NACE Cathodic Protection Technologist Level 3 Case-Based Exam

Exam Preparation Guide
July 2019
# Table of Contents

## Introduction .................................................................................................................................................. 3

- Target Audience ........................................................................................................................................ 3
- Requirements ............................................................................................................................................ 4

## Exam Blue Print ........................................................................................................................................ 5

## Types of Questions ........................................................................................................................................ 7

- Description of Questions .......................................................................................................................... 7
- Sample Questions ..................................................................................................................................... 7

## Problem Statement ...................................................................................................................................... 7

## Key Assumptions ......................................................................................................................................... 8

## Reference Material ....................................................................................................................................... 8

## Questions .................................................................................................................................................... 10

- Answer Key ............................................................................................................................................. 11

## Preparation ................................................................................................................................................. 12

- Training—None Required ....................................................................................................................... 12
- Recommended Study Material ............................................................................................................... 12
- Books ....................................................................................................................................................... 12
- Standards ................................................................................................................................................ 12
- Reference Material Provided in the Exam .............................................................................................. 13
Introduction

The Cathodic Protection Technologist Case-Based exam is designed to assess whether a candidate has the requisite knowledge and skills that a minimally qualified Cathodic Protection Technologist must possess. The exam consists of 30 multiple-choice, multiple-choice with more than one correct answer, and matching questions related to a case, scenario, or problem that requires the application of knowledge based on the Cathodic Protection (CP) body of knowledge. A candidate should have theoretical concepts and practical application of CP with a strong focus on CP field work, interpretation of CP data, and troubleshooting.

<table>
<thead>
<tr>
<th>Exam Name</th>
<th>NACE-Cathodic Protection Technologist Case-Based Exam</th>
</tr>
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<tbody>
<tr>
<td>Exam Code</td>
<td>NACE-CP3-Case</td>
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<tr>
<td>Time</td>
<td>4 hours</td>
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<tr>
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<td>30</td>
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<tr>
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NOTE: A pass/fail grade is provided at the end of the exam. The Theory and Case-Based exams are scored separately, and candidates must pass both exams.

*Exam time includes 4 minutes for the non-disclosure agreement and 6 minutes for the system tutorial.

NOTE: The CP 3 course manual is **NOT** provided in the exam. Reference material is provided as a PDF for questions that require a equation, conversion chart, or other reference.

Target Audience

A Cathodic Protection Technologist (CP 3) is responsible for observing, recording, and measuring the effectiveness of CP systems. This certification is geared toward persons who have a high level of working knowledge of CP systems and years of extensive field experience in CP. A CP Technologist should have good understanding of mathematical procedures and scientific knowledge of corrosion processes.

NOTE: There is **NOT** a direct progression from Cathodic Protection Technician (CP 2) to Cathodic Protection Technologist (CP 3). Substantial experience involving all aspects of CP, including design and formal education in math/science/engineering is critical to a student’s success on this exam. Attendance in the Cathodic Protection Technician (CP 2) course is strongly recommended before attempting Cathodic Protection Technologist (CP 3). However, additional experience and education are also recommended.
Requirements

Cathodic Protection Technologist (CP3)

Requirements for Cathodic Protection Technologist (CP3):
1 Prerequisite + Work Experience + 2 Core Exams + Application

The following prerequisite is required:
None

Work Experience Requirements:
Choose one of the following work experience options:

- 8 years verifiable CP work experience
- 6 years verifiable CP work experience
  And
  2 years post high school training from approved math / science technical / trade school
- 3 years verifiable CP work experience
  And
  4-year physical science or engineering degree

Core Exam Requirements:
The following exams are required: (2 core exams required)

- Cathodic Protection level 3 exam (Theory)
- Cathodic Protection level 3 exam (Case-Based)

Application Requirement:
Approved Cathodic Protection Technologist (CP3) application

Submit Application – candidates must apply for this certification by submitting an on-line application which is subject to approval. Applications must be submitted within 3 years of successful completion of exam.

Certification renewal requirements – Recertification application* required every 3 years –

- Recertification Application (1)
- Professional Development Hours (24)
- Work Experience Years (1.5)
- Renewal Fee (Members $240.00 USD; Non-members $450.00 USD)

Upon successful completion of requirements, the candidate will be awarded a Cathodic Protection Technologist Certification.

Next Level of Certification:
Cathodic Protection Specialist (CP 4)
**Exam Blue Print**

### Instruments
- Understand the operation of a digital Volt-Ohm meter (Multimeter) and how it is used to measure current, voltage and resistance.
- Use a volt-ohm meter (Multimeter) to determine the voltage and current output of a rectifier.
- Understand the operation of a soil resistivity meter.
- Use a volt-ohm meter to determine the current output of sacrificial anodes installed on your system.
- Conduct a soil resistivity test with a soil resistivity meter or equivalent instrument.
- Conduct soil resistivity measurements by using a Soil Box.
- Understand and able to perform layer resistivity calculations.
- Conduct single-point soil resistivity readings with a "Collins Rod".
- Install interrupters in rectifiers or bonds for the purpose of taking “On” and “Instant off” structure to electrolyte potential readings.
- Understand the various types of pipe locating instruments and be able to utilize them to locate pipelines or cables in all underground environments.

### Shunts
- Understand how to determine the amount of current flowing through various size shunts by reading the milli-Volt (mV) drop across it with a Volt-Ohm meter and applying the correct conversion factor.
- Understand how to determine the direction of current flow through a shunt by observing the polarity of the mV reading.
- Read shunts in rectifiers to determine the output current.
- Read shunts in bonds with foreign structures.
- Read shunts for individual anodes associated with deep well ground beds.
- Utilize an external shunt to determine the output current of a rectifier with a broken amp meter.
- Read shunts that are installed in galvanic anodes to determine output current.

### Field Tests
- Perform current requirement test.
- Perform soil pH test.
- Perform IR Drop test.
- Run "shorted casing test" on casings that are suspected of being shorted and interpret the results of the test.
- Perform coating examinations on sections of pipeline that have been excavated.
- Perform soil resistivity test to evaluate the area for a conventional ground bed site.
- Conduct Pearson surveys to evaluate the coating condition of a section of pipeline.
- Conduct computerized close interval surveys where needed and evaluate the graphs produced from the data.
- Locate breaks in header cables with an "audio type" pipe and cable locator.
- Investigate shorts on a pipeline or other structure.
- Verify the results of shorted casing test.
- Understand the factors that affect cathodic protection system performance at the anode, at the structure performance, in the electrolyte, in the metallic path, at the power supply, because of anode arrangement and interference.
- Perform advanced cathodic protection testing using correct measurement techniques to monitor CP system performance and accurately interpret the data collected to ensure optimum cp system performance.
- Based on data collected, determine if correction/modifications to system components are necessary.
- Identify errors in data collection/CP measurements including contact resistance errors, voltage drop errors and, reference electrode errors.

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3% 3% 27%
- Utilize the instruments required to accomplish advanced cathodic protection testing and collection of cathodic protection systems measurements.
- Conduct cathodic protection surveys including close interval surveys and DCVG where needed or required and evaluate the graphs produced from the data collected during the surveys.
- Troubleshoot rectifiers and make corrections/repair as necessary.
- Perform efficiency test on rectifiers.
- Install new rectifiers.
- Understand the use of external CP coupons and be able to identify if the use of external coupons is needed for a CP system.
- Understand in-line and direct inspection (*understand and be able to implement ECDA*).

**DC Stray Current Interference**

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<tbody>
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- Conduct and document interference test where stray currents are suspected.
- Once interference tests have been run, suggest method of control that will mitigate the effects of the stray current.
- Understand how IR Drop test stations can be used to evaluate stray current.
- Understand how Coupon Test station can be used to determine the presence of and the mitigation of stray current.
- Calculate the resistance required for to provide the amount of current drain desired at a resistance bond installation.
- Understand the causes (sources) and the effects of interference.
- Understand the methods available to mitigate interference.

**AC Mitigation**

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<tr>
<td>23%</td>
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- Understand the safety requirements when installing test stations under high voltage power lines.
- Take appropriate steps to mitigate the effects of excessive AC voltage induced on underground structures.

**Corrosion Theory**

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- Understand the composition of a basic galvanic cell and the electrochemical reactions that allow corrosion to occur at the anode rather than the cathode.
- Describe the characteristics of anodic and cathodic reactions.
- Understand and apply the principles of electricity and electrical circuits (series, parallel, and series-parallel circuits) (including the application of Ohm’s and Kirchhoff’s Laws to electrical circuits.)
- Perform calculations using Ohm’s Law and calculations related to series and parallel circuits.
- Understand how corrosion cells are formed on metal objects that are underground or otherwise immersed in an electrolyte.
- Understand Faraday’s Law and perform calculations using Faraday’s law to determine required anode weight for cathodic protection.

**Polarization**

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- Understand the cause and effect of polarization in a galvanic cell.
- Understand activation, concentration and resistance polarization and the mathematical expressions of these concepts.
- Understand the factors that affect polarization (area, temperature, relative movement, ion concentration, oxygen concentration).

**Cathodic Protection**

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- Understand the concept cathodic protection and be knowledgeable of the Components required for both galvanic and impressed current systems.
- Be able to design and install simplistic forms of galvanic and impressed current cathodic protection facilities.
Understand the relationship between cathodic protection and other methods of corrosion mitigation.
Understand the factors that affect the amount of current required for a cathodic protection system.
Understand the NACE criteria for Cathodic Protection and be able to apply the criteria and make adjustments as necessary to CP systems in order to comply with the criteria defined by the company where the technologist is employed.
Understand IR drop and be able to determine the IR drop and apply correction techniques as needed.
Understand and apply E Log I criteria and construct polarization curves.
Understand the concept of current distribution and be able to determine ideal current distribution for a CP system taking into account the factors affecting current distribution (anode-to-cathode separation distance, electrolyte and structure resistivity variation, current attenuation).
Understand the effects of current path geometry, protective coatings and polarization on current distribution.

DESIGN
- Utilize field data to accomplish the calculations required to design cathodic protection current sources.
- Select site locations and implement the design of cathodic protection current sources for distribution or transmission pipeline systems.
- Design cathodic protection systems for the inside of water tanks.
- Design cathodic protection for the tank bottoms of aboveground storage tanks.
- Design cathodic protection for underground storage tanks.
- Work with engineering in the proper use of insulation for newly designed facilities.
- Provide information on underground coating performance for those selecting coatings for new facilities.

Types of Questions
Description of Questions
This closed-book exam consists of multiple-choice questions which may have multiple answers and require selection of more than one answer choice, as well as matching items. The cases require a candidate to apply knowledge and skills to answer the questions based on the problem presented in each case. The questions are based on the knowledge and skills required in the CP industry for a Cathodic Protection Technologist.

Sample Questions
The sample questions are included to illustrate the formats and types of questions that will be on the exam. Your performance on the sample questions should not be viewed as a predictor of your performance on the actual exam.

Problem Statement
The subject pipeline is a 24-inch outside diameter 4,500 linear foot horizontal directional drill under a river. The Pipeline is provided with a mill applied 16 mil thick Fusion Bonded Coating and a 60 mil thick...
Abrasion Resistant Overcoat. The pipeline girth welds are field coated with a 70 mil thick liquid epoxy coating. CP is to be provided by a local system dedicated to the HDD Pipeline.

**Key Assumptions**
The coating quality and CP current requirement are to be assessed prior to the pipeline being welded to (connected to) the upstream and downstream pipeline segments beyond the limits of the direction drill.

**Reference Material**
*What is Coating Conductance?*
- A relative measure of the ability of a coating to conduct (collect) current from the CP System.
- Conductance was originally designated in units called mhos (ohm spelled backwards, symbol is Ω).
- Today the International Unit for Conductance is Siemens (S = 1/Ω).

A Typical Test Setup Schematic is shown below:

A coating Quality Comparator is shown in the following Table:
Applicable Formulas (Would Be Provided)

- \textit{Applied Test Current} = I_T
- \textit{Voltage Shift resulting from Applied Test Current} \(\Delta V_1\) and \(\Delta V_2\)
- \textit{Resistance-to-Earth of Pipe} \(R_P = \frac{\Delta V_{AVG}}{\Delta I_T}\)
- \textit{Pipe Coating Resistance} \(R_c = R_P \times A\) where \(A = \pi dL\)
- \textit{Pipe Coating Conductance} \(S\) is \(1/R_c\)

Applicable Data

- The Native (Static) Pipe-to-Electrolyte Potentials at Locations \(V_1\) and \(V_2\) are -0.700 Volts/CSE and -0.630 volts/CSE respectively.
- The Applied test current is 0.050 Amperes.
- The Current Applied “On” Pipe-to-Electrolyte Potentials at Location \(V_1\) and \(V_2\) are -1.400 Volts/CSE and -1.300 Volts/CSE respectively.
- The Current “Off” Pipe-to-Electrolyte Potentials at Locations \(V_1\) and \(V_2\) are -0.850 Volts/CSE and -0.780 volts/CSE respectively.
Questions

1. What technique is best used to assess the protective coating quality of the pipeline?
   a. Close Interval Potential survey
   b. Pipe-to-Electrolyte Potential Measurement
   c. Coating Conductance Measurement
   d. Coating Attenuation Survey

2. In the example provided, what is the calculated Pipe-to-Earth Resistance $R_P$?
   a. 28,274 Ohms
   b. 3,400 Ohms
   c. 300,000 Ohms
   d. 29,400 Ohms
   e. 302,400 Ohms

3. In the example provided, what is the calculated Pipe Coating Resistance $R_C$?
   a. 650,000 Ohm-ft$^2$
   b. 302,535 Ohm-ft$^2$
   c. 250,364 Ohm-ft$^2$
   d. 52,298 Ohm-ft$^2$
   e. 102,000 Ohm-ft$^2$

4. In the example provided, what is the calculated Pipe Coating Conductance S?
   a. 1.305 µS
   b. 200 µS
   c. 3.304 µS
   d. $10 \times 10^{-6}$ S
   e. $23 \times 10^{-6}$ S

5. Using the data provided, what is the total current required to achieve a minimum polarized pipe potential of -0.900 Volts/cse?
   a. 100 mA
   b. 50 mA
   c. 0.090 Amperes
   d. 0.050 Amperes
   e. 1.500 Amperes

6. Using the information provided, rate the quality of the coating.
   a. Poor
   b. Fair
   c. Good
   d. Excellent
   e. Very Poor
Answer Key

1. C
2. A
3. B
4. C
5. C
6. C
Preparation

Training—None Required
NACE Cathodic Protection Technologist—Course CP 3 (Available)
NACE Cathodic Protection Technician—Course CP 2 (Available)
NACE Cathodic Protection Tester—Course CP 1 (Available)

Recommended Study Material

Books
NACE Cathodic Protection Technologist—CP 3 course material

Standards
EQUATIONS

RESISTANCE TO EARTH OF SINGLE VERTICAL ANODE

\[ R_V = \left[ \frac{0.00521 \rho}{L} \right] \ln \left( \frac{8L}{d} \right) - 1 \]

Where
- \( R_V \) = resistance in ohms
- \( \rho \) = resistivity in ohm-cm
- \( L \) = anode length in feet
- \( d \) = anode diameter in feet

RESISTANCE TO EARTH OF MULTIPLE VERTICAL ANODES

\[ R_V = \left[ \frac{0.00521 \rho}{NL} \right] \ln \left( \frac{8L}{d} \right) - 1 + \left[ \frac{2L}{S} \right] \ln(0.66N) \]

Where
- \( R_V \) = resistance in ohms
- \( \rho \) = resistivity in ohm-cm
- \( L \) = anode length in feet
- \( N \) = number of anodes
- \( S \) = twice the anode depth in feet
- \( d \) = anode diameter in feet

RESISTANCE TO EARTH OF SINGLE HORIZONTAL ANODE

\[ R_H = \left[ \frac{0.00521 \rho}{L} \right] \ln \left( \frac{4L^2 + 4L \sqrt{S^2 + L^2}}{dS} \right) + \frac{S}{L} - \frac{\sqrt{S^2 + L^2}}{L} - 1 \]

Where
- \( R_H \) = resistance in ohms
- \( \rho \) = resistivity in ohm-cm
- \( L \) = anode length in feet
- \( S \) = twice the anode depth in feet
- \( d \) = anode diameter in feet

RESISTANCE TO EARTH OF MULTIPLE HORIZONTAL ANODES

\[ R_T = \frac{R_H}{N} F \]

Where
- \( R_T \) = resistance of multiple horizontal anodes in ohms
- \( F \) = Anode Interference or Crowding Factor
- \( R_H \) = resistance of single horizontal anode in ohms
- \( N \) = number of anodes
ANODE INTERFERENCE BETWEEN ANODES (Crowding Factor)

\[ F = 1 + \frac{\rho}{\pi S R_H} \ln 0.66N \]

Where
- \( F \) = Anode Interference or Crowding Factor
- \( \rho \) = resistivity in ohm-m
- \( R_H \) = resistance of single horizontal anode in ohms
- \( N \) = number of anodes
- \( S \) = distance between anodes in m

CALCULATE PIPE OR CABLE RESISTANCE FROM RESISTIVITY (Pouillet’s Law)

\[ R = \frac{\rho L}{A} \]

Where
- \( R \) = resistance in ohms
- \( \rho \) = resistivity in ohm-cm
- \( A \) = cross-sectional area in cm²
- \( L \) = length in cm

WENNER SOIL RESISTIVITY

\[ \rho = 2\pi AR \]

Where
- \( \rho \) = soil resistivity in ohm-cm
- \( A \) = distance between probes in cm
- \( R \) = soil resistance in ohms {instrument reading}

OR

\[ \rho = 191.5 AR \]

Where
- \( \rho \) = soil resistivity in ohm-cm
- \( A \) = distance between probes in feet
- \( R \) = soil resistance in ohms {instrument reading}

KIRCHHOFF’S LAW

\[ V_m = \frac{R_m}{R_t} \times E_t \]

Where
- \( V_m \) = voltage drop across the voltmeter
- \( R_m \) = voltmeter input resistance
- \( R_t \) = total resistance
- \( E_t \) = true potential
ATTENUATION

\[ \alpha = \sqrt{rg} \]

Where
- \( \alpha \) = attenuation constant
- \( r \) = longitudinal resistance of structure in ohms
- \( g \) = conductance to earth in S

\[ r' = R_L A_S \]

Where
- \( r' \) = specific leakage resistance in ohm-m\(^2\) (ohm-ft\(^2\))
- \( R_L \) = average total leakage resistance in ohms
- \( A_S \) = total surface area in m\(^2\) (ft\(^2\))

\[ R_G = \frac{r'}{\sqrt{g}} \]

Where
- \( R_G \) = characteristic resistance
- \( r \) = longitudinal resistance of structure in ohms
- \( g \) = conductance to earth in S

AC CURRENT DENSITY

\[ i_{AC} = \frac{8V_{AC}}{\rho \pi d} \]

Where
- \( i_{AC} \) = AC current density in A / m\(^2\)
- \( V_{AC} \) = AC Volts in V
- \( \rho \) = soil resistivity in ohm-m
- \( d \) = holiday diameter in m

TEMPERATURE CONVERSION

\[ ^\circ C = \frac{5}{9} (^\circ F - 32^\circ) \]

\[ ^\circ F = \frac{9}{5} (^\circ C) + 32^\circ \]

REFERENCE ELECTRODE TEMPERATURE CONVERSION

\[ E = E^{0}_25^\circ C/SHE + k_t(T - 25^\circ C) \]

Where
- \( k_t \) = temperature coefficient in \( mV/({^\circ C}) \)
- \( E \) = reference potential at temperature \( T \) in \( ^\circ C \) (SHE)
- \( E^{0}_25^\circ C/SHE \) = reference potential at 25\(^\circ\)C
INPUT IMPEDANCE MEASUREMENT CORRECTION

\[ E_{true} = \frac{V_h(1 - K)}{1 - K \frac{V_h}{V_l}} \]

Where
- \( E_{true} \) = true potential in V
- \( K \) = input resistance ratio \( \frac{R_l}{R_h} \)
- \( R_l \) = lowest input resistance in ohms
- \( R_h \) = highest input resistance in ohms
- \( V_l \) = voltage measured with lowest input resistance in V
- \( V_h \) = voltage measured with highest input resistance in V

LENGTH OF BARE STRUCTURE RECEIVING PROTECTION

\[ L = 2d \tan 60^\circ \]

Where
- \( d \) = perpendicular distance between anode and structure
- \( L \) = length of structure receiving protection

BARNES LAYER

\[ R_{L2} = \frac{R_1 R_2}{(R_1 - R_2)} \]

Where
- \( R_{L2} \) = resistance of layer 2 in ohms
- \( R_1 \) = resistance measured to depth \( S_1 \) in ohms
- \( R_2 \) = resistance measured to depth \( S_2 \) in ohms
- \( L_2 = S_2 - S_1 \)

NERNST EQUATIONS

\[ E_M = E_M^o + \frac{RT}{nF} \ln \frac{\alpha^{M^{n^+}}}{\alpha^{M^o}} \]

Where
- \( E_M \) = metal potential
- \( E_M^o \) = metal potential at standard conditions
- \( R \) = universal gas constant (J/mol·°K)
- \( T \) = absolute temperature in kelvin
- \( F \) = Faraday’s Constant (96,500 coulombs)
- \( \alpha^{M^{n^+}} \) = metal ion activity
- \( \alpha^{M^o} \) = metal activity
- \( n \) = number of electrons transferred
## CONVERSIONS

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<tr>
<td>EMF</td>
<td>electromotive force – any voltage unit</td>
</tr>
<tr>
<td>E or e</td>
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</tr>
<tr>
<td>V</td>
<td>volts</td>
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<tr>
<td>mV</td>
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<td>mA</td>
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<tr>
<td>µA</td>
<td>microamperes or microamps</td>
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<td>R or Ω</td>
<td>Resistance</td>
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<td>100 millivolts</td>
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<tr>
<td>0.010 volt</td>
<td>10 millivolts</td>
</tr>
<tr>
<td>0.001 volt</td>
<td>1 millivolt</td>
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<tr>
<td>0.000001 volt</td>
<td>1 microvolt</td>
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<td>1 kilo-ohm</td>
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<td>1 milliohm</td>
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<tr>
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<td>1 micro-ohm</td>
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<tr>
<td>1 foot</td>
<td>30.48 cm</td>
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<tr>
<td>U.S. Customary/Metric Conversion for Units of Measure Commonly Used in Corrosion-Related Publications</td>
<td></td>
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<tr>
<td>------------------------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>1 A/ft² = 10.76 A/m²</td>
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</tr>
<tr>
<td>1 acre = 4,047 m² = 0.4047 ha</td>
<td></td>
</tr>
<tr>
<td>1 Ah/ib = 2.205 Ah/kg</td>
<td></td>
</tr>
<tr>
<td>1 bbl (oil, U.S.) = 159 L = 0.159 m³</td>
<td></td>
</tr>
<tr>
<td>1 bpd (oil) = 159 L/d = 0.159 m³/d</td>
<td></td>
</tr>
<tr>
<td>1 Btu = 1,055 J</td>
<td></td>
</tr>
<tr>
<td>1 Btu/ft² = 11,360 J/m²</td>
<td></td>
</tr>
<tr>
<td>1 Btu/h = 0.2931 W</td>
<td></td>
</tr>
<tr>
<td>1 Btu/h/ft² = 3.155 W/m² (K-factor)</td>
<td></td>
</tr>
<tr>
<td>1 Btu/h/ft²°F = 5.678 W/m²K</td>
<td></td>
</tr>
<tr>
<td>1 Btu/in/ft²°F = 0.1442 W/mK</td>
<td></td>
</tr>
<tr>
<td>1 cfm = 28.32 L/min = 0.02832 m³/min = 40.78 m³/d</td>
<td></td>
</tr>
<tr>
<td>1 cup = 236.6 mL = 0.2366 L</td>
<td></td>
</tr>
<tr>
<td>1 cycle/s = 1 Hz</td>
<td></td>
</tr>
<tr>
<td>1 ft = 0.3048 m</td>
<td></td>
</tr>
<tr>
<td>1 ft² = 0.0929 m² = 929 cm²</td>
<td></td>
</tr>
<tr>
<td>1 ft³ = 0.02832 m³ = 28.32 L</td>
<td></td>
</tr>
<tr>
<td>1 ft³bf (energy) = 1.356 J</td>
<td></td>
</tr>
<tr>
<td>1 ft³bf (torque) = 1.356 Nm</td>
<td></td>
</tr>
<tr>
<td>1 ft/s = 0.3048 m/s</td>
<td></td>
</tr>
<tr>
<td>1 gal (Imp.) = 4.546 L = 0.004546 m³</td>
<td></td>
</tr>
<tr>
<td>1 gal (U.S.) = 3.785 L = 0.003785 m³</td>
<td></td>
</tr>
<tr>
<td>1 gal (U.S.)/min (gpm) = 3.785 L/min = 0.2271 m³/h</td>
<td></td>
</tr>
<tr>
<td>1 gal/bag (U.S.) = 89 mL/kg (water/cement ratio)</td>
<td></td>
</tr>
<tr>
<td>1 grain = 0.06480 g = 64.80 mg</td>
<td></td>
</tr>
<tr>
<td>1 grain/ft³ = 2.288 g/m³</td>
<td></td>
</tr>
<tr>
<td>1 grain/100 ft³ = 22.88 mg/m³</td>
<td></td>
</tr>
<tr>
<td>1 hp = 0.7457 kW</td>
<td></td>
</tr>
<tr>
<td>1 microinch (µin) = 0.0254 µm = 25.4 nm</td>
<td></td>
</tr>
<tr>
<td>1 in = 0.0254 m = 2.54 cm = 25.4 mm</td>
<td></td>
</tr>
<tr>
<td>1 in² = 6.452 cm² = 645.2 mm²</td>
<td></td>
</tr>
<tr>
<td>1 in³ = 16.387 cm³ = 0.01639 L</td>
<td></td>
</tr>
<tr>
<td>1 in³bf (torque) = 0.113 Nm</td>
<td></td>
</tr>
<tr>
<td>1 inHg = 3.386 kPa</td>
<td></td>
</tr>
<tr>
<td>1 inH₂O = 249.1 Pa</td>
<td></td>
</tr>
<tr>
<td>1 knot = 0.5144 m/s</td>
<td></td>
</tr>
<tr>
<td>1 ksi = 6.895 MPa</td>
<td></td>
</tr>
<tr>
<td>1 lb = 453.6 g = 0.4536 kg</td>
<td></td>
</tr>
<tr>
<td>1 lb/ft² = 0.155 J</td>
<td></td>
</tr>
<tr>
<td>1 lb/ft³ = 16.02 kg/m³</td>
<td></td>
</tr>
<tr>
<td>1 lb/100 gal (U.S.) = 0.0554 m³</td>
<td></td>
</tr>
<tr>
<td>1 lb/1,000 bbl = 0.000554 m³</td>
<td></td>
</tr>
<tr>
<td>1 mA/in² = 0.155 mA/cm</td>
<td></td>
</tr>
<tr>
<td>1 mA/ft² = 10.76 mA/m</td>
<td></td>
</tr>
<tr>
<td>1 Mbpd (oil) = 159 kL/d = 159 m³/d</td>
<td></td>
</tr>
<tr>
<td>1 mile = 1.609 km</td>
<td></td>
</tr>
<tr>
<td>1 square mile = 2.590 km</td>
<td></td>
</tr>
<tr>
<td>1 mile (nautical) = 1.852 km</td>
<td></td>
</tr>
<tr>
<td>1 mil = 0.0254 mm = 25.4 µm</td>
<td></td>
</tr>
<tr>
<td>1 MMcfd = 2.832 x 10⁴ m³/d</td>
<td></td>
</tr>
<tr>
<td>1 mph = 1.609 km/h</td>
<td></td>
</tr>
<tr>
<td>1 mpy = 0.0254 mm/y = 25.4 µm/y</td>
<td></td>
</tr>
<tr>
<td>1 oz = 28.35 g</td>
<td></td>
</tr>
<tr>
<td>1 oz fluid (Imp.) = 28.41 mL</td>
<td></td>
</tr>
<tr>
<td>1 oz fluid (U.S.) = 29.57 mL</td>
<td></td>
</tr>
<tr>
<td>1 oz/ft² = 2.993 Pa</td>
<td></td>
</tr>
<tr>
<td>1 oz/gal (U.S.) = 7.49 g/L</td>
<td></td>
</tr>
<tr>
<td>1 psi = 0.006895 MPa = 6.895 kPa</td>
<td></td>
</tr>
<tr>
<td>1 qt (Imp.) = 1.1365 L</td>
<td></td>
</tr>
<tr>
<td>1 qt (U.S.) = 0.9464 L</td>
<td></td>
</tr>
<tr>
<td>1 tablespoon (tbs) = 4.929 mL</td>
<td></td>
</tr>
<tr>
<td>1 teaspoon (tsp) = 29.57 mL</td>
<td></td>
</tr>
<tr>
<td>1 ton (short) = 907.2 kg</td>
<td></td>
</tr>
<tr>
<td>1 U.S. bag cement = 42.63 kg (water/cement ratio)</td>
<td></td>
</tr>
<tr>
<td>1 ton (short) = 0.9464 L</td>
<td></td>
</tr>
<tr>
<td>1 ton (short) = 907.2 kg</td>
<td></td>
</tr>
<tr>
<td>1 yd = 0.9144 m</td>
<td></td>
</tr>
<tr>
<td>1 yd² = 0.8361 m²</td>
<td></td>
</tr>
<tr>
<td>1 yd³ = 0.7646 m³</td>
<td></td>
</tr>
</tbody>
</table>
### COMMON REFERENCE ELECTRODES AND THEIR POTENTIALS AT TEMPERATURE COEFFICIENTS

<table>
<thead>
<tr>
<th>Reference Electrode</th>
<th>Electrolyte Solution</th>
<th>Potential @ 25°C (V/SHE)</th>
<th>Temperature Co-efficient (mV/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu / CuSO₄ (CSE)</td>
<td>Sat. CuSO₄</td>
<td>+0.316</td>
<td>0.9</td>
</tr>
<tr>
<td>Ag / AgCl (SJ) (SSC)</td>
<td>0.6M NaCl (3½%)</td>
<td>+0.256</td>
<td>−0.33</td>
</tr>
<tr>
<td>Ag / AgCl (LJ) (SSC)</td>
<td>Sat. KCl</td>
<td>+0.222</td>
<td>−0.70</td>
</tr>
<tr>
<td>Ag / AgCl (LJ) (SSC)</td>
<td>0.1N KCl</td>
<td>+0.288</td>
<td>−0.43</td>
</tr>
<tr>
<td>Sat. Calomel (SCE)</td>
<td>Sat KCl</td>
<td>+0.244</td>
<td>−0.70</td>
</tr>
<tr>
<td>Zn (ZRE)</td>
<td>Saline Solution</td>
<td>−0.79</td>
<td>---</td>
</tr>
<tr>
<td>Zn (ZRE)</td>
<td>Soil</td>
<td>−0.80</td>
<td>---</td>
</tr>
</tbody>
</table>

SJ – solid junction          LJ – liquid junction
REFERENCE ELECTRODE CONVERSION SCALE

(SJ) = only solid silver chloride (AgCl) over the silver wire.

(LJ) = a silver wire surrounded by a concentrated solution of KCl.
### TYPICAL CONSUMPTION RATE AND CAPACITIES OF DIFFERENT ANODE MATERIALS IN SOILS OR FRESH WATERS

<table>
<thead>
<tr>
<th>Galvanic Anode Material</th>
<th>Theoretical Consumption Rate</th>
<th>Theoretical Capacity</th>
<th>Typical Efficiency (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg / A-γ</td>
<td>lb. / A-γ</td>
<td>A-γ / kg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>3.98</td>
<td>8.76</td>
<td>0.250</td>
</tr>
<tr>
<td>Zinc</td>
<td>10.76</td>
<td>23.50</td>
<td>0.093</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.94</td>
<td>6.49</td>
<td>0.340</td>
</tr>
<tr>
<td>Impressed Current Anode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite / Carbon</td>
<td>0.1 to 1.0</td>
<td>0.22 to 2.2</td>
<td>10.1 to 1.0</td>
</tr>
<tr>
<td>High Silicon Iron</td>
<td>0.25 to 1.0</td>
<td>0.55 to 2.2</td>
<td>4.0 to 1.0</td>
</tr>
<tr>
<td>Steel</td>
<td>9.1</td>
<td>20</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Note: Platinum clad and mixed metal oxide coated anodes are quantified by thickness of the surface film rather than by weight.

(1) Efficiency of galvanic anodes is dependent on the anode current density.
REFERENCES & STANDARDS USED TO DEVELOP THE REFERENCE MATERIAL


