

CONTENTS

Preface	xiii
1 Introduction to Oilfield Metallurgy and Corrosion Control	1
Costs, 1	
Safety, 2	
Environmental Damage, 2	
Corrosion Control, 3	
References, 3	
2 Chemistry of Corrosion	4
Electrochemistry of Corrosion, 4	
Electrochemical Reactions, 4	
Electrolyte Conductivity, 5	
Faraday's Law of Electrolysis, 5	
Electrode Potentials and Current, 5	
Corrosion Rate Expressions, 8	
pH, 10	
Passivity, 10	
Potential-pH (Pourbaix) Diagrams, 11	
Summary, 11	
References, 12	
3 Corrosive Environments	13
External Environments, 13	
Atmospheric Corrosion, 14	
Water as a Corrosive Environment, 15	
Soils as Corrosive Environments, 16	
Corrosion under Insulation, 17	
Internal Environments, 18	
Crude Oil, 19	
Natural Gas, 19	
Oxygen, 19	

- CO₂, 20
- H₂S, 22
- Organic Acids, 27
- Scale, 27
- Microbially Influenced Corrosion (MIC), 28
- Mercury, 31
- Hydrates, 31
- Fluid Flow Effects on Corrosion, 33
- Summary, 33
- References, 34

4 Materials

36

- Metallurgy Fundamentals, 36
 - Crystal Structure, 36
 - Strengthening Methods, 37
 - Mechanical Properties, 38
 - Fracture, 42
 - Creep, 45
 - Thermal Expansion, 45
- Forming Methods, 45
 - Wrought versus Cast Structures, 45
 - Welding, 46
- Materials Specifications, 49
 - API, 49
 - AISI—The American Iron and Steel Institute, 49
 - ASTM International—formerly the American Society for Testing and Materials, 49
 - ASME, 49
 - SAE International, 49
 - UNS, 50
 - NACE—The Corrosion Society, 50
 - Other Organizations, 50
 - Use of Materials Specifications, 50
- Carbon Steels, Cast Irons, and Low-Alloy Steels, 51
 - Classifications of Carbon Steel, 52
 - Strengthening Methods for Carbon Steels, 53
 - Heat Treatment of Carbon Steels, 53
 - Quenched and Tempered (Q&T) Steels, 54
 - Carbon Equivalents and Weldability, 54
 - Hard Spots, 55
 - Cleanliness of Steel, 55
 - Cast Irons, 55
- CRAs, 55
 - Iron-Nickel Alloys, 56
 - Stainless Steels, 56
 - Nickel-Based Alloys, 60
 - Cobalt-Based Alloys, 61
 - Titanium Alloys, 62
 - Copper Alloys, 63
 - Aluminum Alloys, 66
 - Additional Considerations with CRAs, 68
- Polymers, Elastomers, and Composites, 70
- References, 72

5 Forms of Corrosion

75

- Introduction, 75
- General Corrosion, 75
- Galvanic Corrosion, 77
 - Galvanic Coupling of Two or More Metals, 77
 - Area Ratio, 78
 - Polarity Reversal, 83
 - Conductivity of the Electrolyte, 83
 - Control of Galvanic Corrosion, 83
- Pitting Corrosion, 84
 - Occluded Cell Corrosion, 84
 - Pitting Corrosion Geometry and Stress Concentration, 85
 - Pitting Initiation, 85
 - Pitting Resistance Equivalent Numbers (PRENs), 86
 - Statistics, 86
 - Prevention of Pitting Corrosion, 86
- Crevice Corrosion, 87
 - Alloy Selection, 88
 - Filiform Corrosion, 88
- Intergranular Corrosion, 89
 - Stainless Steels, 89
 - Corrosion Parallel to Forming Directions, 90
 - Aluminum, 90
 - Other Alloys, 91
- Dealloying, 91
 - Mechanism, 91
 - Selective Phase Attack, 91
 - Susceptible Alloys, 92
 - Control, 92
- Erosion Corrosion, 92
 - Mechanism, 92
 - Velocity Effects, 93
 - Materials, 95
 - Cavitation, 95
 - Areas of Concern, 95
 - Control, 98
- Environmentally Induced Cracking, 98
 - SCC, 99
 - HE and H₂S-Related Cracking, 101
 - Hydrogen Attack, 105
 - Liquid Metal Embrittlement (LME), 105
 - Corrosion Fatigue, 106
- Other Forms of Corrosion Important to Oilfield Operations, 107
 - Oxygen Attack, 107
 - Sweet Corrosion, 107
 - Sour Corrosion, 108
 - Mesa Corrosion, 108
 - Top-of-the-Line (TOL) Corrosion, 108
 - Wire Line Corrosion, 109
 - Additional Forms of Corrosion Found in Oil and Gas Operations, 109
- Additional Comments, 113
- References, 114

6 Corrosion Control 117

- Protective Coatings, 117
 - Paint Components, 117
 - Coating Systems, 118
 - Corrosion Protection by Paint Films, 118
 - Desirable Properties of Protective Coating Systems, 119
 - Developments in Coatings Technology, 120
 - Useful Publications, 120
 - Surface Preparation, 120
 - Purposes of Various Coatings, 123
 - Generic Binder Classifications, 124
 - Coatings Suitable for Various Service Environments or Applications, 126
 - Coatings Inspection, 126
 - Areas of Concern and Inspection Concentration, 131
 - Linings, Wraps, Greases, and Waxes, 133
 - Coatings Failures, 137
 - Metallic Coatings, 143
- Water Treatment and Corrosion Inhibition, 146
 - Oil Production Techniques, 147
 - Water Analysis, 148
 - Gas Stripping and Vacuum Deaeration, 148
 - Corrosion Inhibitors, 148
- Cathodic Protection, 154
 - How Cathodic Protection Works, 155
 - Types of Cathodic Protection, 157
 - Cathodic Protection Criteria, 168
 - Inspection and Monitoring, 170
 - Cathodic Protection Design Procedures, 174
 - Additional Topics Related to Cathodic Protection, 177
 - Summary of Cathodic Protection, 180
 - Standards for Cathodic Protection, 180
- References, 182

7 Inspection, Monitoring, and Testing 186

- Inspection, 187
 - Visual Inspection (VI), 187
 - Penetrant Testing (PT), 188
 - Magnetic Particle Inspection (MT), 188
 - Ultrasonic Inspection (UT), 189
 - Radiography (RT), 190
 - Eddy Current, 191
 - Positive Material Identification (PMI), 192
 - Thermography, 192
 - Additional Remarks about Inspection, 193
- Monitoring, 193
 - Monitoring Probes, 193
 - Mass-Loss Coupons and Probes, 194
 - Electrical Resistance (ER) Probes, 197
 - Electrochemical Corrosion Rate Monitoring Techniques, 197
 - Hydrogen Probes, 200
 - Sand Monitoring, 201

Fluid Analysis, 201
 Bacterial Growth Monitoring, 203
 Additional Comments on Monitoring, 204
 Testing, 204
 Hydrostatic Testing, 204
 Laboratory and Field Trial Testing, 204
 References, 207

8 Oilfield Equipment

209

Drilling and Exploration, 209
 Wireline, 212
 Coiled Tubing, 212
 Wells and Wellhead Equipment, 213
 History of Production, 214
 Downhole Corrosive Environments, 214
 Tubing, Casing, and Capillary Tubing, 220
 Inhibitors for Tubing and Casing in Production Wells, 223
 Internally Coated Tubing for Oilfield Wells, 226
 Material and Corrosion Concerns with Artificial Lift Systems, 228
 Wellheads, Christmas Trees, and Related Equipment, 231
 Facilities and Surface Equipment, 233
 Piping, 233
 Storage Tanks, 236
 Heat Exchangers, 238
 Other Equipment, 241
 Bolting and Fasteners, 241
 Flares, 249
 Corrosion under Insulation, 249
 Pipelines and Flowlines, 249
 Pipeline Problems and Failures, 252
 Forms of Corrosion Important in Pipelines and Flowlines, 253
 Repairs and Derating Due to Corrosion, 254
 Casings for Road and Railway Crossings, 255
 Pipeline Materials, 256
 Hydrotesting, 257
 External Corrosion, 257
 Internal Corrosion, 260
 Inspection and Condition Assessment, 262
 References, 265

Index

270