Cathodic Protection Specialist Level 4 Case-Based Exam

Exam Preparation Guide

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Introduction

The Cathodic Protection Specialist (CP 4) Case-Based Exam is designed to assess whether a candidate has the requisite knowledge and skills that a minimally qualified Cathodic Protection Specialist must possess. The exam consists of 25 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 interpretation of CP data and troubleshooting.

Exam Name	AMPP-Cathodic Protection Specialist Case-Based Exam
Exam Code	NACE-CP4-Case-Based
Time	4 hours*
Number of Questions	25
Format	Computer Based Testing- CBT

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 4 course manual is **NOT** provided in the exam. Reference material is provided as a PDF for questions that require an equation, conversion chart, or other reference.*

Target Audience

CP 4 certification is geared toward persons involved in the design, installation, and maintenance of CP systems. Prior to taking the exam or the training course, students must have completed college or university-level courses in algebra, geometry, and trigonometry, and must have significant practical experience in cathodic protection.

NOTE: There is NOT a direct progression from Cathodic Protection Technologist (CP 3) to Cathodic Protection Specialist (CP 4). Substantial experience, beyond that of a CP 3, involving all aspects of CP, including design and formal education in math/science/engineering is critical to a candidate's success on this exam. Attendance in the Cathodic Protection Technologist (CP 3) course is strongly recommended before attempting Cathodic Protection Specialist (CP 4). However, additional experience and education are also recommended.

Requirements

Cathodic Protection Specialist (CP 4)

Requirements for Cathodic Protection Specialist (CP 4):
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:
12 years verifiable CP work experience
6 years verifiable CP work experience **AND** 4-year physical science or engineering degree **AND** Advanced physical science or engineering degree **OR** PE, PE Eng or equivalent
Core Exam Requirements:
The following exams are required: (2 core exams required)
Cathodic Protection Specialist Level 4 Exam (Theory) Cathodic Protection Specialist Level 4 Exam (Case-Based)
Application Requirement:
Approved Cathodic Protection Specialist (CP 4) application

NOTE: Completion of course does not entitle the candidate to the certification.

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.

Upon successful completion of requirements, the candidate will be awarded a **Cathodic Protection Specialist (CP 4) Certification.**

Exam Blueprint

Basics

A. Understand the relationship between voltage, current, and resistance as expressed by Ohm's Law.
B. Understand basic AC and DC circuits, to include series, parallel, and series-parallel.
C. Understand the composition of a basic galvanic cell and the electro-chemical reactions that allow corrosion to occur at the anode rather than the cathode.
D. Understand the cause and effect of polarization in a galvanic cell.
E. Understand the concept cathodic protection and the two primary methods of applying it to metal objects underground or otherwise immersed in an electrolyte.
F. Understand how corrosion cells are formed on metal objects that are underground or otherwise immersed in an electrolyte.
G. Understand the concept of shielding and how it can affect metallic objects that are cathodically protected.
H. Understand the principles of magnetism and how it applies to transformers.
I. Be able to identify different forms of corrosion.
J. Understand the effect of polarization on environment.

Insulators and Shorts

A. Understand the need for insulation or isolation between facilities.
B. Understand the effect a metallic short can have on your CP system.
C. Test to see if an insulator is shorted using pipe to soil readings.
D. Test an insulator with an electronic insulator-checking instrument.
E. Locate and clear shorts on an underground pipeline system.

Reference Cells

A. Understand the construction and operation of reference cells and maintain them in a manner that will provide comparative readings.
B. Install permanent reference cells and check them periodically to ensure that are in good working order.
C. Abide by the recommendations in the MSDS sheet pertaining to the handling and disposal of Copper Sulfate.
D. Use an antimony half-cell in comparison to a copper/copper sulfate half cell for determining the pH of soils.

Field Tests

A. Perform current requirement test.
B. Perform soil pH test.
C. Perform IR Drop test.
D. Run "shorted casing test" on casings that are suspected of being shorted and interpret the results of the test.
E. Perform coating examinations on sections of pipeline that have been excavated.
F. Perform soil resistivity test to evaluate the area for a conventional ground bed site.
G. Conduct Pearson surveys to evaluate the coating condition of a section of pipeline.
H. Conduct computerized close interval surveys where needed and evaluate the graphs produced from the data.
I. Locate breaks in header cables with an "audio type" pipe and cable locator.
J. Investigate shorts on a pipeline or other structure.
K. Verify the results of shorted casing test.
L. 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.
M. 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.
N. Based on data collected, determine if correction/modifications to system components are necessary.

O. Identify errors in data collection/CP measurements including contact resistance errors, voltage drop errors, and reference electrode errors.
P. Utilize the instruments required to accomplish advanced cathodic protection testing and collection of cathodic protection systems measurements.
Q. 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.
R. Troubleshoot rectifiers and make corrections/repair as necessary.
S. Perform efficiency test on rectifiers.
T. Install new rectifiers.
U. Understand the use of external CP coupons and be able to identify if the use of external coupons is needed for a CP system.
V. Understand in-line and direct inspection (understand and be able to implement ECDA).

DC Stray Current Interference

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

AC Mitigation

A. Understand the safety requirements when installing test stations under high voltage power lines.
B. Take appropriate steps to mitigate the effects of excessive AC voltage induced on underground structures.

Internal

A. Collect data on ER probes.

Polarization

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

Cathodic Protection

A. Understand the concept cathodic protection and be knowledgeable of the components required for both galvanic and impressed current systems.
B. Be able to design and install simplistic forms of galvanic and impressed current cathodic protection facilities.
C. Understand the relationship between cathodic protection and other methods of corrosion mitigation.
D. Understand the factors that affect the amount of current required for a cathodic protection system.
E. 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 specialist is employed.
F. Understand IR drop and be able to determine the IR drop and apply correction techniques as needed.
G. Understand and apply E Log I criteria and construct polarization curves.
H. 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).
I. Understand the effects of current path geometry, protective coatings, and polarization on current distribution.

Design

A. Utilize field data to accomplish the calculations required to design cathodic protection current sources.
B. Select site locations and implement the design of cathodic protection current sources for distribution or transmission pipeline systems
C. Design cathodic protection systems for the inside of water tanks
D. Design cathodic protection for the tank bottoms of aboveground storage tanks.
E. Design cathodic protection for underground storage tanks
F. Work with engineering in the proper use of insulation for newly designed facilities.
G. 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 Specialist.

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.

Pipeline Interference Case

Two gas pipelines come from separate processing plants, located near the seashore. They cross each other with a separation of 3.2 ft (1 m) at a location 656.2 ft (200 m) away from one of the plants. Each pipeline has an impressed current cathodic protection system.

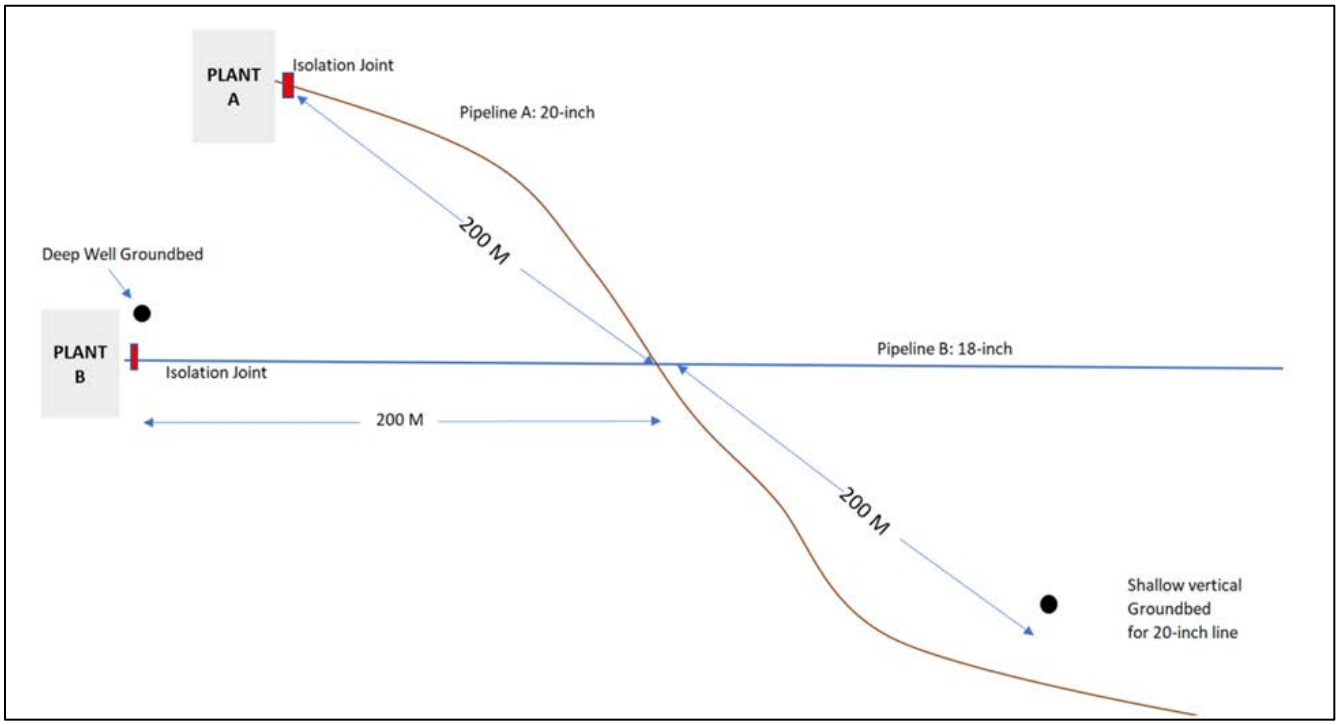
Pipeline A has a diameter of 18 in (45.7 cm) and FBE coating. Its cathodic protection system consists of a transformer / rectifier unit connected to a 295.3 ft (90 m) deep anode groundbed. It has been operating for 25 years.

Pipeline B is 20 in (50.8 cm), and is coated with 3-LPE. It is being protected by a shallow vertical anode groundbed connected to a thermogenerator. The pipeline has been operating for 30 years.

Interference between the two structures was detected. Pipeline A was picking up current from the groundbed that protects Pipeline B, and discharged the current to Pipeline B at the crossing point. This caused blisters (disbonding) on the coating for Pipeline A.

Since these systems are located near the coast, the soil surrounding the structures has high chloride content and low resistivity (500–1000 ohm-cm), and the ambient temperature is around 77°F (25°C).

CP Design:



Questions

1. What mitigation measures would be most suitable for this situation?
   SELECT ALL THAT APPLY

   A. Resistance bond between the pipelines
   B. Magnesium anodes connected to Pipeline A at the crossing
   C. Zinc anodes connected to Pipeline A at the crossing
   D. Reapplication of the coating at disbonded areas

2. What test should be conducted in order to determine the presence of interference after mitigation?

   A. DCVG
   B. Coating conductance test
   C. CIS involving all current sources
   D. Soil analysis

3. The specialist decides to connect galvanic anodes for mitigation at the crossing. Which of the following indicates the structure to which they should they be connected, and why?

   A. Pipeline B, to avoid current from being picked up at the pipeline wall
   B. Pipeline A, to avoid current from being discharged at the pipeline wall
   C. Pipeline B, to avoid current from being discharged at the pipeline wall
   D. Pipeline A, to avoid current from being picked up at the pipeline wall

4. After a resistance between the two pipelines was connected for testing, the following data was collected (with both CP systems being interrupted):

	Without Resistance		**With Resistance**	
	Pipeline A	**Pipeline B**	**Pipeline A**	**Pipeline B**
ON (mV Vs CSE)	-1.121	-1520	-1350	-1480
OFF (mV Vs CSE)	-1.202	-1180	-1020	-920

What can be concluded from this test?

   A. The resistance is mitigating the interference because it is reducing current flow from Pipeline B to Pipeline A.
   B. The resistance is limiting CP current for Pipeline B, leaving it unprotected.
   C. The resistance is preventing current discharge from Pipeline A, mitigating the interference.
   D. The resistance is ineffective as mitigation, because potentials are too high after it is connected.

Answer Key

1. A and C
2. C
3. B
4. C

Preparation

Training—None Required

AMPP Cathodic Protection Specialist—Course CP 4 (Available)

AMPP Cathodic Protection Technologist—Course CP 3 (Available)

AMPP Cathodic Protection Technician—Course CP 2 (Available)

AMPP Cathodic Protection Tester— Course CP 1 (Available)

Recommended Study Material

Books

Peabody, A. W. (2001). *Peabody's control of pipeline corrosion* (No. Ed. 2). NACE.

AMPP Cathodic Protection Specialist—CP 4 course material

Standards

NACE ISP 0207 (2007). “Performing Close Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines.”

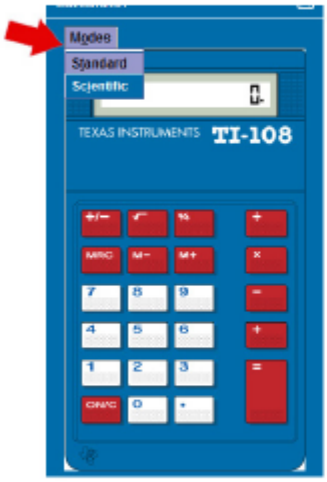
NACE SP 0169 (2013). “Control of External Corrosion on Underground of Submerged Metallic Piping Systems.”

NACE SP 0177 (2014). “Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems."

Calculators

Students will have access to either a TI Standard or TI Scientific calculator for use during the CBT Exam.

Standard Calculator



Standard Mode Functions

Add	+	
Subtract	-	
Multiply	X	
Divide	÷	
Negative	(-)	
Percentage	%	
Square Root	√	Example: 4 √
Reciprocal (Inverse)	x	Example: 1 ÷ 2 =
Store value to variable	M+	Example: 3 * 5 = M+
Access variable	MRC	Example: 7 + MRC =
Clear variable	M- MRC	

Scientific Calculator

Scientific Mode Functions

Add	+	
Subtract	-	
Multiply	X	
Divide	÷	
Negative	(-)	
Percentage	2nd [%]	
Square Root	√	Example: 2nd √ 4 enter
Reciprocal (Inverse)	X^{-1}	Example: 2 X^{-1} enter
Store value to variable	sto▶ X^{yzt}	Example: 3 * 5 enter sto▶ X^{yzt} enter
Access variable	X^{yzt} or 2nd [recall]	Example: 7 + 2nd [recall] enter enter

Numeric Notation

Standard (Floating Decimal) Notation (digits to the left and right of decimal	mode menu options **NORM** SCI ENG FLOAT 0 1 2 3 **4** 5 …	 e.g. 123456.78 e.g. 123456.7800
Scientific Notation (1 digit to the left of decimal and appropriate power of 10)	mode menu options NORM **SCI** ENG	 e.g. 1.2345678*105
Engineering Notation (numer from 1 to 999 times 10 to an integer power that is a multiple of 3)	mode menu options NORM **SCI** ENG	 e.g. 123.45678*103

Fractions

Simple fractions	n/d
Mixed numbers	2nd [Un/d]
Conversion b/w simple fraction and mixed number	2nd [n/d ◀ ▶ Un/d]
Conversion b/w fraction and decimal	2nd [f ◀ ▶ d]

Powers, roots, and inverses

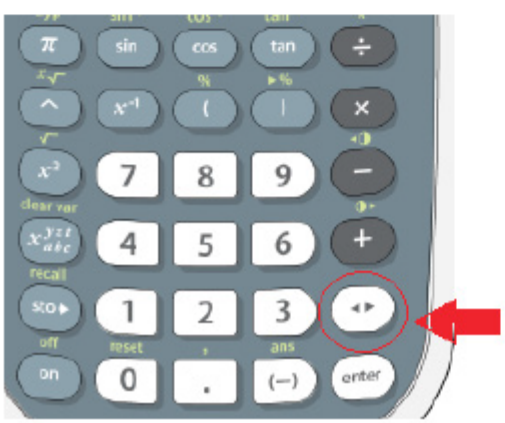
Square a value	x^2	
Cube a value	^	
Raise value to specified power	^	Example (2^4) 2 ^ 4
Square root	2nd [√]	Example (√16): 2nd [√] 16
Reciprocal	x^{-1}	Example (n^{th} root): 5th root of 8: 5 2nd [^{x}√] 8

Pi

PI (π)	π

Toggle

The scientific calculator might show the results of certain calculations as a fraction - possibly involving pi or a square root. To convert this kind of result to a single number with a decimal point, you will need to use the "toggle answer" button circled in the picture below. Pressing this button will change the display from a fractional to a decimal format.



Answer Toggle

Press the ◀▶ key to toggle the display result between fraction and decimal answers, exact square root and decimal, and exact pi and decimal.

Example

Answer toggle	2nd [√‾] 8 enter	√8 2√2
	◀▶	√8 2√2 2√2▸ 2.828427125

Note: If you find this onscreen calculator difficult to use, raise your hand and ask the Test Administrator to provide you with a hand-held calculator. **If available,** you will be provided with a scientific or non-scientific calculator. Candidates are not permitted to bring their own calculator into the testing room.

Reference Material Provided in the Exam

NOTE: All references, including equations, were taken from original sources and may differ from those used in course manuals and presentations

EQUATIONS

RESISTANCE TO EARTH OF SINGLE VERTICAL ANODE

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

Where

R_v = resistance in ohms
ρ = resistivity in ohm-cm
L = anode length in feet
d = anode diameter in feet

OR

$$R_v = \left[\frac{\rho}{2\pi L}\right]\left[\ln\left[\frac{8L}{d}\right] - 1\right]$$

Where

R_v = resistance in ohms
ρ = resistivity in ohm-m
L = anode length in m
d = anode diameter in m

RESISTANCE TO EARTH OF MULTIPLE VERTICAL ANODES

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

Where

R_v = resistance in ohms
ρ = resistivity in ohm-cm
L = anode length in feet
N = number of anodes
S = anode spacing in feet center to center
d = anode diameter in feet

OR

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

Where

R_v = resistance in ohms
ρ = resistivity in ohm-m
L = anode length in m
N = number of anodes
S = anode spacing center-to-center in m
d = anode diameter in m

NOTE: Use the units specified.

RESISTANCE TO EARTH OF SINGLE HORIZONTAL ANODE

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

Where

R_H = resistance in ohms
ρ = resistivity in ohm-cm
L = anode length in feet
S = twice the anode depth in feet
d = anode diameter in feet

OR

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

Where

R_H = resistance in ohms
ρ = resistivity in ohm-m
L = anode length in m
S = twice the anode depth in m
d = anode diameter in m

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

COUPLING FACTOR

$$\mathrm{R} = \Delta\mathrm{V} \ / \ \Delta\mathrm{I}$$

Where

R = coupling factor in mV / A
ΔV= pipe-to-soil potential shift in mV
ΔI = applied current A

ANODE INTERFERENCE BETWEEN ANODES (Crowding Factor)

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

Where

F = Anode Interference or Crowding Factor
ρ = 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)

$$R = \rho L / A$$

Where

R = resistance in ohms
ρ = resistivity in ohm-cm
A = cross-sectional area in cm^2
L = length in cm

LENGTH OF BARE STRUCTURE RECEIVING PROTECTION

$$L = 2d \tan 60°$$

Where

d = perpendicular distance between anode and structure
L = length of structure receiving protection

TEMPERATURE CONVERSION

$$°C = \frac{5}{9}(°F - 32°)$$

$$°F = \frac{9}{5}(°C) + 32°$$

WENNER SOIL RESISTIVITY

$$\rho = 2\pi AR$$

Where

ρ = soil resistivity in ohm-cm
A = distance between probes in cm
R = soil resistance in ohms {instrument reading}

OR

$$\rho = 191.5\, AR$$

Where

ρ = soil resistivity in ohm-cm
A = distance between probes in feet
R = soil resistance in ohms {instrument reading}

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

ATTENUATION

Where

I_S = current at sending end in Amps

E_s = potential at sending end in mV

y = number of unit lengths from sending end

x = number of unit lengths from receiving end

I_r = current at receiving end in Amps

E_r = potential at receiving end in mV

$$E = E_r \cosh(\alpha x) + R_G I_r \sinh(\alpha x)$$

$$E = E_s \cosh(\alpha y) - R_G I_s \sinh(\alpha y)$$

$$I = I_r \cosh(\alpha x) + \frac{E_r}{R_G} \sinh(\alpha x)$$

$$I = I_S \cosh(\alpha y) - \frac{E_s}{R_G} \sinh(\alpha y)$$

$$\alpha = \sqrt{rg}$$

Where

α = 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)

$$R_G = \sqrt{\frac{r}{g}}$$

Where

R_G = characteristic resistance
r = longitudinal resistance of structure in ohms
g = conductance to earth in S

$$R_{SO} = R_G \coth(\alpha x)$$

Where

R_{SO} = Resistance looking into open line in ohms

$$R_G = \sqrt{R_{SO} R_{SS}}$$

Where

R_{SS} = Resistance looking into open line in ohms

AC CURRENT DENSITY

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

Where

i_{AC} = AC current density in A / m²
V_{AC} = AC Volts in V
ρ = soil resistivity in ohm-m
d = holiday diameter in m

REFERENCE ELECTRODE TEMPERATURE CONVERSION

$$E = E^{o}_{25°C/SHE} + k_t(T - 25^{o}C)$$

Where

K_t = temperature coefficient in $mV/(°C)$
E_t = reference potential at temperature T in °C (SHE)
$E^{o}_{25°C/SHE}$ = reference potential at 25°C

KIRCHHOFF'S LAW

$$V_m = \frac{R_m}{R_t} E_t$$

Where

V_m = voltage drop across the voltmeter
R_m = voltmeter input resistance
R_t = total resistance
E_t = true potential

FARADAY'S LAW

$$\Delta m = \frac{MQ}{zF}$$

Where

Δm = mass of dissolved metal
M = atomic weight
Q = transferred electric charge
z = valance of the metal ions
F = Faraday's constant

MINIMUM WEIGHT OF ANY ANODE MATERIAL

$$W = \frac{I_{cp} L C_r}{UE} \quad \textbf{or} \quad W = \frac{I_{cp} L}{C_a UE}$$

Where

W = minimum weight of anode material in kg (lb)
I_{cp} = cathodic protection in amps
L = life of anode in years
C_r = theoretical consumption rate of anode material in $\frac{kg}{Amp-yr}\left(\frac{lb}{Amp-yr}\right)$
C_a = theoretical capacity of anode material in $\frac{Amp-yr}{kg}\left(\frac{Amp-yr}{lb}\right)$
U = utilization factor
E = electrochemical efficiency

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
α^{M^o} = metal activity
n = number of electrons transferred

CONVERSIONS

EMF	electromotive force – any voltage unit
E or e	any voltage unit
V	volts
mV	millivolts
µV	microvolts
I	any amperage unit
mA	milliamperes or milliamps
µA	microamperes or microamps
R or Ω	Resistance

1,000,000 volts	= 1 megavolt
1,000 volts	= 1 kilovolt
1.0 volt	= 1000 millivolts
0.100 volt	= 100 millivolts
0.010 volt	= 10 millivolts
0.001 volt	= 1 millivolt
0.000001 volt	= 1 microvolt

1,000,000 amperes	= 1 mega-ampere
1,000 amperes	= 1 kiloampere
1.0 ampere	= 1000 milliamperes
0.100 ampere	= 100 milliamperes
0.010 ampere	= 10 milliamperes
0.001 ampere	= 1 milliampere
0.000001 ampere	= 1 microampere

1,000,000 ohms	= 1 mega-ohm
1,000 ohms	= 1 kilo-ohm
1.0 ohms	= 1000 milliohms
0.100 ohm	= 100 milliohms
0.010 ohm	= 10 milliohms
0.001 ohm	= 1 milliohm
0.000001 ohm	= 1 micro-ohm

1 meter	= 100 cm
1 meter	= 1000 mm
1 inch	= 2.54 cm
1 foot	= 30.48 cm

U.S. Customary/Metric Conversion for Units of Measure Commonly Used in Corrosion-Related Publications

1 A/ft^2	= 10.76 A/m^2
1 acre	= 4,047 m^2 = 0.4047 ha
1 A·h/lb	= 2.205 A·h/kg
1 bbl (oil, U.S.)	= 159 L = 0.159 m^3
1 bpd (oil)	= 159 L/d = 0.159 m^3/d
1 Btu	= 1,055 J
1 Btu/ft^2	= 11,360 J/m^2
1 Btu/h	= 0.2931 W
1 Btu/h·ft^2	= 3.155 W/m^2 (K-factor)
1 Btu/h·ft^2·°F	= 5.678 W/m^2·K
1 Btu·in/h·ft^2·°F	= 0.1442 W/m·K
1 cfm	= 28.32 L/min = 0.02832 m^3/min = 40.78 m^3/d
1 cup	= 236.6 mL = 0.2366 L
1 cycle/s	= 1 Hz
1 ft	= 0.3048 m
1 ft^2	= 0.0929 m^2 = 929 cm^2
1 ft^3	= 0.02832 m^3 = 28.32 L
1 ft·lbf (energy)	= 1.356 J
1 ft·lbf (torque)	= 1.356 N·m
1 ft/s	= 0.3048 m/s
1 gal (Imp.)	= 4.546 L = 0.004546 m^3
1 gal (U.S.)	= 3.785 L = 0.003785 m^3
1 gal (U.S.)/min (gpm)	= 3.785 L/min = 0.2271 m^3/h
1 gal/bag (U.S.)	= 89 mL/kg (water/cement ratio)
1 grain	= 0.06480 g = 64.80 mg
1 grain/ft^3	= 2.288 g/m^3
1 grain/100 ft^3	= 22.88 mg/m^3
1 hp	= 0.7457 kW
1 microinch (µin)	= 0.0254 µm = 25.4 nm
1 in	= 0.0254 m = 2.54 cm = 25.4 mm
1 in^2	= 6.452 cm^2 = 645.2 mm^2
1 in^3	= 16.387 cm^3 = 0.01639 L
1 in·lbf (torque)	= 0.113 N·m
1 inHg	= 3.386 kPa

1 inH_2O	= 249.1 Pa
1 knot	= 0.5144 m/s
1 ksi	= 6.895 MPa
1 lb	= 453.6 g = 0.4536 kg
1 lbf/ft^2	= 47.88 Pa
1 lb/ft^3	= 16.02 kg/m^3
1 lb/100 gal (U.S.)	= 1.198 g/L
1 lb/1,000 bbl	= 2.853 mg/L
1 mA/in^2	= 0.155 mA/cm^2
1 mA/ft^2	= 10.76 mA/m^2
1 Mbpd (oil)	= 159 kL/d = 159 m^3/d
1 mile	= 1.609 km
1 square mile	= 2.590 km^2
1 mile (nautical)	= 1.852 km
1 mil	= 0.0254 mm = 25.4 µm
1 MMcfd	= 2.832 x 10^4 m^3/d
1 mph	= 1.609 km/h
1 mpy	= 0.0254 mm/y = 25.4 µm/y
1 oz	= 28.35 g
1 oz fluid (Imp.)	= 28.41 mL
1 oz fluid (U.S.)	= 29.57 mL
1 oz/ft^2	= 2.993 Pa
1 oz/gal (U.S.)	= 7.49 g/L
1 psi	= 0.006895 MPa = 6.895 kPa
1 qt (Imp.)	= 1.1365 L
1 qt (U.S.)	= 0.9464 L
1 tablespoon (tbs)	= 14.79 mL
1 teaspoon (tsp)	= 4.929 mL
1 ton (short)	= 907.2 kg
1 U.S. bag cement	= 42.63 kg (94 lb)
1 yd	= 0.9144 m
1 yd^2	= 0.8361 m^2
1 yd^3	= 0.7646 m^3

TABLES / SCALES

COMMON REFERENCE ELECTRODES AND THEIR POTENTIALS AT TEMPERATURE COEFFICIENTS

Reference Electrode	Electrolyte Solution	Potential @ 25°C ($V/_{SHE}$)	Temperature Co-efficient (mV/°C)
Cu / $CuSO_4$ (CSE)	Sat. $CuSO_4$	+0.316	0.9
Ag / AgCl (SJ) (SSC)	0.6M NaCl (3½%)	+0.256	−0.33
Ag / AgCl (LJ) (SSC)	Sat. KCl	+0.222	−0.70
Ag / AgCl (LJ) (SSC)	0.1N KCl	+0.288	−0.43
Sat. Calomel (SCE)	Sat KCl	+0.244	−0.70
Zn (ZRE)	Saline Solution	−0.79	---
Zn (ZRE)	Soil	−0.80	---

SJ – solid junction LJ – liquid junction

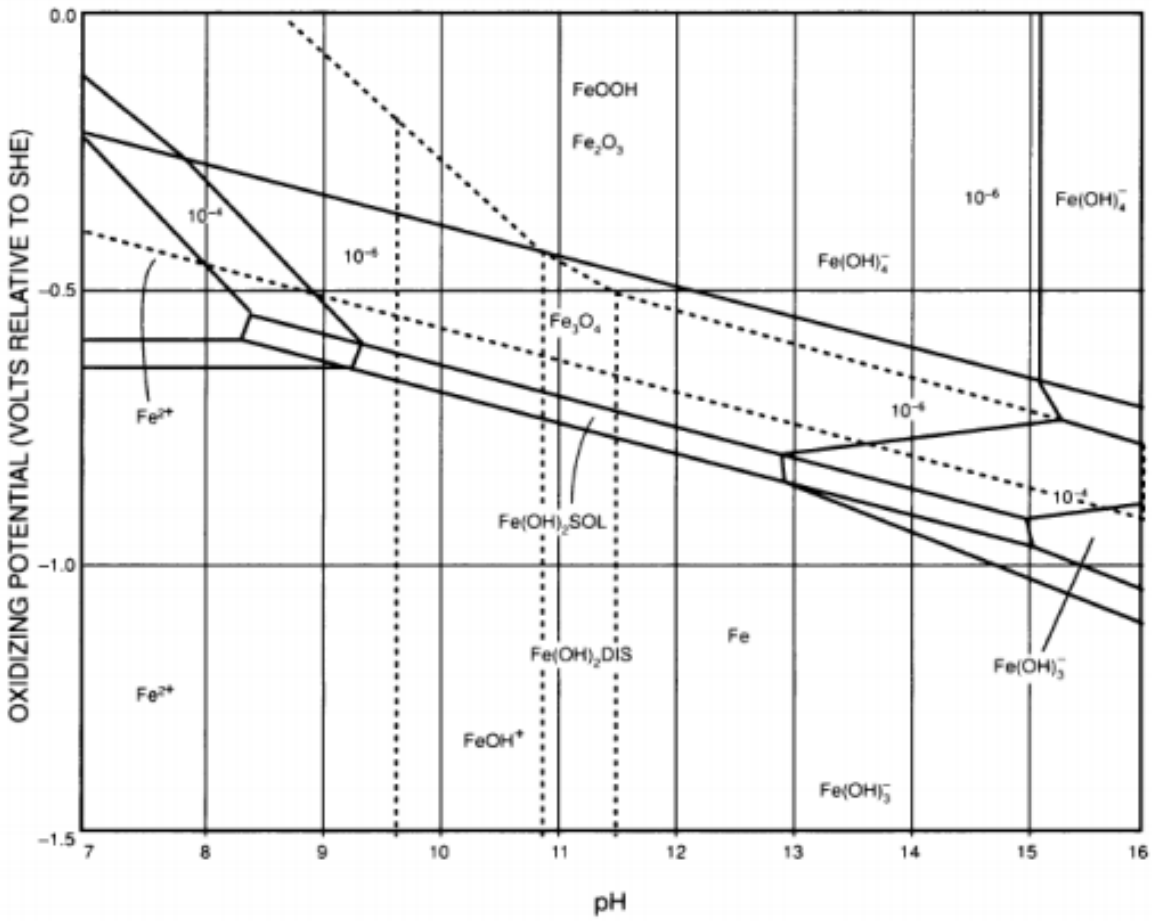
TYPICAL CONSUMPTION RATE AND CAPACITIES OF DIFFERENT ANODE MATERIALS IN SOILS OR FRESH WATERS

		Theoretical Consumption Rate		Theoretical Capacity		Typical Efficiency (1)
		kg / A-y	lb. / A-y	A-y / kg	A-y / lb.	%
Galvanic Anode Material	Magnesium	3.98	8.76	0.250	0.114	50
	Zinc	10.76	23.50	0.093	0.042	90
	Aluminum	2.94	6.49	0.340	0.155	85 - 95
Impressed Current Anode	Graphite / Carbon	0.1 to 1.0	0.22 to 2.2	10.1 to 1.0	4.5 to 0.45	
	High Silicon Iron	0.25 to 1.0	0.55 to 2.2	4.0 to 1.0	1.8 to 0.45	
	Steel	9.1	20	0.11	0.05	90

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

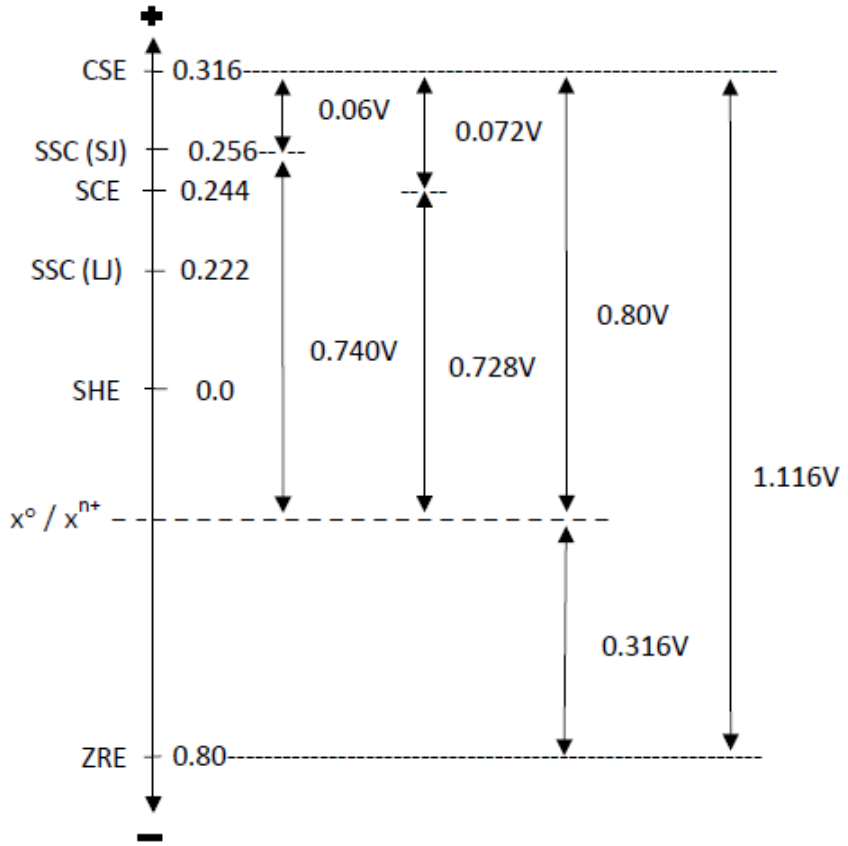
(1) Efficiency of galvanic anodes is dependent on the anode current density.

TYPICAL POTENTIAL-pH (POURBAIX) DIAGRAM IRON IN WATER AT 25°C



IONIC SPECIES ARE AT ACTIVITIES OF 10^{-4} AND 10^{-6}

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.

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