

Contents

1. GLOSSARY

NACE/ASTM Standard Terminology Relating to Corrosion	1
NACE/ASTM Standard Acronyms Relating to Corrosion.....	38
Standard Abbreviations and Unit Symbols.....	49

2. CONVERSION TABLES

SI Quick Reference Guide	57
International System of Units (SI)	58
Prefixes	60
General Conversion Factors.....	61
Metric and Decimal Equivalents of Fractions of an Inch	64
Condensed Metric Practice Guide for Corrosion	65
Corrosion Rate Relationships	70
Approximate Equivalent Hardness Numbers and Tensile Strengths for Steel	71
Common Gage Series Used for Sheet Thickness	73
Sheet Gage—Thickness Conversions (inches)	73
Temperature Conversions	75
Stress Conversions	79
Sheet Gage—Thickness Conversions (mm)	82

3. PHYSICAL AND CHEMICAL DATA

Physical Properties of Gases and Liquids	83
Physical Properties of Elements.....	85
Processes for Reagent Water Production.....	87
Physical Properties of Water	89
Properties of Dry Saturated Steam—English Units.....	90
—SI Units.....	92
Vapor Pressure of Water Below 100° C	95
Dew Point of Moist Air.....	97
Relative Humidities for Condensation.....	105
Absolute Atmospheric Humidities.....	106
Vapor Pressure vs Temperature for Volatile Compounds.....	107
Approximate pH Values at 25° C.....	108
Boiling Points vs Concentration of	
Common Corrosive Media	109
pH Values of Pure Water at Different Temperatures.....	110
Solubility of Gases in Water.....	111
Solubility of Air in Water and Solvents.....	112
Solubility of Water in Gasoline.....	113
Solubility of Water in Specific Hydrocarbons	113
Thermocouple Data.....	114

4. CORROSION TESTING

Hypothetical Cathodic and Anodic Polarization Diagram.....	115
Typical Cathodic and Anodic Polarization Diagram.....	116
Hypothetical Cathodic and Anodic Polarization	
Plots for a Passive Anode	117
Typical Standard Potentiostatic Anodic Polarization Plot	118
Cyclic Potentiodynamic Polarization Curves in	
Chloride Solution	119
Data for Tafel Equation Calculations.....	120
Hypothetical Polarization Resistance Plot	121
Polarization Resistance Method for Determining	
Corrosion Rates.....	122
Values of the Constant B for the Polarization	
Resistance Method	123
Hydrogen Overvoltage on Various Electrode Materials	124
Standard Reference Potentials and Conversion Table	125
Electrochemical Series.....	127
Conversion Factors	128
EMF Series for Metals.....	133

Typical Potential-pH (Pourbaix) Diagram Iron in Water at 25° C	134
Partial Listing of Alloys and Species Conducive to Environmental Cracking.....	135
Standard Environments for Environmental Cracking Tests.....	136
Specimen Types Used in Environmental Cracking Tests	137
Intergranular Corrosion Tests.....	138
Exfoliation Corrosion of Aluminum Alloy.....	139
Dealloying Nomenclature	139
Dealloy Mechanisms	140
Combinations of Alloys and Environments Subject to Dealloying ..	141
Comparison of Crevice Corrosion Tests.....	142
Polarization Diagrams for a Galvanic Couple (Metals A and B)	143
Practical Galvanic Series	144
Galvanic Corrosion Test Circuit Using a Potentiostat as a Zero Resistance Ammeter	145
Low Cost Potentiostat Circuit	145
Typical High Temperature/High Pressure Tests Conditions....	146
Corrosion Rate Conversion Factors	148
Densities of Common Alloys	149
Density of Materials.....	151
Equivalent Weight Values for Metals and Alloys.....	153
Corrosion Rate Calculation from Mass Loss.....	159
Values of Constants for Use in Faraday's Equation	160

5. CORROSION EVALUATION

Chemical Cleaning Procedures for Removal of Corrosion Products	161
Electrolytic Cleaning Procedures for Removal of Corrosion Products.....	166
Etchants for Revealing Microstructures in Alloys	168
Comparison of Surface Analysis Techniques	170
Standard Rating Chart for Pits	172
Cross-Sectional Shape of Pits.....	172
Standard Dot Patterns for Number of Pits	173
Random Dot Patterns	173
Standard Coating Ratings Systems.....	174
Rating of Painted Surface	175
Abbreviations Describing Defects	177
Rating of Electroplated Panels Subjected to Atmospheric Exposure	178

6. ATMOSPHERIC CORROSION

Environmental Pollutants Causing Corrosion	181
Classification of Test Sites According to ISO 9223	
Environmental Criteria.....	183
Metals Used in the ISOCORRAG Program.....	185
Composition of Unalloyed Carbon Steel Used in the Collaborative Program.....	185
Corrosion Losses of Steel—1, 2, 4, and 8 years Exposure.....	186
Corrosion Losses of Zinc—1, 2, 4, and 8 years Exposure	188
Corrosion Losses of Copper—1, 2, 4, and 8 years Exposure....	190
Corrosion Losses of Aluminum—1, 2, 4, and 8 years Exposure	192
Atmospheric Corrosion of Steel and Zinc at Various Test Sites	194
Atmospheric Corrosion of Steel vs Time in an Industrial Atmosphere.....	196
Corrosion of Structural Steel in Various Environments	197
Effect of Amount of Zinc on Service Life of Galvanized Sheet in Various Environments	198
Development of Rust on Zinc and Cadmium-Plated Steels in a Marine Atmosphere.....	199
Atmospheric Corrosion of Zinc in Various Locations as a Function of Time	200
Lifetimes of Hot Dip Zinc and Zinc-Alloy Coatings.....	201
Atmospheric Corrosion of Various Metals and Alloys	201
Corrosion of Copper Alloys in Marine Atmospheres	202
Corrosion of Copper and Copper Alloys in $\mu\text{m}/\text{Year}$	203
Corrosion in $\mu\text{m}/\text{Year}$ of Nickel and Its Alloys in Various Atmospheres	203
Relative Performance of Stainless Steels Exposed in a Marine Atmosphere	204

7. SEAWATER AND COOLING WATER CORROSION

Composition of Substitute Ocean Water	205
Typical Seawater Properties at Worldwide Sites	207
Environment/Depth Profile in the Gulf of Mexico	208
Specific Conductance of Seawater vs Temperature and Chlorinity	209
Corrosion Factors for Carbon Steel in Seawater.....	210
Zones of Corrosion for Steel Piling in Seawater	211
Rates of General Wastage of Metals in Quiet Seawater	212

Corrosion Rate of Carbon Steel vs Depth	213
Effect of Velocity on the Corrosion of Metals in Seawater	214
Suggested Velocity Limits for Condenser Tube Alloys	
in Seawater	215
Galvanic Series in Seawater	216
Practical Galvanic Series.....	? 217
Corrosion of Steel in Aerated Water.....	217
Calculation of Calcium Carbonate Saturation Index (Langelier Index)	218
Water Analysis Conversion Factors.....	219
Common Groups of Algae.....	219
Common Types of Bacteria Causing Slime Problems	220
Microorganisms Commonly Implicated in Biological Corrosion.....	221
Microbiocides Used in Cooling Water Systems	222

8. CATHODIC PROTECTION

Application and Data for Cathodic Protection Reference	
Electrodes.....	223
Criteria for Cathodic Protection.....	224
Summary of Protection Current Densities Used in	
CP Applications	225
Approximate Current Requirements for Cathodic	
Protection of Steel.....	226
Design Criteria for Offshore Cathodic Protection Systems	227
Effect of Applied Cathodic Current on Corrosion	
and Potential of Steel in Flowing Seawater	228
Systems for Coastal and Harbor Structures	229
Protection Potentials Cathodic Protection	
for Metals and Alloys	230
Composition and Properties of Solid Impressed	
Current Anodes.....	232
Properties of Metals in Platinum Type Impressed	
Current Anodes.....	233
Composition and Properties of Noble Metal Anodes.....	234
Platinum Consumption Rates for Cathodic	
Protection Anodes.....	235
Properties of Impressed Current Anodes for Soils.....	236
Properties of Galvanic Anodes	237
Composition and Properties of Aluminium Alloys	
for Anodes	237
Composition and Properties of Magnesium Anodes	238

Composition and Properties of Zinc Anodes	240
Comparison of Zinc and Magnesium Anodes for Soils	241
Resistance of Galvanic Anodes—Dwight's Equation.....	242
Calculation Formulas for Simple Anodes	243
Classification of Soils.....	245
Typical Resistivities of Some Waters and Soil Materials.....	245
Soil Resistivity vs Corrosivity	246
Soil Corrosivity Classes for Uncoated Steel.....	247
Resistivity of Various Minerals and Soils	248
Composition of Petroleum and Metallurgical Coke Backfill....	249
Weights of Carbonaceous Backfill.....	249
Composition of Backfills for Zinc and Magnesium Anodes.....	250
Properties of Concentric Stranded Copper Single Conductors ...	251
Temperature Correction Factors for Resistance of Copper	252
Steel Pipe Resistance.....	253
Alloy Pipe Resistance	254
Typical Attenuation on a Pipeline	254
Corrosion of Steels, Copper, Lead, and Zinc in Soils.....	255
Effect of Chlorides, Sulfates, and pH Corrosion of Buried Steel Pipelines.....	256
Environmental Factors on Corrosion Rate of Steel in Soils	257
Corrosion Rates of Zinc Coatings on Steel in Soils at Various Locations.....	258
Corrosion of Galvanized Pipe in Various Soils	259
Estimating Service Life of Galvanized Steel in Soils.....	260

9. PROCESS AND OIL INDUSTRIES CORROSION

Nondestructive Methods for Evaluating Materials.....	261
Caustic Soda Service Chart.....	269
Sulfuric Acid Service Graph	270
Code for Sulfuric Acid Graph	271
Alloys for Sulfuric Acid Service	272
Alloys for Nitric Acid Service	275
Alloys for Hydrochloric Acid Service	276
Alloys for Hydrofluoric Acid Service	277
Estimate of Sulfur Trioxide in Combustion Gas	278
Calculated Sulfuric Acid Dewpoint in Flue Gas.....	279
Operating Limits for Steels in Hydrogen Service to Avoid Decarburization and Fissuring.....	280
Liquid Metal Cracking	281

Stress Corrosion Cracking Systems	282
Hydrogen Degradation of Metals—Classification	283
Potential Sulfide Stress Cracking Region as Defined by the 0.05 psia Criterion.....	286
Composition of Alloys for High-Temperature Chemical Processing Environments.....	287
Maximum Temperature for Continuous Service in Dry Hydrogen Chloride and Dry Chlorine.....	288
Corrosion Rates in Dry Chlorine at Different Temperatures	289
Maximum Service Temperature in Air for Stainless Steels and Alloy Steels.....	290
High Temperature Sulfidic Corrosion of Steels and Stainless Steels	291
High Temperature H ₂ S/H ₂ Corrosion of 5Cr-0.5Mo Steel.....	292
High Temperature H ₂ S/H ₂ Corrosion of Stainless Steels	293
Ash Fusion Temperatures of Slag-Forming Compounds.....	294
Distribution Ratio of Ammonia and Amines in Steam and Steam Condensate.....	295
Common Types of Scale-Forming Minerals.....	296
Chemical Cleaning Solutions for Specific Scales	297
Components of Boiler Deposits.....	299
Paths of Conventional Crude Oils from Well to Wheel	300
Paths of Natural Gas from Reservoir to the User	301
Predominant Corrosion Types in Various Segments of the Oil and Gas Industry.....	302
Compositions of Commonly Used Oil Field Corrosion- Resistant Alloys	307
Dimensions of Seamless and Welded Wrought Steel Pipe.....	308
Standard Wall Steel Pipe—Dimensions, Capacities, and Weights.....	310

10. METALLIC MATERIALS

Unified Numbering System for Metals and Alloys.....	313
Common Names of UNS Alloys	315
Comparable Alloy Designations	318
Compositions and Typical Mechanical Properties Aluminum Alloys.....	321
Copper Alloys.....	323
Carbon and Low Alloy Steels	328
Cast Irons.....	331

Tool Steels.....	333
Cast Heat Resistant Stainless Steels	335
Cast Corrosion Resistant Stainless Steels	336
Austenitic Stainless Steels.....	339
Austenitic Stainless Steels (High Mn)	341
Martensitic Stainless Steels	345
Ferritic Stainless Steels	347
Duplex Stainless Steels.....	350
Precipitation-Hardenable Stainless Steels	352
Nickel Alloys.....	354
CrMo Nickel Alloys.....	357
Cobalt Alloys.....	363
Refractory Alloys (Mo, Cb, Ta, W, Zr).....	366
Titanium Alloys.....	368
Lead Alloys	373
Magnesium Alloys.....	373
Precious Metals (Au, Ag, Pt, Pd)	375
Zinc Alloys	375
API Grades of Casting and Tubing.....	376
Maximum Allowable Stress in Tension (ASME Code)	
Aluminum Alloys	380
Copper Alloys	381
Carbon and Low Alloy Steels	382
Stainless Steels	383
Nickel Alloys	386
Titanium and Zirconium Alloys	388
Compositions and Applications of Tin-Base Solders.....	389
Properties of Tin-Base Solders	390
Diffusion (Coatings) Treatments	391
Creep Strength of Metals.....	393
Temper Designations—Copper Alloys.....	396
Temper Designations—Magnesium Alloys	398
Temper Designations—Aluminum Alloys.....	399
Melting Temperatures of Common Alloys.....	401
Coefficients of Thermal Expansion of Common Alloys.....	402
Strength and Electrical Conductivity Relationship	
for Copper and Its Alloys	403
Classification of Copper Alloys	404
Classification of Ferrous Casting Alloys.....	405
Classification of Steels.....	406
Iron-Carbon Equilibrium Diagram.....	407
Critical Transformation Temperatures for Steels	408

Temper and Radiation Color of Carbon Steel.....	409
Annealing Temperatures for Austenitic Stainless Steels and Related Alloys	410
Annealing Treatments for Ferritic Stainless Steels	412
Annealing Temperatures and Procedures for Martensitic Stainless Steels	413
Schoefer Diagram for Estimating Ferrite Content in Austenitic Fe-Cr-Ni Alloy Castings	414
Delta Ferrite Content of Stainless Steel Weld Metals.....	415
Overview of Joining Processes	416
Preheat Temperatures for Welding Carbon and Alloy Steels.....	419
Postweld Heat Treatment Requirements for Carbon and Alloy Steels.....	421
Filler Metals Suitable for Welding Joints Between Dissimilar Austenitic Stainless Steels.....	424
Electrodes and Filler Metals for Dissimilar Joints Between Nickel Alloys and Other Metals	425
Designations for Nickel-Base Electrodes and Filler Metals.....	426

11. NONMETALLIC MATERIALS

Typical Property Ranges for Plastics.....	428
Properties of Elastomers	436
Properties of Selected Chemically Reactive Adhesives	440
Properties of Hot-Melt Adhesives	441
Oxygen and Water Permeability in Plastic Films	442
Polyethylene Line Pipe—Dimensions and Properties	443
PVC and CPVC Line Pipe—Dimensions and Properties.....	446
FRP Thermosetting Resin Line Pipe—Dimensions and Properties	447
Types of Portland Cement	450
Chemical Requirements for Portland Cements.....	451
Hydraulic Cements.....	452
Chemical Resistant Mortars and Grouts.....	453
Properties of Selected Engineering Ceramics	455
Properties of Graphite and Silicon Carbide.....	460
Properties of Glass and Silica	461
Properties of High Temperature Refractories	462
Typical Properties of Ceramic Bricks and Chemical Stoneware.....	463

12. PROTECTIVE COATINGS

Protective Coating Classifications	465
Characteristics of Commonly Applied Coatings	467
Alkyd Coatings—Properties.....	469
Solvent Dry Lacquers—Properties	470
Epoxy Coatings—Properties	471
100% Solids Coatings—Properties.....	473
Urethane Coatings—Properties.....	475
Heat-Condensing Coatings—Properties.....	476
Coalescent-Emulsion Coatings—Properties	477
Abrasive/Profile Comparative Chart	478
Comparative Maximum Heights of Profile Obtained with Various Abrasives	479
Properties of Abrasives.....	480
Pickling Methods for Various Metals	481
Comparison of Primers.....	483
Compatibility of Coating Materials with Various Primers	484
Resistant Properties of Binders for Coatings	486
Reinforcing Pigments in Coatings.....	487
Metallic Pigments in Coatings.....	487
Properties of Generic Coatings for Atmospheric Service.....	488
Temperature Limits of Coatings.....	490
Radiation Toleration of Coatings.....	490
Coefficient of Friction—Slip Factors for Various Surface Finishes and Coatings	491
Water Permeability of Plasticized PVC Films	492
Permeance of Organic Topcoats	492
Chemical Resistance of Coatings for Immersion Service	493
Typical Physical Properties of Surface Coatings for Concrete.....	497
Types of Pipeline Coatings.....	499
Zinc Coatings—Summary of Properties	500
Zinc Coatings—Properties	501
Effect of pH on Corrosion of Zinc in Aerated Aqueous Solutions	503
Inorganic Zinc Coatings and Compositions	504
Rust Preventives	505
Film Thickness Formulas.....	507
Dry Film Thickness of Coatings as a Function of Solids Content and Coverage Rate.....	508
Pressure Loss in Hose	510

Approximate Square Feet Per Linear Foot and Per Ton for Different Steel Members.....	514
Surface Area Per Ton of Steel for Various Types of Construction.....	520
Square Feet of Area and Gallon Capacity Per Foot of Depth in Cylindrical Tanks.....	521
Properties of Flammable Liquids Used in Paints and Lacquers.....	523
Do's and Don'ts for Steel Construction to be Coated.....	525
Surface Finishing of Welds in Preparation for Lining	526
13. STANDARDS	
Standards in Corrosion Technology	529
Acronyms for Standards Organizations	530
International Standards Organizations.....	533
National Standards Organizations.....	535
INDEX.....	539