NACE Cathodic Protection Technician Level 2 Theory Exam

Exam Preparation Guide

November 2019

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Introduction

The Cathodic Protection Technician (CP 2) Theory Exam is designed to assess whether a candidate has the requisite knowledge and skills that a minimally qualified Cathodic Protection Technician must possess. The exam consists of 90 multiple-choice questions covering intermediate and basic areas of the Cathodic Protection Body of Knowledge (BOK). A candidate should have intermediate-level knowledge of corrosion theory, CP concepts, types of CP systems, and advanced field measurement techniques.

Test Name	NACE CP2 – Cathodic Protection Technician – Theory Exam
Test Code	NACE-CP2-001
Time	2 ½ hours*
Number of Questions	90
Format	Computer Based Testing (CBT)

NOTE: A pass/fail grade is provided at the end of the exam.

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

NOTE: The 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

Candidates for Cathodic Protection Technician (CP 2) should ideally have several years of CP field experience and possess intermediate-level knowledge of corrosion theory, CP concepts, the types of CP systems in common use, and be competent with basic rectifier diagnostics, as well as intermediate field measurement techniques and equipment. CP Technician candidates could also be practicing technicians or engineers with a more modest level of CP experience, but with more significant relevant technical education.

Typically, Cathodic Protection Technicians are responsible for testing and maintaining the effectiveness of operating CP systems and supervising or assisting with the installation of CP systems. This includes troubleshooting, identifying interference conditions, performing over-the-line surveys, and evaluating the results obtained.

Requirements

Cathodic Protection Technician (CP 2)

- 1 Prerequisite + Work Experience + 2 Core Exams + Application

The following prerequisite is required:
Successful completion of Cathodic Protection Tester (CP 1), or equivalent training
Work Experience Requirements:
Choose one of the following work experience options:
3 years verifiable CP work experience
2 years verifiable CP work experience **AND** 2 years post high school training from approved math / science or technical / trade school
1 year 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 Technician (CP 2) Practical Exam (hands-on) Cathodic Protection Technician (CP 2) Theory Exam (multiple choice, closed-book, with relevant references)
Application Requirement:
Approved Cathodic Protection Technician (CP 2) application

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

Note: The Cathodic Protection Technician (CP 2) Practical Exam is given at the conclusion of the NACE Cathodic Protection Technician (CP 2) course.

Upon successful completion of requirements, the candidate will be awarded a Cathodic Protection Technician (CP 2) Certification.

Next Level of Certification:

Cathodic Protection Technologist (CP 3)

CP 2 – Knowledge and Skill Areas Tested

NOTE: At the end of the CBT exam, the candidate will receive a bar chart of strengths and weaknesses that correspond to these domains.

1. **Basics**

   A. Be familiar with basic chemistry related to corrosion and role of acids and alkaline conditions.

   B. Understand how corrosion cells are formed on metal objects that are underground or otherwise immersed in an electrolyte.

   C. Be familiar with the Galvanic Series of metals.

   D. Understand the composition of a basic galvanic corrosion cell and the electrochemical reactions occur at the anode and the cathode.

   E. Understand and identify the forms of corrosion.

   F. Understand the physical and chemical characteristics of metals and electrolytes that at affect corrosion rate and polarization.

   G. Understand the cause and effect of polarization in a galvanic cell.

   H. Understand the relationship between voltage, current and resistance as expressed by Ohm's Law.

   I. Understand basic AC and DC circuits, including series, parallel and series-parallel.

   J. Understand the application of Kirchhoff's electrical circuit laws.

   K. Understand the concept of cathodic protection and the two primary methods of applying it to metal objects underground or otherwise immersed in an electrolyte.

   L. Understand and use the Nernst Equation to calculate the potential of a metal in a specific environment.

   M. Understand and use Evans Diagrams to demonstrate the effects that various factors have on corrosion and cathodic protection.

   N. Understand the characteristics and application methods of common pipeline coatings.

   O. Understand the concept of shielding and how it can affect metallic objects that are cathodically protected.

   P. Understand the use of Faraday's first law in relation to cathodic protection and corrosion of metals.

   Q. Be familiar with NACE standards and prominent international standards related to Cathodic Protection of steel and other structures in buried and immersed conditions.

   R. Be familiar with CP criteria in NACE and prominent international standards and special conditions or precautions related to their use.

   S. Understand and demonstrate the application of the E Log-I CP technique.

   T. Understand environmental and physical conditions that affect the application of CP criteria.

   U. Understand and demonstrate the applications and effects of electrically close and remote anodes.

   V. Understand what amphoteric material are the effect that cathodic protection may have on them.

W. Understand the safety considerations and methods for dealing with spark hazards and current in piping.

X. Understand Lock-Out/Tag-Out procedures.

Y. Understand common hazards related to cathodic protection work activities.

2. **Rectifiers**

A. Be capable of reading electrical schematics.

B. Use a digital volt-ohm meter (Multimeter) to determine the voltage and current output of a rectifier.

C. Understand how to install and commission new rectifiers.

D. Understand the procedure for performing an efficiency test on a rectifier.

E. Understand a transformer rectifier circuit and be able to follow the input AC voltage through the transformer to the rectification stack and the DC from the stack to the load.

F. Understand the types of rectifying circuits.

G. Understand the principles of magnetism and how it applies to transformers.

H. Repair rectifiers that have received damage from surges or lightning.

I. Know how to change the connections of a rectifier to receive 240 Volts or 120 Volts input AC.

J. Know how to test a transformer's primary and secondary out of the circuit with an ohm meter.

K. Know how to test a transformer in the circuit with an AC voltmeter.

L. Know how to calculate the secondary voltage for a transformer.

M. Understand the differences in a selenium and silicon diodes and the advantages and disadvantages of each when used in a CP rectifier.

N. Understand the various type of circuit breakers that can be used in CP rectifiers and the advantages and disadvantages of each.

O. Understand the circuits required in CP rectifiers for single and three phase AC inputs and be able to troubleshoot them.

P. Understand the various types of circuit configurations that can provide rectification: Full wave, single wave, full wave bridge.

Q. Understand the effects of filtering configurations used in CP rectifiers and the advantages each can provide.

R. Know how to modify a CP rectifier that is found to be interfering with EFM, SCADA or radio communication signals.

S. Know how to install chokes when the pulsating DC is causing problems with EFM calibration.

T. Understand the different types of rectifier operating modes: constant voltage, constant current, constant potential.

U. Understand the causes of common abnormal CP circuit conditions and their resulting effects on rectifier DC output.

3. **CP Current Source**
    A. Understand the basic aspects of common impressed current CP power sources other than transformer/rectifiers.
    B. Understand the different types of impressed current and galvanic anodes and their applications in soil and water environments.
    C. Install both impressed current and galvanic anodes, document the installation and test to ensure proper operation.
4. **Reference Cells**
    A. Understand the different types of reference cells, where they are used and their related conversion factors.
    B. Understand the construction and operation of reference cells and maintain them in a manner that will provide accurate readings.
    C. Understand the effects of temperature and electrolyte ion concentration on the calibration of reference cells.
    D. Install permanent (stationary) reference cells and check them periodically to insure they are in good working order.
    E. Understand the recommendations in the Safety Data Sheet pertaining to the handling and disposal of Copper Sulfate.
    F. Use an antimony half-cell in comparison to a copper/copper sulfate half-cell for determining the pH of soils.
5. **Instruments**
    A. Understand the operation of digital and analog Volt-Ohm meters (Multimeters) and how they are used to measure current, voltage and resistance.
    B. Understand and demonstrate other methods to measure current in CP circuits, such as, clamp-on ammeters and zero resistance ammeters.
    C. Use a digital Volt-Ohm meter to determine the current output of sacrificial anodes.
    D. Understand the various types of pipe locating instruments and be able to utilize them to locate pipelines, cables, shorts and broken cables in all underground environments.
    E. Understand the advantages and disadvantages of conductive and inductive pipe and cable locators.
    F. Understand the methods and equipment for testing pipeline coatings for holidays (damage) before burial.
    G. Be familiar with the use of in-line inspection tools for pipelines.
6. **CP Test Leads**
    A. Install jumper test leads across an isolation flange according to common industry practice.
    B. Install test leads for a potential test station according to common industry practice.

C. Install test leads for an interference bond according to common industry practice.

D. Install test leads for a foreign line crossing.

E. Install and calibrate 2-wire and 4-wire line current test stations.

F. Understand the common methods of making test lead and cable attachments to structures.

G. Understand the equipment and procedures to make test lead and cable attachments to a pipe or tank by using an exothermic weld kit.

H. Understand the equipment and procedures to make repairs and/or splices to bond leads, header cables and test leads.

I. Understand the equipment and procedures to add additional positive or negative cables to an existing rectifier circuit.

7. **Field Tests**

A. Understand the procedure and equipment for performing and analyzing a current requirement test.

B. Understand the procedure and equipment for a soil pH test.

C. Understand and demonstrate the methods for correcting for IR Drop errors in structure-to-electrolyte potentials.

D. Understand and demonstrate the effects of resistances in a CP measurement circuit and impedance in a Volt-Ohm meter on the true and measured potentials.

E. Conduct a Wenner 4-pin soil resistivity test with a soil resistance meter or equivalent instrument and calculate the soil resistivity.

F. Conduct soil resistivity measurements by using a Soil Box.

G. Understand and be able to perform Barnes Layer soil resistivity calculations.

H. Conduct single-point soil resistivity readings with a “Collins Rod”.

I. Install current interrupters in rectifiers or bonds for the purpose of taking “On” and “Instant off” structure-to-electrolyte potential readings.

J. Demonstrate the different types of “shorted casing tests” on buried pipelines and casings and interpret the results of the tests regarding electrical isolation, metallic short and electrolytic couple.

K. Understand the procedures and calculations for determining pipe resistance to remote earth, coating conductance and specific conductance.

L. Know how to perform examinations of the coating and pipe on sections of pipeline that have been excavated.

M. Understand the use of soil resistivity tests for selecting sites for installing impressed current or galvanic anodes.

N. Know how to locate breaks in header cables with a “audio type” pipe and cable locator.

O. Understand the basic principles of corrosion and CP testing on reinforced concrete structures.

P. Analyze reinforcing-to-reference electrode potential measurement for probability of corrosion.

8. **Periodic Surveys**

   A. Conduct annual structure-to-electrolyte surveys on all facilities.

   B. Conduct a polarization decay test.

   C. Conduct rectifier readings.

   D. Conduct surveys of bonds.

   E. Conduct surveys of diodes or current reversing switches.

   F. Conduct soil resistivity surveys.

   G. Conduct cell-to-cell surveys.

   H. Collect data on external CP coupon test stations.

   I. Conduct offshore platform and riser surveys.

   J. Be familiar with the purposes, procedures, equipment and data evaluation of the

9. **Insulators and Shorts**

   A. Understand the use of electrical isolation between facilities or equipment and the advantages and disadvantages of different types of isolation devices.

   B. Understand the use of protective devices for isolation devices.

   C. Understand the effects a metallic short can have on a CP system.

   D. Understand the test to determine if an isolation device is shorted using pipe-to-soil potential readings.

   E. Understand the procedure and equipment to test the effectiveness of an isolator with an electronic isolation checking instrument.

   F. Understand methods and equipment used to locate and clear shorts on an underground pipeline system.

10. **Shunts**

   A. Understand the procedures and calculation methods to determine the amount of current in a shunt by reading the milli-Volt (mV) drop across it with a digital voltmeter.

   B. Understand how to determine the direction of current in a shunt by observing the polarity of the mV reading.

   C. Understand how to read shunts in rectifiers to determine the output current.

   D. Understand how to read shunts in bonds with foreign structures and properly record the current magnitude and direction.

   E. Understand how to read shunts for individual anodes associated with impressed current ground beds.

   F. Understand how to utilize an external shunt to determine the output current of a rectifier with a broken amp meter.

   G. Understand how to read shunts that are installed in galvanic anodes to determine output current.

11. **DC Stray Current Interference**

A. Understand the causes and general solutions for Dynamic and Static stray current interferences.
B. Understand the principles of and solutions to "Anodic" and "Cathodic" stray current situations.
C. Conduct and document interference tests where stray currents are suspected and analyze the results.
D. Once interference tests have been run, suggest methods of control that will mitigate the effects of the stray current.
E. Understand how Line Current test stations can be used to evaluate stray current.
F. Understand how Coupon Test station can be used to determine the presence of and used in the mitigation of stray current.
G. Calculate the resistance required for to provide the amount of current drain desired at a resistance bond installation.

12. **AC Mitigation**

A. Understand the safety requirements when installing or working with test stations and other equipment near high voltage power lines.
B. Understand the causes and types of AC interference (or interactions) with pipelines and related safety standards and safe work practices.
C. Understand procedures and equipment used to mitigate the effects of excessive AC voltage induced on underground structures.
D. Know the AC voltage safety limit for pipelines and how to test for it safely.
E. Be able to safely test a rectifier cabinet for AC voltage before touching it.
F. Understand conditions where AC corrosion can occur.

13. **Internal**

A. Collect data on Electrical Resistance (ER) probes.

14. **Atmospheric**

A. Perform periodic atmospheric corrosion inspections and document your findings according to accepted industry practice.

15. **Recordkeeping and Administrative**

A. Record readings from periodic surveys and any other inspection and maintenance activities according to the common industry practice.
B. Maintain all records required by the respective policy or regulation for the life of the facility involved.
C. Understand the importance of accurate facility records and drawings, such as pipeline alignment sheets and other system maps and be able to provide accurate locations where work was done or new facilities installed.

Types of Questions

Description of Questions

This closed-book exam consists of multiple-choice questions where some questions may have multiple answers that require more than one answer choice, as well as matching items. The questions are based on the knowledge and skills required in the CP industry for a Cathodic Protection Technician. While the NACE training course is an excellent method of preparation, it is not the only reference used in the development of the questions. Additional references can be found in the Reference section.

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 test.

1. What is the current in a 91 m (300 ft) span of 762 mm (30 in) pipe weighing 176.65 kg/m (118.7 lb/ft), if the voltage drop across that span is 0.62 mV?

   A. 0.850 A

   B. 1.176 A

   C. 2.802 A

   D. 2.585 A

2. What is the pipe-to-earth resistance of a 3 km (1.86 mi) section of 32 cm (12.75 in) diameter pipe that has a 4-wire current span at each end with the following data?

Eon TS1 = -1320 mV	Eon TS2 = -1240 mV
Eoff TS1 = -1000 mV	Eoff TS2 = -1080 mV
Ion TS1 = 3.0 A	Ion TS2 = 2.6 A
Ioff TS1 = 1.0 A	Ioff TS2 = 1.0 A

   A. 0.052 Ω

   B. 0.076 Ω

   C. 0.15 Ω

   D. 0.60Ω

3. When an ammeter with an internal resistance of 0.15 Ω is inserted into a circuit that is normally operating at 5 V and 20 A, what will the ammeter current read?

   A. 0.08 A

   B. 10 A

   C. 12.5 A

   D. 50 A

Answer Key

1. **A**
2. **D**
3. **C**

Preparation

Training—None Required

NACE Cathodic Protection Technician – CP 2 Course (Available)

NACE Cathodic Protection Tester – CP 1 Course (Available)

Recommended Study Material

Books

Peabody, A. W. (2001). *Peabody's Control of Pipeline Corrosion* (No. Ed. 2). NACE International.

NACE Cathodic Protection Technician – CP 2 course material

Standards

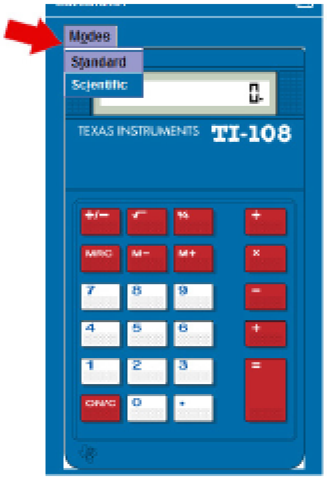
Latest editions should be used for all standards. Certain content from these standards is incorporated in the NACE Cathodic Protection Tester (CP 1) course materials and some of them are included in the course manual.

- NACE International SP 0169 (2013). "Control of External Corrosion on Underground of Submerged Metallic Piping Systems." NACE International.
- NACE International SP 0176 (2007) SG. "Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production." NACE International.
- NACE International SP 0177 (2014). "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems." NACE International.
- NACE International SP 0200 (2014). "Steel-Cased Pipeline Practices." NACE International.
- NACE International SP 0207 (2007). "Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines." NACE International.

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 e.g. 123456.78 FLOAT 0 1 2 3 **4** 5 … 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

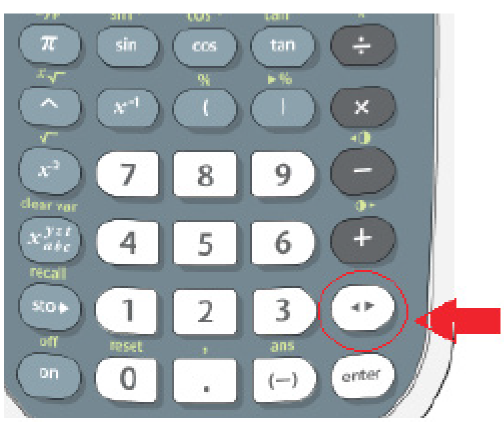
Square a value	x^2	
Cube a value	^	
Raise value to specified power	^	Example (2^4) 2 ^ 4
Square root	2nd [√]	Example (√16): 2nd [√] 16
Reciprocal	x^{-1}	Example (n^{th} root): 5^{th} root of 8: 5 2nd [^{x}√] 8

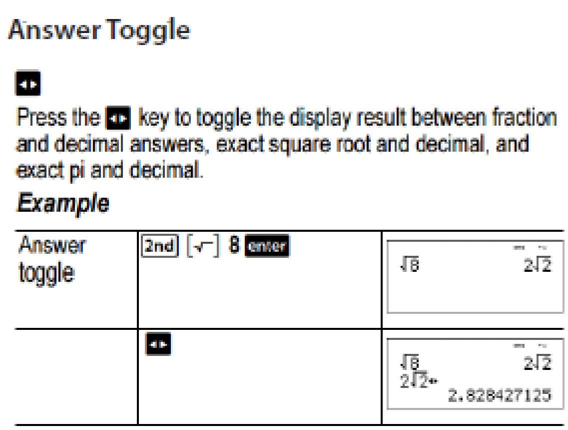
Pi

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 2.828427125

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.

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

EQUATIONS

RESISTIVITY (POUILLET'S LAW)

$$\rho = \frac{RA}{L} \qquad \textbf{OR} \qquad R = \frac{\rho A}{L}$$

Where

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

*length and area can be in any unit, as long as they are consistent

AREA OF A CIRCLE

$$\pi = r^2$$

Where

π = approximately 3.14
r = radius of circle

SURFACE AREA OF A CYLINDER

$$\pi \times D \times L$$

Where

π = approximately 3.14
D = diameter of cylinder*
L = length of cylinder*

*length and diameter can be in any unit, as long as they are consistent

FARADAY'S LAW

$$W_t = KIT$$

Where

W_t = weight loss in kg*
K = electrochemical equivalent in kg / A-yr
I = current in amps
T = time in years

*weight can be in any unit, as long as they are consistent

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}

*pin spacing can be in any unit, as long as it is consistent with resistivity

OR

$$\rho = 191.5\, AR$$

Where

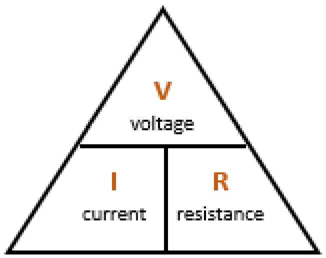
ρ = soil resistivity in ohm-cm

A = distance between probes in feet

R = soil resistance in ohms {instrument reading}

OHM'S LAW

$$V = IR \qquad I = \frac{V}{R} \qquad R = \frac{V}{I}$$



POWER

$$P = EI$$
$$P = I^2R$$

Where

P = power in watts

R = resistance in ohms

E = voltage in volts

I = current in amps

SERIES CIRCUIT

$$V_T = V_1 + V_2 + V_3$$

$$I_T = I_1 = I_2 = I_3$$

$$R_T = R_1 + R_2 + R_3$$

PARALLEL CIRCUIT

$$V_T = V_1 = V_2 = V_3$$

$$I_T = I_1 + I_2 + I_3$$

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

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
- $L_2 = S_2 - S_1$

TRUE STRUCTURE TO ELECTROLYTE POTENTIAL

$$E_{true} = V_{meter} \text{ x } \frac{R_{total}}{R_{meter}}$$

Where

- E_{true} = true potential in volts
- V_{meter} = voltmeter reading in volts
- R_{total} = total circuit resistance in ohms
- R_{meter} = voltmeter input resistance in ohms

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

Where

- E_{true} = true potential in volts
- 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 volts
- V_h = voltage measured with highest input resistance in volts

CONSUMPTION RATE (K) FOR VARIOUS METALS

Metal	kg / A-yr	lb / A-yr
Carbon	1.3	2.86
Aluminum	3.0	6.5
Magnesium	4.0	8.8
Iron / Steel	9.1	20.1
High Silicon / Chromium Iron	0.5	1.0
Nickel	9.6	21.2
Copper (Monovalent)	20.8	45.8
Zinc	10.7	23.6
Tin	19.4	42.8
Lead	33.9	74.7

RELATIVE VALUES OF TYPICAL REFERENCE ELECTRODES TO COPPER–COPPER SULFATE REFERENCE ELECTRODE

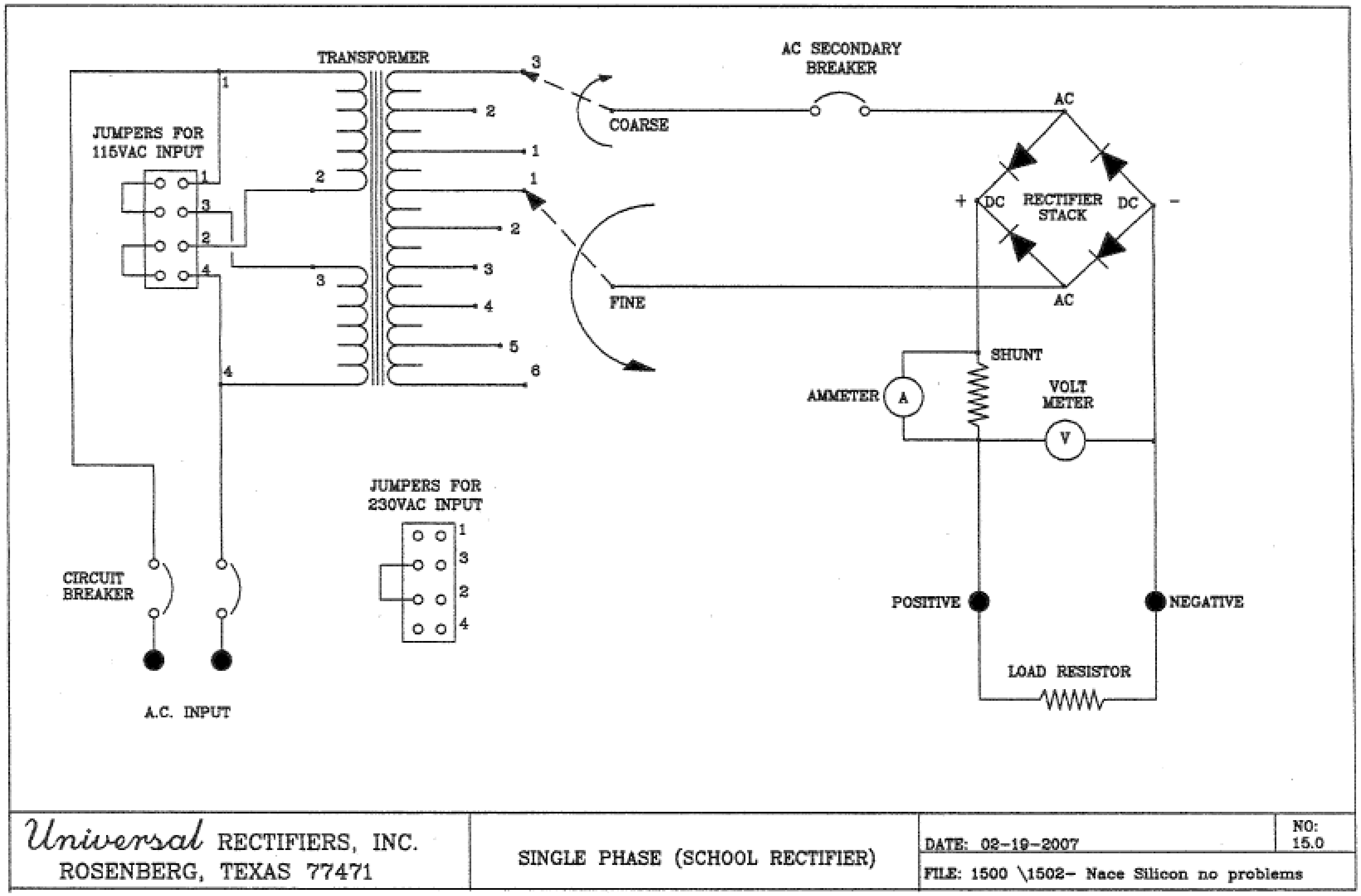
Electrode (Half-Cell)	Potential (Volt)
Copper–Copper Sulfate (Saturated) (CSE)	0.000
Silver–Silver Chloride (3.5%) (SSC)	-0.060
Saturated Calomel (SCE)	-0.072
Hydrogen (SHE)	-0.316
Pure Zinc (ZN)	-1.100

Based on seawater resistivity of 20 ohm-cm

SHUNT TYPES AND VALUES

	Shunt Rating		Shunt	Shunt
	Amps	mV	ohms	A / mV
Holloway Type				
RS	5	50	0.01	0.1
SS	25	25	0.001	1
SO	50	50	0.001	1
SW or CP	1	50	0.05	0.02
SW or CP	2	50	0.025	0.04
SW or CP	3	50	0.017	0.06
SW or CP	4	50	0.0125	0.08
SW or CP	5	50	0.01	0.1
SW or CP	10	50	0.005	0.2
SW	15	50	0.0033	0.3
SW	20	50	0.0025	0.4
SW	25	50	0.002	0.5
SW	30	50	0.0017	0.6
SW	50	50	0.001	1
SW	60	50	0.0008	1.2
SW	75	50	0.00067	1.5
SW	100	50	0.0005	2
J.B. Type				
Agra-Mesa	5	50	0.01	0.1
Cott or MCM				
Red	2	200	0.1	0.01
Yellow	8	80	0.01	0.1
Orange	25	25	0.001	1

RECTIFIER CIRCUIT



PRACTICAL GALVANIC SERIES

Material	Potential (V)*
High Potential Magnesium	-1.75
Magnesium Alloy	-1.60
Zinc	-1.10
Aluminum Alloy	-1.05
Clean Carbon Steel	-0.50 to -0.80
Rusted Carbon Steel	-0.20 to -0.50
Cast / Ductile Iron	-0.50
Lead	-0.50
Steel in Concrete	-0.20
Copper	-0.20
High Silicon Iron	-0.20
Carbon, Graphite	+0.30

*Potentials with respect to Saturated Cu–$CuSO_4$ Electrode

SPECIFIC COATING RESISTANCE

$$R_{CE} = A_{PIPE} \text{ x } R_C$$

Where

R_{CE} = specific coating resistance in ohm-m^2

A_{PIPE} = surface area of pipe in m^2*

R_C = pipe coating resistance in ohms

*area can be in any unit, as long as they are consistent

4-WIRE LINE CURRENT TEST CALIBRATION

$$K = \frac{I_{test}}{\Delta V_{test}}$$

Where

K = calibration factor in amps / mV

I_{test} = test current applied to pipe section in amps

$\Delta V_{test} = V_{test,current\ applied} - V_{test,\ no\ current\ applied}$ in mV

CURRENT IN PIPE

$$I = KV$$

Where

I = pipeline current in amps

K = calibration factor in amps / mV

V = Voltage drop in pipeline section in mV

PIPE COATING RESISTANCE

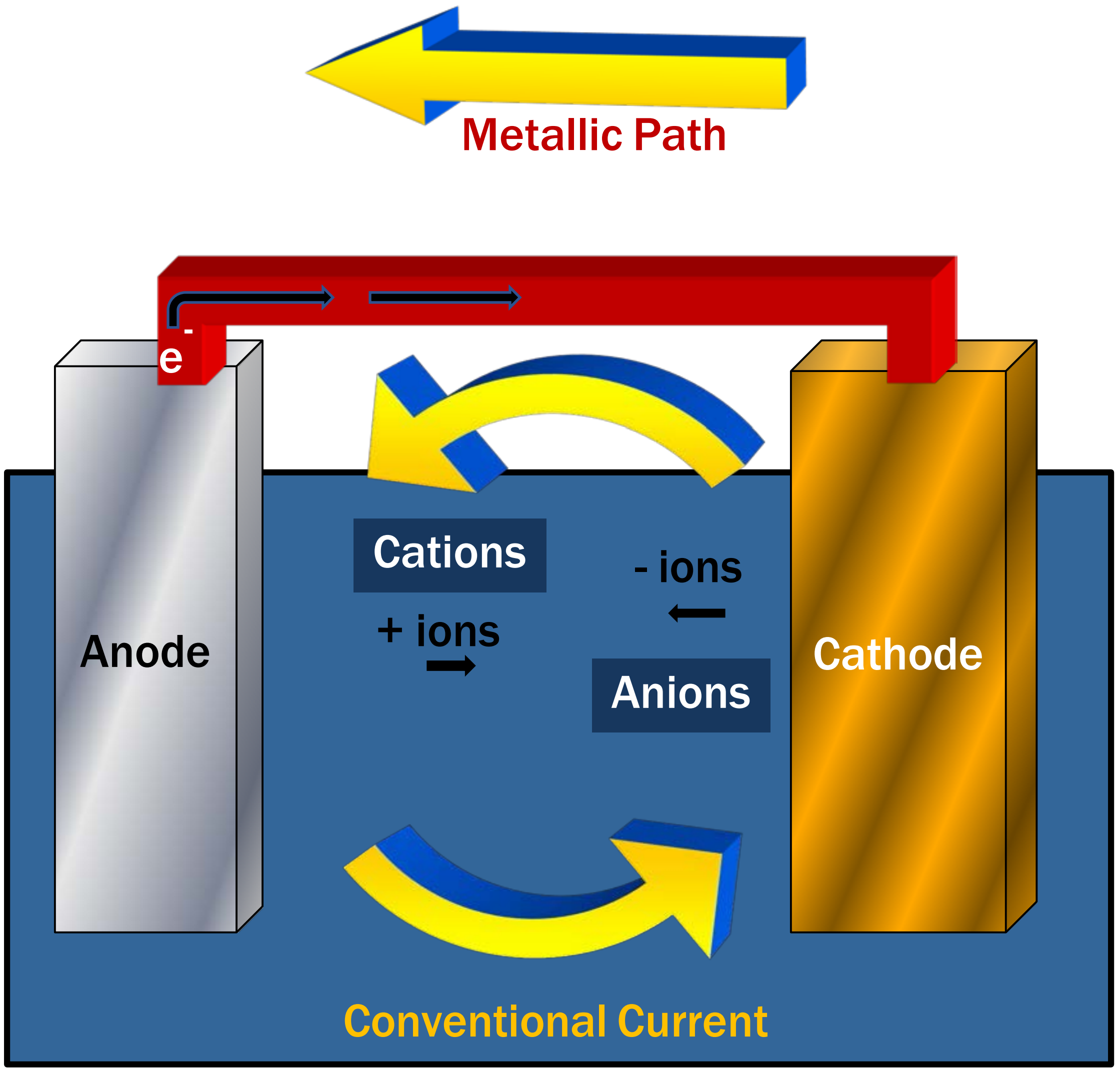
$$R_c = \frac{\Delta E_{ave}}{I_C}$$

Where

R_c = pipe coating resistance in ohms

ΔE_{ave} = average potential change across pipe section in volts

I_c = current applied across pipe section in amps


Metallic Path
e-
Anode
Cations
+ ions
- ions
Anions
Cathode
Conventional Current

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

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