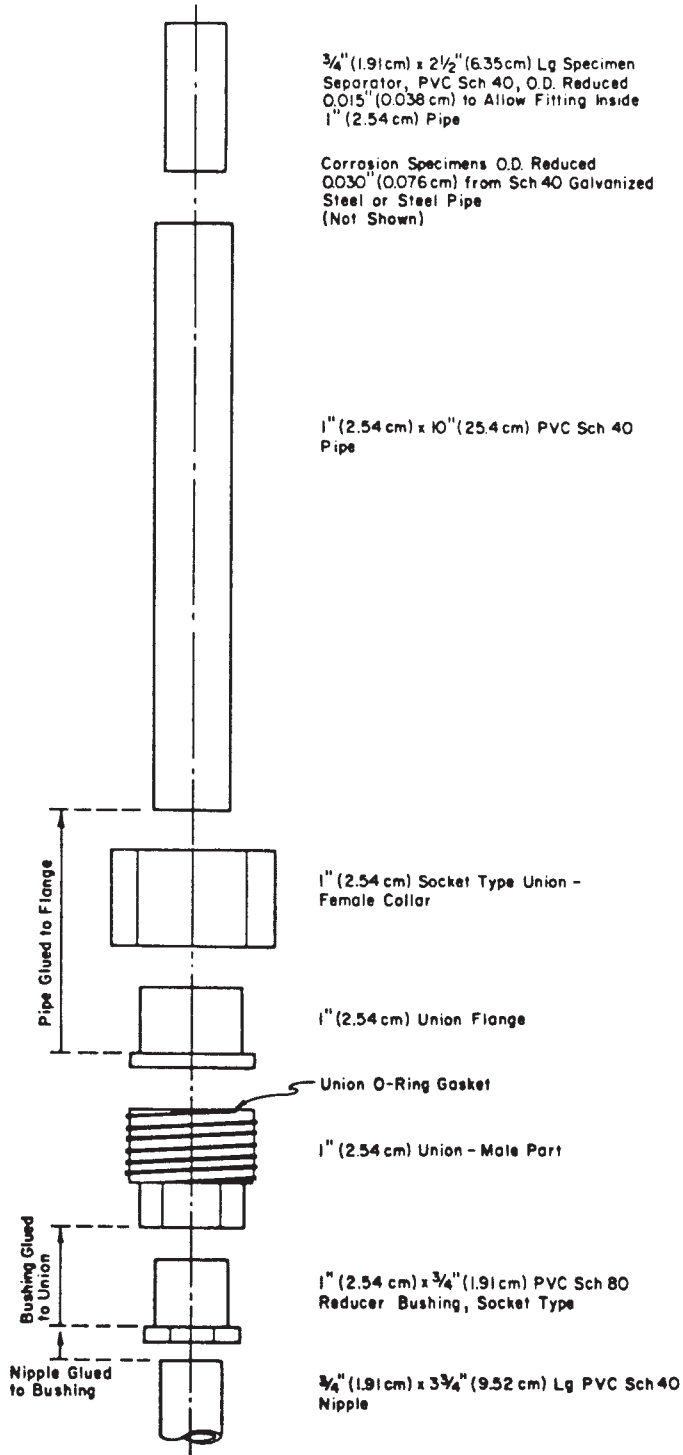


FIG. 4 CERL Pipe Loop System—Specimen Holder Details

22.2 If the inserts show the presence of rust or other coatings that were not removed, clean copper and steel inserts with (1 + 3) hydrochloric acid, inhibited, until free of the coating. Place rubber stoppers in each end of galvanized inserts

TABLE 2 Factors for Converting Weight Loss Measurements into Corrosion Rates

Type of Specimen		Conversion Factors (F) ^A		
Pipe size (in.), Class	Material	(weight loss (g/d) to corrosion rate)		
		mdd	mpy	mmpy
1/2, Schedule 80	steel pipe	2259	413	10.49
1/2, Schedule 80	galvanized pipe	2293	462	11.74
1/2, Type L	copper tube	2263	364	9.24
3/4, Schedule 40	steel pipe	1497	274	6.95
3/4, Schedule 40	galvanized pipe	1512	305	7.74
3/4, Schedule 40	copper pipe	1497	241	6.11
1, Schedule 40	steel pipe	1176	215	5.46
1, Schedule 40	galvanized pipe	1189	240	6.09
1, Type L	copper tube	1203	193	4.91

^A Corrosion rate = (F) × (weight loss, g/d).

^B mdd = milligrams per square decimetre per day.

^C mpy = mils per year.

^D mmpy = millimetres per year.

to prevent attack of internal galvanized surface by the acid. In the case of copper, expose in concentrated HCl for 2 min; however, steel inserts may require a much longer exposure. After cleaning, remove stoppers, rinse inserts with water, and passivate (see Note 1) steel (not copper or galvanized internal surface) surfaces by soaking inserts in dilute passivating solution for at least 1/2 min. Now air-dry and keep in desiccator until weighed. Record weight and insert number; then inserts are ready to be painted.

NOTE 1—It is not necessary to passivate steel inserts if they are not rinsed with acetone and then allowed to air dry. For long periods of storage or under moist conditions of storage, passivation may be justified.

22.3 The exterior and ends of the inserts are coated with a polyamide epoxy paint. Blend the epoxy base and epoxy catalyst according to the paint manufacturer's instructions. Place rubber stoppers into the ends of the inserts to protect the interior surfaces during painting. Air spray the inserts to produce a 5 mil dry-film thickness coating. Allow to air dry for 24 h and remove the stoppers.

22.4 Store inserts in a desiccator until installed in the tester assembly (Fig. 3 and Fig. 4).

23. Procedure

23.1 Install the test assembly in a similar-sized pipe line in the system to be observed.

23.1.1 A minimum straight run of 915 mm (3 ft) of piping shall precede the test assembly to prevent undue flow distortion.

23.1.2 Construct a by-pass valve and piping arrangement in order to allow insert removal while the system is operating.

23.1.3 Install a water meter following the test assembly in order to obtain maximum information concerning the flow rate and total flow.

23.2 The minimum recommended test period is preferably 120 days.

23.2.1 Remove the downstream insert at this time and evaluate.

23.2.2 If feasible, expose the upstream insert preferably for a test period of 12 months.

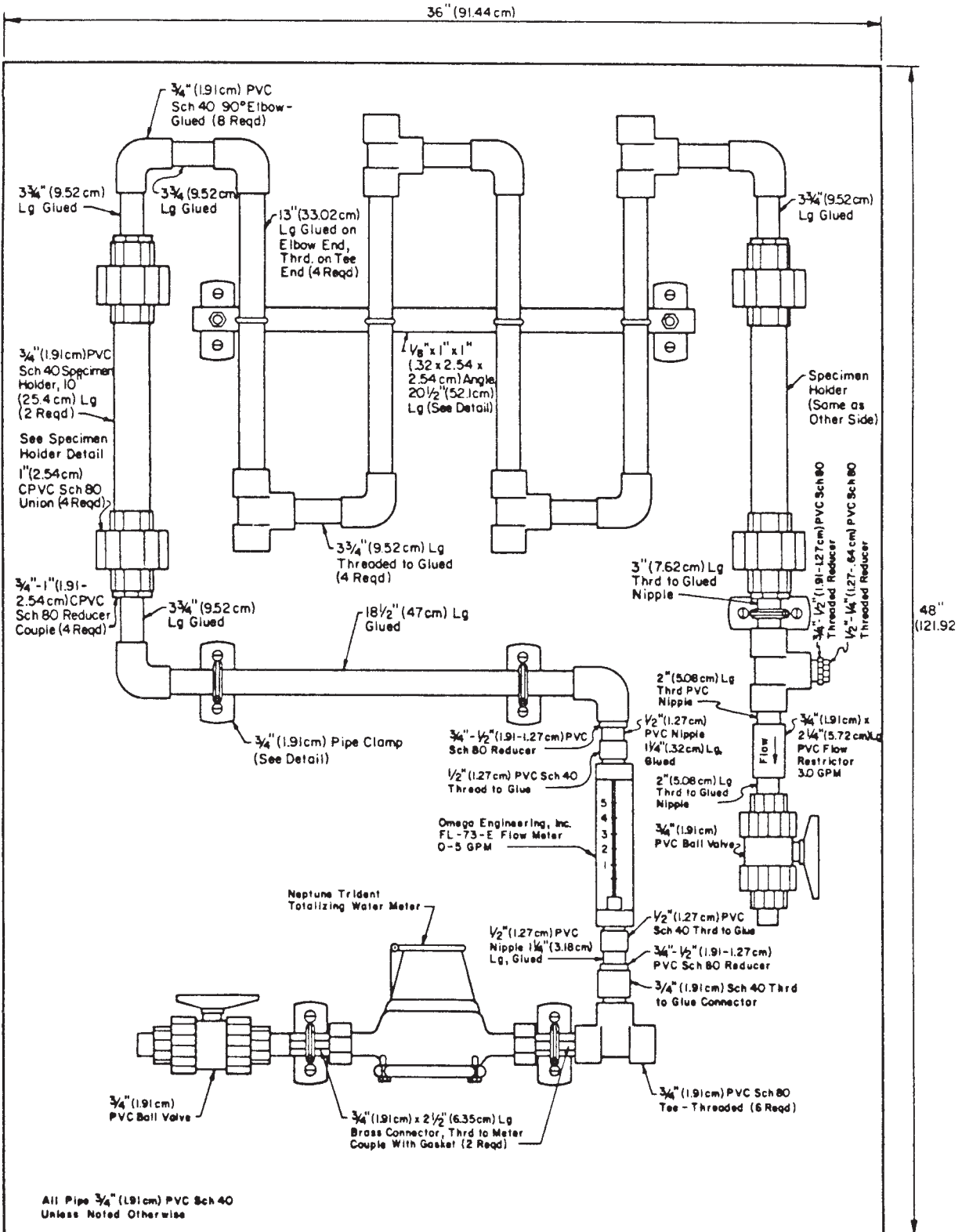


FIG. 5 CERL Pipe Loop System—Assembly Drawing

Institution or Plant Location: _____
 Type of Water: _____
 Location: _____
 Insert Type: _____ Insert No.: _____
 Date Installed: _____
 Date Removed: _____
 Lab No.: _____ Total Days: _____
 Date Reported: _____
 Comments: _____
 Pitting Evaluation: Number: _____ Size and Shape: _____
 Distribution: _____ Depth: _____
 Insert Weight:
 (1) Previous to installation: _____ g
 (2) After installation (+) scale and
 corrosion prods: _____ g
 (3) After installation (-) loose scale and
 corrosion prods: _____ g
 (4) After installation (-) all removable scale and
 corrosion prods: _____ g
 Scale and Corrosion Products:

	g	g/day
(A) Gain or loss during installation (1-2)	_____	_____
(B) Loose scale and corrosion prods (2-3)	_____	_____
(C) Tight scale and corrosion prods (3-4)	_____	_____
(D) Total scale and corrosion prods (2-4)	_____	_____
(E) Actual weight loss of insert (1-4) = W	_____	_____
$g/m^2 \cdot d$ (for steel, galvanized) = $117 W/T =$	_____	_____
$g/m^2 \cdot d$ (for copper) = $120 W/T =$	_____	_____
mmpy = $g/m^2 \cdot d \times 365/d$ ($d = \text{days}$) =	_____	_____

FIG. 6 Report Sheet on Corrosion Specimens (Test Method B)

24. Collateral Data

24.1 Record pertinent information on the physical and chemical characteristics of the environment in which the test is made on the test report sheet (Fig. 6).

24.2 Include also the location of the tester, insert material, insert number, installation data, removal date, and other descriptive information in the test report sheet (Fig. 6).

25. Inspection

25.1 Divert the flow of water from the tester and remove the insert from the test assembly.

25.2 Record the corrosion pattern, if any, as uniform or showing evidence of erosion, grooving, roughness, or pitting. Observe and record the appearance of the painted surface (excellent, blistered, peeling, etc.). If the paint has failed to effectively coat the metal surface during the exposure period and appreciable corrosion has occurred on the external surface, the accuracy of the corrosion test results may be seriously questioned.

26. Cleaning of Inserts

26.1 After removal from the corroding environment, dry insert in a 105°C oven for 24 h (except for copper inserts which shall be dried in a desiccator for 24 h), close ends of insert with rubber stoppers, immerse insert in an epoxy paint stripper to loosen the paint on the exterior, and remove all the paint film from the insert. After removing the stoppers, dry again in a 105°C oven for 1 h, cool in a desiccator for 1 h (except for copper inserts which shall be dried in a desiccator for 24 h), and weigh to the nearest 0.001 g. Record the weight on line (2) of the report sheet (Fig. 6).

26.1.1 **Caution:** While removing paint, avoid contact with stripper solution by wearing rubber gloves and working in an exhaust hood.

26.2 Scrape the insert with a spatula to remove loose deposits and wash with a brush and scouring powder. Dry the insert and weigh as previously noted after stripping. Record the weight on line (3) of Fig. 6.

26.3 Immerse steel inserts in a freshly prepared solution of inhibited hydrochloric acid (see 21.4) for several minutes or until all corrosion products are removed. Copper inserts are immersed in concentrated hydrochloric acid for 1 to 2 min to remove deposits, but do not use the copper acid bath to clean steel inserts.

26.3.1 Immerse galvanized inserts in an inhibited sulfamic acid solution (10 %) (see 21.6) for 5 min to loosen the deposits. Remove deposits by brushing and placing in an ultrasonic cleaner if necessary. In this case, place inserts in a 2-L polyethylene beaker containing the inhibited acid and place beaker in ultrasonic equipment containing water.

26.3.2 Rinse all inserts with water and acetone, dry in a 105°C oven for 1 h (except for copper inserts, which shall be dried in a desiccator for 24 h), cool in a desiccator for 1 h, and weigh to the nearest 0.001 g. Record the weight on line (4) of Fig. 6.

26.4 After sawing the inserts lengthwise in a band saw, inspect the interior surfaces for pitting, recording the number, depth, shape, and distribution of pits (see 7.2 and 12.5) in the pitting evaluation column shown in Fig. 6. Also inspect copper inserts using a microscope to determine if striations resulting from erosion-corrosion may have occurred.

27. Calculation

27.1 Calculate the scale and corrosion products in grams and grams per day, as indicated in Fig. 6.

27.2 Express the rates of corrosion either as weight loss per unit area per unit time or the equivalent rate of penetration. The accepted units are grams per square metre per day ($g/m^2/day$)

and millimetres penetration per year (mmpy) mils per year (mpy). Calculations in gmd or g/m²/day may be made using Eq 4:

$$\begin{aligned} \text{g/m}^2/\text{day} &= 117 W/T, \text{ for steel and galvanized specimens,} \\ &\text{and g/m}^2/\text{day} \\ &= 120 W/T, \text{ for copper specimens} \end{aligned} \quad (4)$$

where:

W = actual weight loss of insert, g, and

T = installation time, days.

27.3 The relationship between corrosion rate in gmd, mmpy, and mpy (27.2) is as follows (see Table 2): Multiply gmd by 0.365/density to obtain mmpy, millimetres per year and mmpy/0.0254 to obtain mpy. The densities (g/cm³) are: steel—7.86; zinc (galvanized)—7.15; copper—8.96; lead—11.34.

28. Interpretation of Results

28.1 This test closely simulates actual piping service conditions and has been observed to yield an accurate measure of corrosion occurring in a piping system.

28.2 Corrosion rates of less than 0.13 mmpy are considered low and are a general indication of satisfactory service life of the metals tested and exposed in the piping system.

28.3 The degree of pitting may be graded (7) and its importance evaluated.

29. Report

29.1 Fig. 6 shall include the observations, weight determinations, and pitting evaluation made in Sections 24 and 25, and the calculations of scale, corrosion products, and corrosion rate in Section 27.

30. Precision and Bias

30.1 Precision is a function of each individual system; therefore, a general statement regarding this property is not practical at this time.

30.2 See 18.2.

31. Keywords

31.1 cooling water corrosion test; coupon corrosion test; distribution water corrosion test method

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