Standard Guide for Laboratory Simulation of Corrosion Under Insulation[1]

This standard is issued under the fixed designation G189; 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 guide covers the simulation of corrosion under insulation (CUI), including both general and localized attack, on insulated specimens cut from pipe sections exposed to a corrosive environment usually at elevated temperature. It describes a CUI exposure apparatus (hereinafter referred to as a CUI-Cell), preparation of specimens, simulation procedures for isothermal or cyclic temperature, or both, and wet/dry conditions, which are parameters that need to be monitored during the simulation and the classification of simulation type.

1.2 The application of this guide is broad and can incorporate a range of materials, environments and conditions that are beyond the scope of a single test method. The apparatus and procedures contained herein are principally directed at establishing acceptable procedures for CUI simulation for the purposes of evaluating the corrosivity of CUI environments on carbon and low alloy pipe steels, and may possibly be applicable to other materials as well. However, the same or similar procedures can also be utilized for the evaluation of *(1)* CUI on other metals or alloys, *(2)* anti-corrosive treatments on metal surfaces, and *(3)* the potential contribution of thermal insulation and its constituents on CUI. The only requirements are that they can be machined, formed or incorporated into the CUI-Cell pipe configuration as described herein.

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]

A106/A106M Specification for Seamless Carbon Steel Pipe for High-Temperature Service
C552 Specification for Cellular Glass Thermal Insulation
C871 Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions
D1193 Specification for Reagent Water
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing
G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements
G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]
G31 Guide for Laboratory Immersion Corrosion Testing of Metals
G46 Guide for Examination and Evaluation of Pitting Corrosion
G59 Test Method for Conducting Potentiodynamic Polarization Resistance Measurements
G102 Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements

3. Terminology

3.1 The terminology used herein, if not specifically defined otherwise, shall be construed to be in accordance with Terminology G15.

[1] This guide is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

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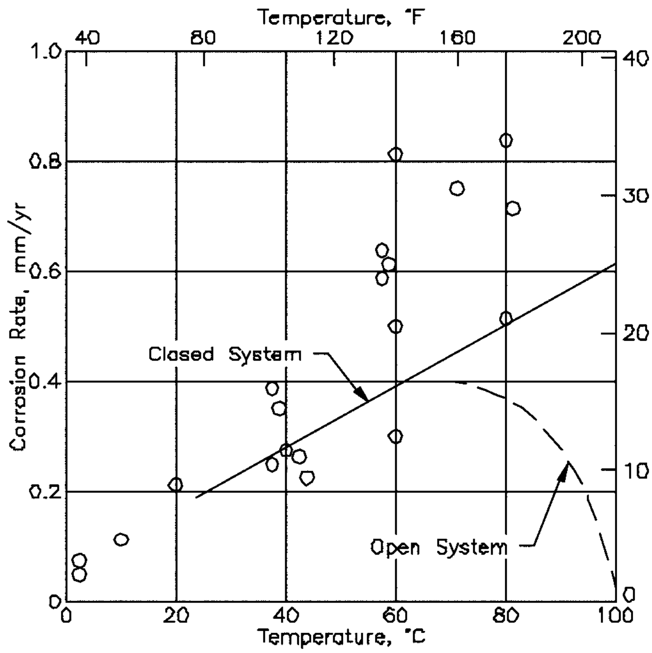
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.



NOTE 1—The actual CUI corrosion rates can be in excess of the those obtain in conventional laboratory immersion exposures.

FIG. 1 Comparison of Actual Plant CUI Corrosion Rates Measurements (Open Data Points Shown is for Plant CUI) with Laboratory Corrosion Data Obtained in Open and Closed Systems

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *corrosion under insulation (CUI)*—the corrosion of steel or other materials under thermal insulation due to the presence of water, oxygen or other corrodants, or combinations thereof.

3.2.2 *control condition*—an exposure condition using a pre-selected environment without the inclusion of inhibitors, protective treatments, or additives to the thermal insulation or exposure environment. It is selected to provide baseline data to which data from other exposure conditions can be compared.

3.2.3 *protection ratio*—ratio of the corrosion rate with the surface treatment or particular insulative material, or both, with that obtained for the control condition.

4. Summary of Guide

4.1 The CUI-Cell consists of three to six ring specimens separated by non-conductive spacers and held together by two blind flanged pipe sections, one on each end. Thermal insulation is placed around one-half of the evaluation section of the cell and sealed providing an annular space to retain a corrosive environment. The other half of the insulation is put in place to have proper heat transfer conditions as a typical insulated pipe section with internal heating. Provisions are given herein to use the specimens as corrosion coupons or electrodes in two separate electrochemical cells. One half of the CUI-Cell can be used to perform a CUI simulation under the control condition while the other can be used to evaluate inhibitors, protective coatings or insulative materials.

4.2 Corrosion measurements can be made using either mass loss data (Procedure A) or electrochemical dynamic polarization resistance methods (Procedure B), or both. This apparatus can be used to conduct laboratory evaluations under isothermal or cyclic temperature and under wet or wet/dry conditions simulating desired conditions in service. Comparison of the measured corrosion rates from exposures conducted with various surface treatments on steel and/or with various insulative materials with corrosion rates obtained with bare steel under the control condition provides the basis for assessment of protection efficiency. A value of protection efficiency of less than 1.0 indicates reduction in the severity of corrosion relative to the control condition whereas a value greater than 1.0 indicates an increase in the severity of corrosion relative to the control condition.

5. Significance and Use

5.1 The corrosion observed on steel and other materials under thermal insulation is of great concern for many industries including chemical processing, petroleum refining and electric power generation. In most cases, insulation is utilized on piping and vessels to maintain the temperatures of the operating systems for process stabilization and energy conservation. However, these situations can also provide the prerequisites for the occurrence of general or localized corrosion, or both, and in stainless steels, stress corrosion cracking. For example, combined with elevated temperatures, CUI can sometimes result in aqueous corrosion rates for steel that are greater than those found in conventional immersion tests conducted in either open or closed systems (see Fig. 1).[4] This figure shows actual CUI

[4] Ashbaugh, W. G., "Corrosion of Metals Under Insulation," *Process Industries Corrosion*, Ed. B. J. Moniz and W. I. Pollock, ASTM STP 880, West Conshohoken, PA, 1986.

data determined in the field compared with the corrosion data from fully immersed corrosion coupons tests.

5.2 This guide provides a technical basis for laboratory simulation of many of the manifestations of CUI. This is an area where there has been a need for better simulation techniques, but until recently, has eluded many investigators. Much of the available experimental data is based on field and in-plant measurements of remaining wall thickness. Laboratory studies have generally been limited to simple immersion tests for the corrosivity of leachants from thermal insulation on corrosion coupons using techniques similar to those given in Practice G31. The field and inplant tests give an indication of corrosion after the fact and can not be easily utilized for experimental purposes. The use of coupons in laboratory immersion tests can give a general indication of corrosion tendencies. However, in some cases, these procedures are useful in ranking insulative materials in terms of their tendencies to leach corrosive species. However, this immersion technique does not always present an accurate representation of the actual CUI tendencies experienced in the service due to differences in exposure geometry, temperature, cyclic temperatures, or wet/dry conditions in the plant and field environments.

5.3 One of the special aspects of the apparatus and methodologies contained herein are their capabilities to accommodate several aspects critical to successful simulation of the CUI exposure condition. These are: *(1)* an idealized annular geometry between piping and surrounding thermal insulation, *(2)* internal heating to produce a hot-wall surface on which CUI can be quantified, *(3)* introduction of ionic solutions into the annular cavity between the piping and thermal insulation, *(4)* control of the temperature to produce either isothermal or cyclic temperature conditions, and *(5)* control of the delivery of the control or solution to produce wet or wet-dry conditions. Other simpler methods can be used to run corrosion evaluations on specimens immersed in various solutions and leachants from thermal insulation. In some cases, these procedures may be acceptable for evaluation of the contribution of various factors on corrosion. However, they do not provide accommodation of the above mentioned factors that may be needed for CUI simulation.

5.4 With the CUI-Cell, the pipe material, insulation and environment can be selected for the desired simulation needed. Therefore, no single standard exposure condition can be defined. The guide is designed to assist in the laboratory simulation of *(1)* the influence of different insulation materials on CUI that, in some cases, may contain materials or additives, or both, that can accelerate corrosion, *(2)* the effect of applied or otherwise incorporated inhibitors or protective coatings on reducing the extent and severity of CUI. This guide provides information on CUI in a relatively short time (approximately 72 h) as well as providing a means of assessing variation of corrosion rate with time and environmental conditions.

6. Apparatus

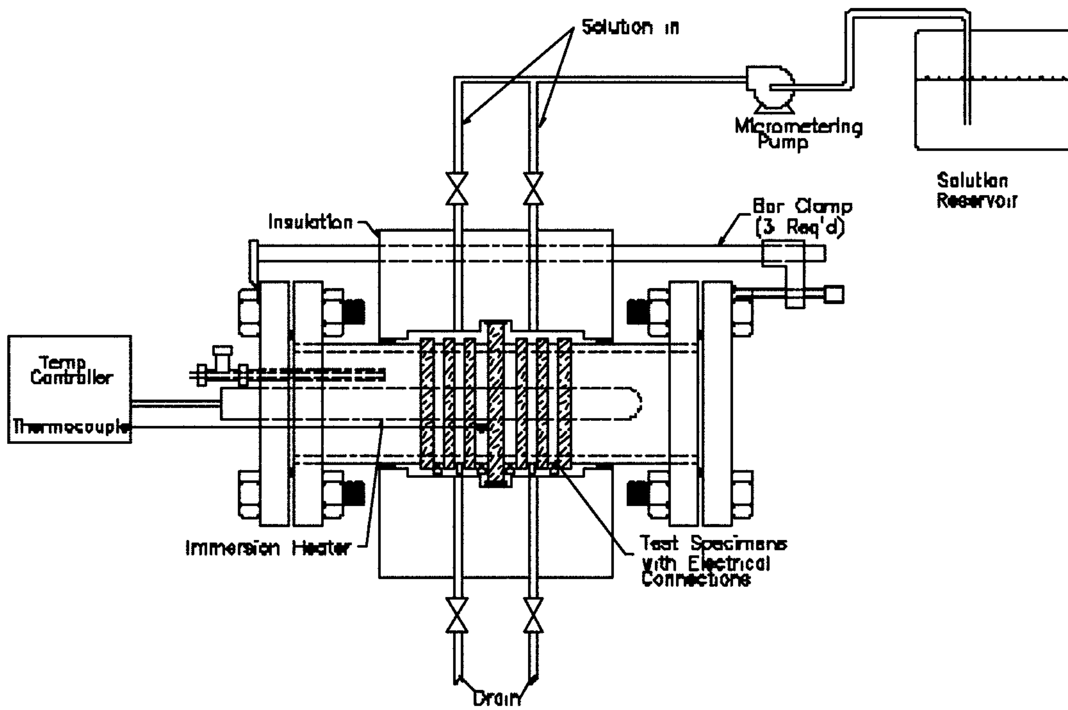
6.1 The CUI-Cell[5] can simulate the severity and modality of corrosion that has been described to occur under thermal insulation.[4,6] Initially this cell was developed for the evaluation of various surface treatments to be applied on the external surface of pipe to remediate CUI problems. However, subsequently, this same apparatus has been used successfully to evaluate the influence of various types of thermal insulation on CUI. In the cell, corrosion is intended to occur on the outer surface of ring specimens machined from a selected material. Fig. 2 shows a schematic representation of the CUI-Cell. The components of the cell include the following:

6.1.1 *Blind Flange Sections*—The CUI-Cell consists of two, nominal two-inch diameter pipe sections [that is, two-inch nominal diameter pipe material with a thickness of 0.187 in. (4.75 mm) as shown in Specification A106/A106M, Grade B, or alternative material to match that being evaluated by this simulation]; one for each end of the cell. Each end includes a bolted flange pair consisting of a weldneck, threaded or lap joint flange and a blind flange and attached pipe section. Pipe clamps or other suitable devices can be used to hold the flanged ends and the ring specimens together. Any device is acceptable that provides adequate sealing force between the various sections of the CUI-Cell.

6.1.2 *Ring Specimens*—The CUI-Cell consists of six ring specimens that are separated by nonporous, nonconductive spacers (see Section 7 for more detailed information). The evaluation portion, which includes alternate ring specimens of the intended material and nonconductive rings, is held together by two blind flanged pipe sections on both ends. The two sets of three ring specimens and spacers should be separated by an extra thick, nonconductive ring spacer (dam) at the center of the CUI-cell. This allows for separate corrosion measurements to be made on each set of specimens. For electrochemical measurements, each ring specimen should contain an attachment screw for connection of electrical leads to the potentiostat (Fig. 2). The connections should be made outside of the area exposed to the corrosive environment. The nonconductive spacers should be made from a machinable, temperature resistant, non-conductive material. Machinable polytetrafluoroethylene (PTFE) resins with high melting points are suitable in most cases for use up to about 400 to 450°F (200 to 230°C).

[5] Abayarathna, D., Ashbaugh, W. G., Kane, R. D., McGowan, N., and Heimann, B., "Measurement of Corrosion Under Insulation and Effectiveness of Protective Coatings," Corrosion/97, Paper No. 266, NACE International, Houston, Texas, March 1997.

[6] Ullrich, O. A., MTI Technical Report No. 7, "Investigation of an Approach for Detection of Corrosion Under Insulation," MTI Project 12, Phase II, Materials Technology Institute of the Chemical Process Industries, March 1982.



NOTE 1—The electrical connections to the specimens and contact of the thermocouple must be made outside of the wetted portion of the CUI-Cell (see Figs. 3 and 4 for more details).

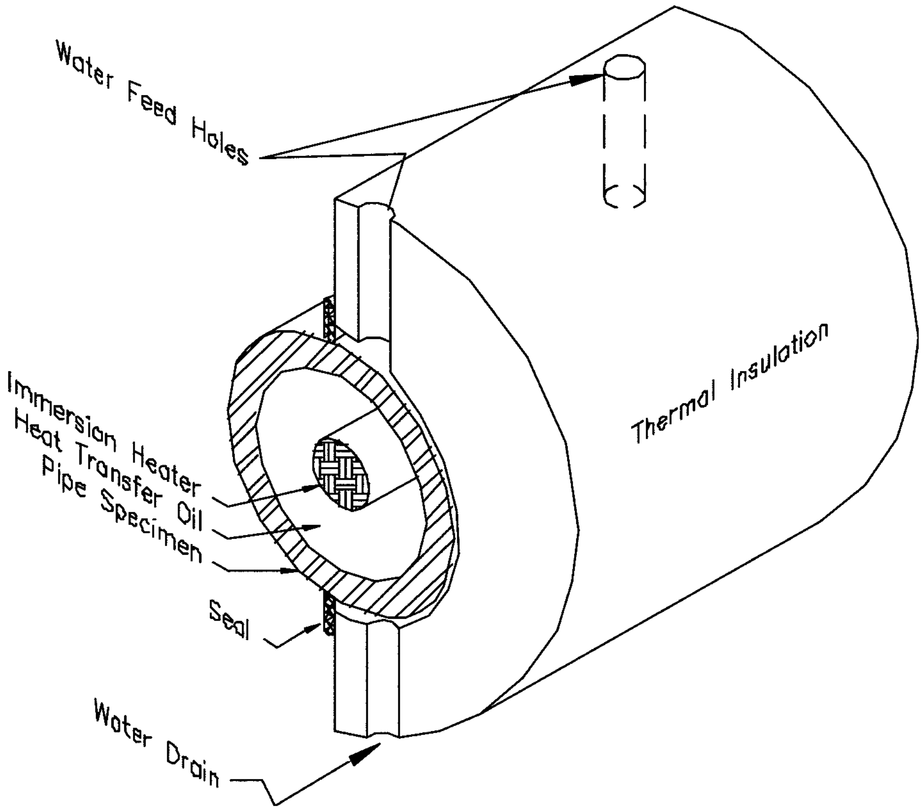
FIG. 2 Schematic of CUI-Cell

6.1.3 *Internal Heater and Temperature Controller*—The temperature on the outer surface of the ring specimens is achieved via an immersion heater (nominally 0.625 in. (1.6 cm) in diameter) having 400 W located on the inside of the pipe section mounted through the center of one of the blind flanges using an NPT connection. The temperature of the evaluation section of the CUI-Cell should be monitored and controlled with a thermocouple contacting the outer surface of the innermost ring specimen at a location outside of the area exposed to the corrosive environment but under the thermal insulation as shown in Figs. 3 and 4. The inside of the pipe section is filled with a heat transfer oil stable at the maximum intended temperature. The oil inside the cell assembly is connected to an oil reservoir of at least 100 mL capacity through a metal tube allowing for the expansion and contraction of the oil with temperature. The temperature controller employed should be able to control temperature to ±2°F (1°C). If cyclic temperature exposures are desired, the controller should have multiple programmable temperature settings, heat-up rates and soak times.

6.1.4 *Thermal Insulation*—Thermal insulation placed on the side of the evaluation section provides the annular space of at least 0.25 in. (6.4 mm) around the outer surface if the specimens to retain the solution as shown in Fig. 2 and in greater detail in Figs. 3 and 4. The thermal insulation should be sealed with silicone adhesive materials forming an annular pocket to hold the solution. Two holes should be drilled in the insulation at both the top and the bottom for the addition and draining of the solution from the annular pocket on the CUI-Cell. Where possible, the thermal insulation should be selected based on those materials used in the particular condition(s) of interest. The control condition should use a water resistant molded foam glass thermal insulation in accordance with Specification C552 with low concentration of chlorides (<40 ppm) and other leachable compounds. For the simulations involving specific surface treatments, solutions or insulative materials, typical materials and environments for the intended application should be used, where possible. Alternatively, those insulative materials specified in the control condition can be used.

6.1.5 *Potentiostat(s)* (For potentiodynamic polarization resistance measurement only.) In cases where electrochemical measurements are to be made, a potentiostat should be used in accordance with Practices G59 and G102 to determine the open circuit potential (OCP) and to make potentiodynamic polarization resistance measurements of current versus electrode potential over a range up to at least ±20 mV of the OCP. The potentiostat(s) should be capable of monitoring both electrochemical cells in the apparatus by using either separate channels, a multiplexer, or by employing two separate potentiostat units (see Fig. 5).

6.1.6 *Micrometering Pump and Solution Reservoir*—In order to maintain or control the addition of the solution during the simulation, or both, a suitable metering pump should be used that can administer a liquid solution to the CUI cell over a range of pumping rates from 0.5 to 5 mL/min. The reservoir should be made from glass or high density polyethylene (HDPE) and should have a volume large enough to hold the entire quantity of solution needed for the complete run at the desired pumping rate. The solution should be conveyed to and



NOTE 1—Opposite half of thermal is added after seals has been made and thermocouple has been inserted into the proper position (see Fig. 2).

FIG. 3 Cross-section of CUI-Cell Showing Orientation of Thermal Insulation

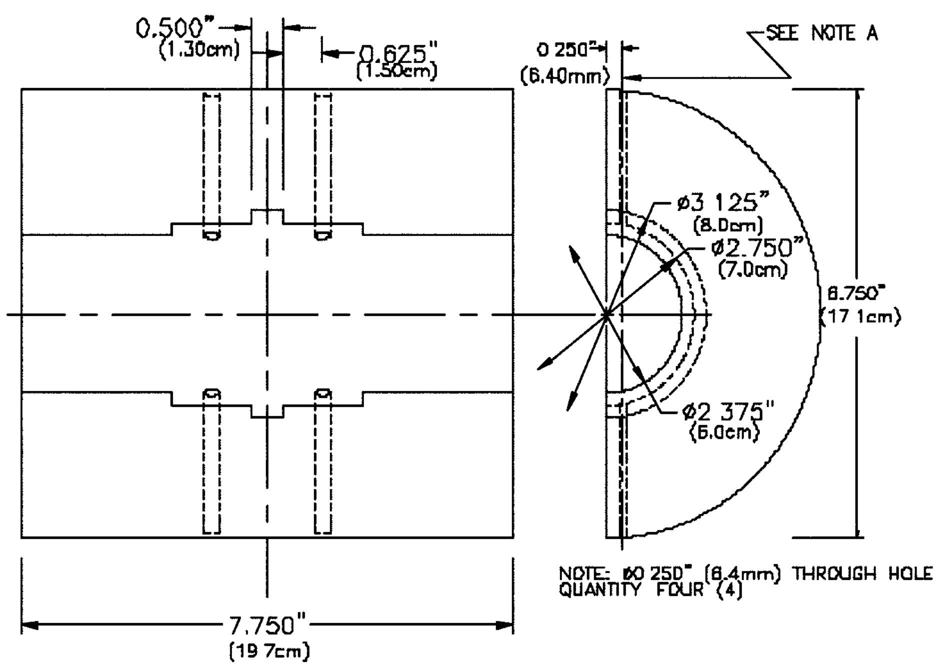
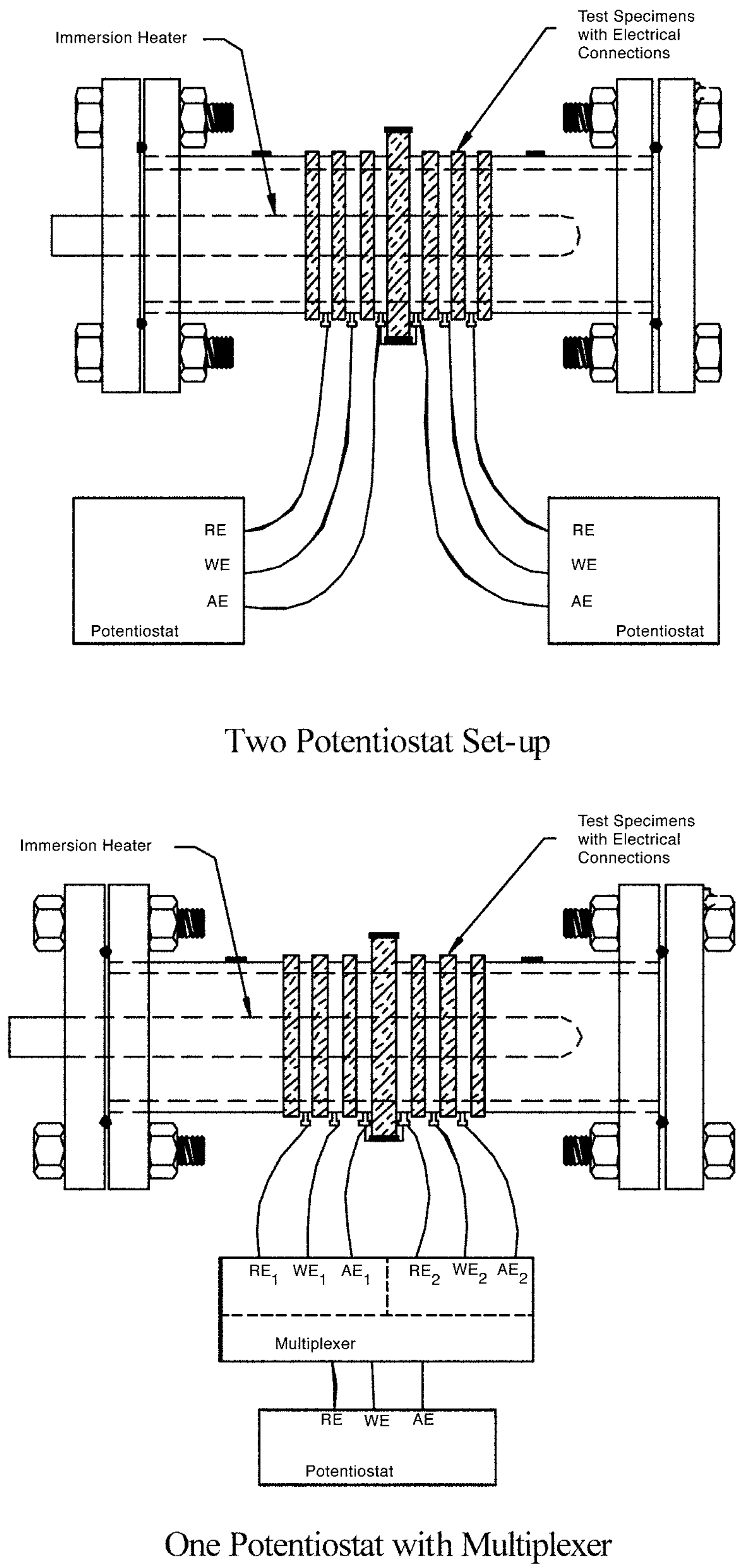


FIG. 4 Dimensions of Thermal Insulation for CUI Simulation

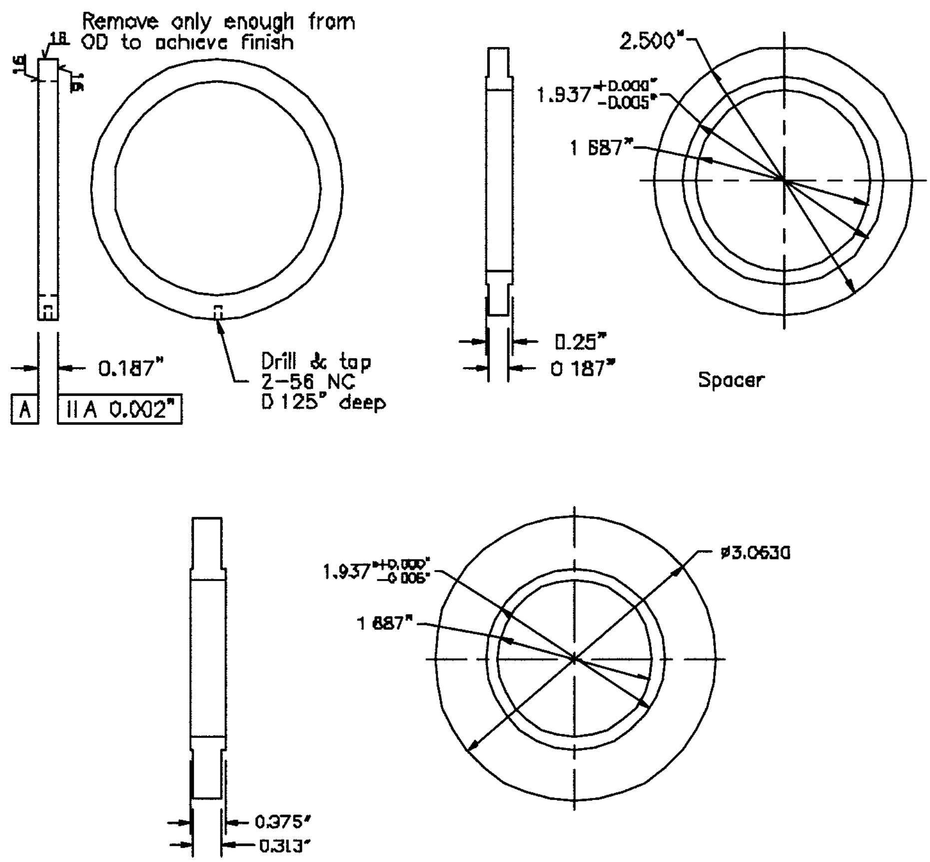
from the cell using 0.125 in. tubing made from a corrosion resistant material. There should be valves with on/off regulation on the lines coming from the outlets in the bottom of the



Top—Set-up with two separate potentiostats.
Bottom—Set-up with one potentiostat and multiplexer.

NOTE 1—Electrical connects to CUI-Cell specimens to be made outside wetted area of cell.

FIG. 5 Schematic of Wiring of Potentiostat to CUI-Cell Ring Specimens for Procedure B



Top Left—Configuration of the ring specimen.
Top Right—Nonconductive spacer.
Bottom—Nonconductive large spacer (dam) located between the two sides of the CUI-Cell.

Dimension Conversion: 1 in. = 2.54 cm.

FIG. 6 Ring specimen and Nonconductive Spacer

CUI-Cell. These valves are used to control the amount of solution in the cell during the wet portion of the exposure.

7. Specimens

7.1 For the purposes of conducting this simulation, the ring specimens should be prepared from a two-inch nominal diameter pipe material with a thickness of 0.187 in. (4.75 mm) and a width of 0.25 in. 6.35 mm). The ring specimens and nonconductive spacers should have interlocking surfaces to assist in sealing for containing of the heat transfer oil on the inside of the cell and the solution on the outside (see Fig. 6). The outer surface of the ring specimens should be polished to a 600 grit finish.

7.2 Unless otherwise required for simulation purposes, the ring specimens can be prepared from carbon steel made in accordance with Specification A106/A106M, Grade B. A mill certification for the actual material should be obtained.

7.3 A minimum of three ring specimens are required for one exposure per evaluation. This provides of triplicate mass loss corrosion and localized corrosion measurements. A minimum of three ring specimens are also needed for electrochemical corrosion measurements. Where such electrochemical corrosion measurements are being made using the potentiodynamic polarization resistance technique, the three ring specimens should be used as the working electrode, auxiliary electrode and reference electrode as described in Practice G59. For comparative evaluations to be conducted simultaneously, a total of six specimens are required for both cases. This includes two sets of three specimens.

8. Environment

8.1 The solution used in CUI simulation should be relevant to the intended application, where possible. It can be based on anticipated service conditions involving various levels of impurities specified for the particular case. It can also consist of a leachants derived from a selected thermal insulation or dilutions prepared from the leachants. Procedures for this extraction and analysis techniques are given in Test Method C871.

8.2 Unless otherwise required for a specific simulation, a suggested solution that can be used to produce an accelerated exposure environment with the CUI-Cell should consist of 100 ppm NaCl dissolved in reagent water made in accordance with Specification D1193 (Type IV) acidified with addition of

H_2SO_4 to pH 6 (±0.1 pH unit) at 75°F (24°C). Five litres of stock solution is made by adding 0.5 g of NaCl to 5 L of reagent water followed by addition of a small quantity of 1 M solution of H_2SO_4 in water using a dropper as needed to attain the required pH. This solution is designed to represent an atmospheric condensate with impurities of chlorides and acids found in industrial and coastal environments.

NOTE 1—The solution exiting the CUI-Cell can be sampled at specific times during the test and analyzed for pH, conductivity, chloride content, iron content, and other chemical species that may be present in the solution or insulative materials. This can allow determination of the extent of concentration of the electrolyte and leaching from the insulation during the test. This information may also be helpful in evaluating the influence of various chemical species (for example, inhibitors) in the insulation, stability of the CUI-Cell environment with time, and performance of materials or surface treatments in the test environment.

9. Simulation of CUI Using Mass Loss and Localized Corrosion

9.1 The ring specimens should be machined from the pipe material and prepared to the specified surface finish (see Section 7). The initial dimensions required for calculation of the exposed surface area and the before-exposure masses of each specimen should be measured and recorded. Just prior to exposure, the specimens should be degreased with a non-chlorinated solvent and their pre-exposure mass (M_i) determined to the nearest 0.1 mg using procedures given in Practice G1.

9.2 The CUI-Cell should be assembled by placing alternate specimens and nonconductive spacers. To separate the two sets of three specimens in the CUI cell, the nonconductive dam should be placed in the center. The blind flanges should be placed on either end of this assembly and clamped together.

9.3 The immersion heater, thermocouple and the extension tube to the oil reservoir should be attached. The internal volume of the CUI cell assembly should be filled with a suitable heat transfer oil for the conditions to be used, heated and checked for leaks.

9.4 The thermal insulation should be mounted in place and sealed to the central evaluation section of the CUI-Cell (see Fig. 2) around its perimeter using silicone rubber or other inert sealing material compatible with the temperature and environment. When the CUI cell is set-up as described herein, approximately one half of the outer surfaces of each ring specimen should be exposed to the solution with the thermal insulation mounted in the near vertical position. This will facilitate filling and draining of the solution into and from the CUI-Cell.

9.5 The valves on the outlet lines from the CUI-Cell should be closed and solution pumped into the annular space between the thermal insulation and the outer surfaces of the ring specimens through the two ports at the top (see Figs. 3 and 4) using a micrometering pump. The pumping rate should be sufficient to fill the CUI-Cell and maintain replenishment of the solution to make-up for solution lost through evaporation and wicking of the solution by the thermal insulation. To assure adequate solution replenishment, once the annular space in the cell is initially filled, a flow of solution should be maintained at a rate that produces an excess solution of a few drops per minute from partially opened valves in the bottom of the CUI-Cell. Exposures at higher temperatures will require higher solution flow rates to maintain the solution in the cell.

TABLE 1 Simulation Codes and Suggested Conditions

Code	Description	Temperature (C)	Min Duration (h)	Cycle (h)
IW	Isothermal–Wet	TBS[A]	72	NA[B]
IWD	Isothermal–Wet/Dry	TBS	72	20 wet / 4 dry
CW	Cyclic Temperature–Wet	TBS	96	24 hot / 24 cold
CWD	Cyclic Temperature–Wet/Dry	TBS	72	20 wet / 4 dry; 20 cold / 4 hot

[A] TBS: To be specified by user.
[B] NA: Not applicable.

The simulation code should be followed by the applicable temperature(s) in degrees centigrade.
Example 1: IW-120C—Isothermal temperature, wet simulation at 120°C.
Example 2: CWD-60C/150C—Cyclic temperature wet/dry simulation at cycling between 60 and 150°C.

NOTE 2—At temperatures above the boiling point of water, steam may be released through the holes in the top of the insulation. In some cases, it may be useful to measure and record the total quantity of solution used in the test to maintain a liquid phase during the wet portion of the test.

9.5.1 To simulate wet/dry conditions, the flow of solution may be temporarily stopped allowing the solution in the CUI cell to dry. For wet/dry conditions, the period of wetting should be 20 h followed by a 4-h drying period. Additionally, exposures may be conducted isothermally, under cyclic temperature or combinations of cyclic temperature and wet/dry conditions. The designations for the various simulation types are categorized in Table 1.

9.6 Following addition of the solution, the apparatus should be heated and the temperature stabilized at the initial temperature using the immersion heater and temperature controller. The minimum duration for simulation of CUI should be as stated in Table 1 that starts when the initial temperature is stabilized which should not be longer than 1 h after addition of the solution and the initiation of heating. The duration is complete when the cell is cooled to 100°F (38°C), which should not be longer than 2 h after turning off the heaters. After completion of the CUI simulation, cooling may be accelerated by removing the half of the insulation that is not being used to contain the solution and by using forced air on this side of the cell or draining of the heat transfer oil, or both, if necessary. Longer duration exposures may be needed to more completely evaluate longer term CUI behavior and the performance of preventive treatments or alternate materials to simulate prolonged in-service exposures.

9.7 At the end of the exposure duration, the cell assembly should be cooled to less than 100°F (38°C), drained and be disassembled. The ring specimens should be rinsed in distilled or deionized water to remove loose material and accumulated salts, and then dried with a non-chlorinated solvent. The exposed area of the ring specimens should be assessed by direct measurement following disassembly of the CUI-Cell.

9.8 The post-exposure specimen mass (M_{f1}) should be first measured before cleaning. The specimens should be then cleaned according to procedures given in Practice G1 and the specimen mass measured again following removal of the corrosion scale (M_{f2}).

9.9 The corrosion scale mass on the specimen per unit area, S, should be obtained according to the following equation:

$$S = (M_{f1} - M_{f2})/A \quad (1)$$

where:

A = exposed area on ring specimen (cm^2), from 9.1.

9.10 The difference in initial pre-exposure mass (M_i) and the post-exposure (after cleaning) mass (M_{f1}) for the ring specimens should be used to obtain an average mass loss corrosion rate over the exposure period according to procedures given in Practice G1 using the following equation:

$$\text{Corrosion Rate} = (K \times M)/(A \times T \times D) \quad (2)$$

where:

K = constant (mpy: 3.45×10^6; mm/y: 8.76×10^4),
M = mass loss (g) given by ($M_i - M_{f1}$),
A = exposed area in (cm^2),
T = time of exposure (h), and
D = density (g/cm^3).

NOTE 3—The exposed area will only be the portion of the outer surface of the ring specimens actually exposed to the solution in the CUI-Cell, not the total outer surface area which needs to be visually confirmed and measured after exposure. In the cases where protective surface treatments or coatings are involved, defected areas should be created in the coating to evaluate the corrosion behavior of the metal in these defected areas. In this latter case, the exposed area will only be the area of the defected region on the specimen as measured after testing.

9.11 Following cleaning, the morphology of any localized corrosion on the exposed portion of the ring specimens should also be characterized using procedures given in Guide G46 and represented in terms of density, size and depth.

9.12 Protection Ratio (PR) for a simulation versus the control condition should be calculated according to the following equation:

$$PR = CR/CR_c \quad (3)$$

where:

CR = the mass loss corrosion rate as determined in 9.9, and
CR_c = the mass loss corrosion rate determined for a control condition as defined in 3.2.2 and 8.2.

10. Simulation of CUI Using Potentiodynamic Polarization Resistance

10.1 The CUI-Cell should be assembled and operated in accordance with 9.1 through 9.7. In addition to the electrochemical measurements described in this section, the ring specimens should be used as mass loss coupons and evaluated according to the procedures given in 9.8 through 9.10. The conventions used should be consistent with those given in Practices G3, G5 and G102.

10.2 The electrical contacts from the potentiostat to each of the two groups of three ring specimens in the CUI-Cell should be made as shown in Fig. 5. Note that the electrical connections to the specimens should be made outside of the wetted portion of the cell (see Figs. 3 and 4 for more details). The center ring specimen of each three specimen set in the CUI-Cell should be used as the working electrode while the other two rings in each set of specimens should be used as the auxiliary and reference electrodes.

10.3 The instantaneous corrosion rates of the two working electrodes should be obtained using the polarization resistance technique given in Practice G59. For isothermal conditions, the measurements should be repeated at intervals of 30 min for the initial 4-h period of exposure. For the remaining duration of the exposure, the interval between measurements may be increased as needed to accurately monitor the changes in corrosion rate with time. For exposures involving cyclic temperature or wet/dry conditions, the measurements should be repeated at intervals of 30 min for the initial period of exposure, during drying and immediately following rehydration. For the remaining duration of the exposure, the interval between measurements may be increased as needed to accurately monitor the changes in corrosion rate with time.

10.4 The values of the Tafel slopes used in calculating the corrosion rates from the polarization resistance should be determined for the solution and conditions simulated using the methods given in Practice G102 or other suitable procedure. These Tafel measurements should be performed either: *(1)* after the polarization resistance measurement have been completed, or *(2)* on a duplicate set of specimens using the same test configuration.

10.5 The actual exposed area of the ring specimens as determined after exposure (see 9.7) should be used in calculation of corrosion rate from the electrochemical data.

10.6 The corrosion rates for both electrochemical cells should be plotted versus time. Appendix X1 shows typical electrochemical data for two cases of CUI simulation.

11. Reporting

11.1 The report for Procedure A should include the following information:

11.1.1 Mill certification for alloy used for specimens.

11.1.2 Indication of the applicable exposure type code from Table 1 and test duration.

11.1.3 Any thermal insulation materials, coatings, surface treatment, inhibitors or other additives should be described to the extent necessary for adequate identification and characterization of corrosion behavior.

11.1.4 The specimen dimensions, exposed area and the before exposure mass, after exposure mass and mass after exposure and cleaning.

11.1.5 Description of the solution used (see Section 8).

11.1.6 Average mass loss corrosion rate and scale mass per unit area for conditions evaluated and for the control condition.

11.1.7 Density, size and depth of pitting for the condition evaluated and for the control condition with the applicable designations given in Guide G46.

11.1.8 The protection ratio for the conditions evaluated versus the control condition.

11.2 The report for use of potentiodynamic polarization resistance should include the following information:

11.2.1 All items given in sections 11.1.1 through 11.1.8.

11.2.2 The calculated electrochemical corrosion rates plotted versus time data for both the condition evaluated and the control condition.

11.2.3 The protection efficiency based on steady state corrosion rates determined from electrochemical measurements.

12. Keywords

12.1 corrosion under insulation; CUI; electrochemistry; mass loss; polarization resistance; protection efficiency; thermal insulation

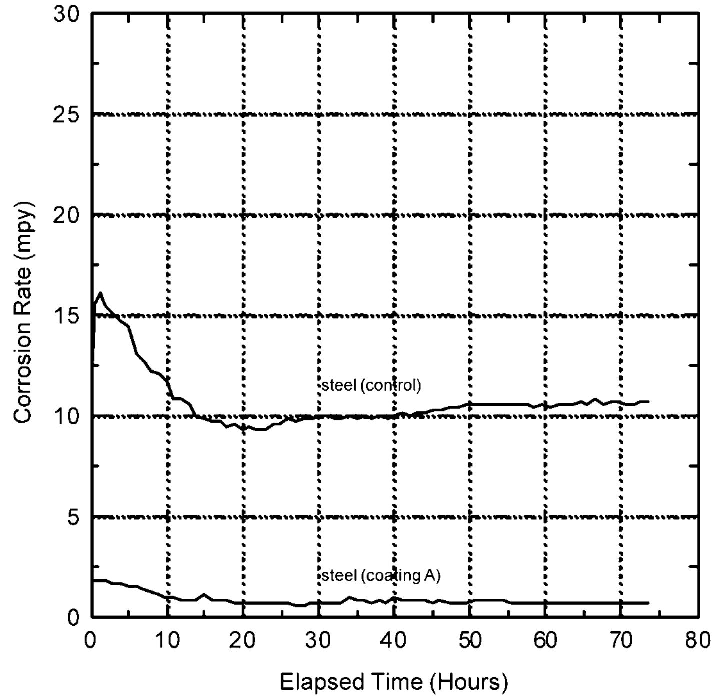
APPENDIX

(Nonmandatory Information)

X1. DATA FROM CUI-CELL

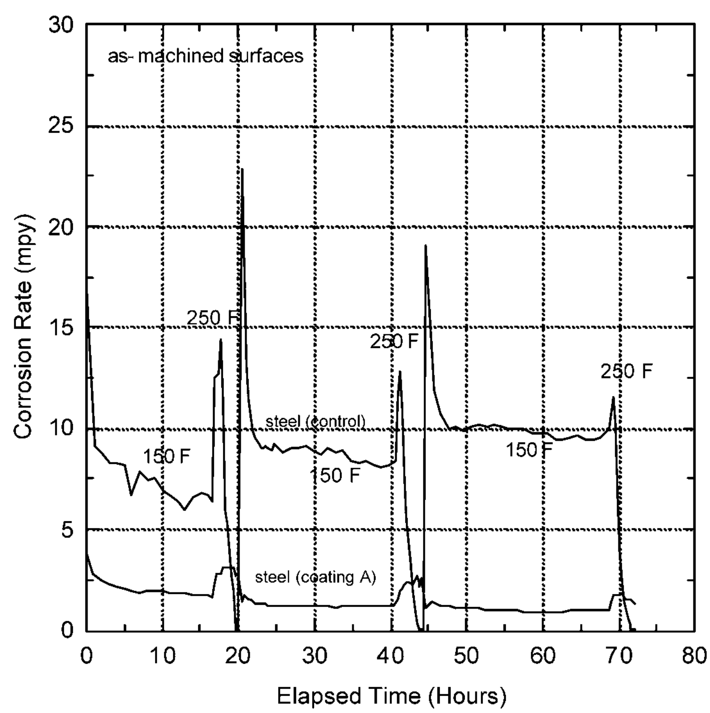
X1.1 Examples of instantaneous corrosion rate versus time produced from electrochemical data obtained in CUI simulations are given in Figs. X1.1 and X1.2 for isothermal and cyclic temperature wet/dry simulations, respectively. It should be noted that the actual values of corrosion rate determined by the electrochemical technique may vary from the average corrosion rates determined by the mass loss of the specimens. However, as shown in Figs. X1.1 and X1.2, the corrosion rates determined from the electrochemical technique may provide valuable information on the changes in corrosion rate with time and the influence of cyclic temperature or wet/dry cycles, or both, and their cumulative effects on the corrosion rate during the course of particular CUI simulations. This type of data can also be used to evaluate the role of changing exposure conditions on the severity of CUI.

X1.2 The behavior during wet/dry exposures is particularly informative but should be considered only in a qualitative manner since drying may limit the accuracy of corrosion rates determined using electrochemical measurements. Corrosion rates tend to increase as drying is approached and again during re-hydration. Also, CUI corrosion rates tend in increase with each wet/dry cycle due to concentration of corrodants on the metal surface. However, in the interim period between drying and re-hydration, there may be a point during the drying cycle where corrosion is still occurring but where there may not be enough liquid to sustain long range electrochemical current flow. With further drying it is highly likely that the corrosion rate will actually reach zero once all water has been removed from the surface of the specimens and the corrosion products. Therefore, the actual CUI corrosion rates determined by mass loss should be considered as average corrosion rates occurring over the total period of exposure which, in the case of wet/dry simulations, is a composite of periods of high, low and possibly zero corrosion rates.



NOTE 1—Solution used was in accordance with 8.2 of this guide. Data are shown for both bare steel and steel with surface treatment run simultaneously in two electrochemical cells in the CUI-Cell using a perlite insulation material. (Corrosion rate conversion: 1 mpy = 0.025 mmpy)

FIG. X1.1 Electrochemical Corrosion Rate Data versus Time for an Isothermal CUI Simulation



NOTE 1—Solution used was in accordance with 8.2 of this guide. Data are shown for both bare steel and steel with a surface treatment (coating A) run simultaneously in two electrochemical compartments in the CUI-Cell using a perlite insulation material. (Corrosion rate conversion: 1 mpy = 0.025 mmpy)

FIG. X1.2 Electrochemical Corrosion Rate Data versus Time for Cyclic Temperature Wet/Dry CUI Simulation Conducted at 150°F (65°C) and 250°F (121°C)