

Contents

Preface xv

Acknowledgments xvii

About the Editors xix

- 1 Green Polymeric Corrosion Inhibitors: Design, Synthesis, and Characterization** 1
Dheeraj S. Chauhan, Mumtaz A. Quraishi, Hussein Al-Qahtani, and Mohammad A. Jafar Mazumder
 - 1.1 Introduction 1
 - 1.2 Corrosion and Its Economic Significance 2
 - 1.3 Corrosion Inhibitors 2
 - 1.3.1 Green Corrosion Inhibitors 2
 - 1.3.2 Importance of Biopolymers as Corrosion Inhibitors 4
 - 1.4 Polysaccharides as Corrosion Inhibitors 4
 - 1.5 Proteins and Polyamino Acids as Corrosion Inhibitors 7
 - 1.6 Chemically Modified Biopolymers as Corrosion Inhibitors 10
 - 1.7 Biopolymer Nanoparticles as Corrosion Inhibitors 13
 - 1.8 Biopolymer Composites as Corrosion Inhibitors 13
 - 1.9 Adsorption and Protection Mechanism of Biopolymers on the Metal Surface 14
 - 1.10 Conclusions and Prospects 16

Acknowledgment 17
 References 17
- 2 Natural Polymers and Their Derivatives as Corrosion Inhibitors for the Oil and Gas Industry** 23
Ali F.S.A. Rahiman, Menaka Ramanathan, and Sethumanickam Subhashini
 - 2.1 Introduction 23
 - 2.2 Reliable Methods for the Study of Polymeric Corrosion Inhibitors 24
 - 2.2.1 Gravimetric Method 25
 - 2.2.2 Electrochemical Methods 25
 - 2.2.3 Gasometric Method 25
 - 2.2.4 Surface Morphological Studies 25

2.3	Natural Polymeric Corrosion Inhibitors	26
2.3.1	Chitosan and its Derivatives	26
2.3.2	Cellulose and its Derivatives	33
2.3.3	Starch and Its Derivatives	35
2.3.4	Pectin and Its Derivatives	37
2.3.5	Dextrin and Its Derivatives	38
2.3.6	Natural Gums and Their Derivatives	38
2.4	Mechanism for Natural Polymeric Corrosion Inhibition	41
2.5	Conclusion and Outtake for Future Work	42
	References	43

3 Current Applications of Carbohydrates as Green Corrosion Inhibitors for the Oil and Gas Industry 55

Ruby Aslam, Mohammad Mobin, Saman Zehra, and Jeenat Aslam

3.1	Introduction	55
3.1.1	Corrosion: An Introduction and Associated Social and Economic Issues	55
3.1.2	Strategies to Control Corrosion	56
3.2	Carbohydrate Polymers: A Sustainable Alternatives	57
3.2.1	Limitations of Using Carbohydrate Polymers as Anticorrosive Material	58
3.2.2	Emerging Trends in Corrosion Protection Offered by Carbohydrates Polymer	59
3.2.2.1	Carbohydrate Polymer Schiff Bases	59
3.2.2.2	Heterocyclic Compound-Modified Carbohydrate Polymers	62
3.2.2.3	Grafted Polymer	65
3.2.2.4	PEG Cross-linked Polymer	66
3.2.2.5	Polymer-Based Surfactant	66
3.2.2.6	Carbohydrate Polymer–Nanoparticle Composites	66
3.2.2.7	Synergistic Effect of Salts/Surfactants with Carbohydrate Polymer	68
3.3	Conclusion	73
	Acknowledgments	74
	References	74

4 Poly(Amino Acid) Corrosion Inhibitors 79

Brahim El Ibrahimi and Nada K. Sebbar

4.1	Introduction	79
4.2	Poly(Amino Acid) Homopolymers as Corrosion Inhibitors	81
4.3	Modified Poly(Amino Acid) and Poly(Amino Acid) Copolymers as Corrosion Inhibitors	84
4.4	Poly(Amino Acid) Composite Polymers as Corrosion Inhibitors	89
4.5	Conclusion	92
	References	92

5	Water-Soluble Polymeric Corrosion Inhibitors	97
	<i>Lipiar K.M.O. Goni, Mohammad A. Jafar Mazumder, Shaikh A. Ali, and Dheeraj S. Chauhan</i>	
5.1	Introduction	97
5.2	Polymers as Water-Soluble Corrosion Inhibitors	98
5.2.1	Mild Steel	98
5.2.2	Carbon Steel	104
5.2.3	Iron	107
5.2.4	Aluminum	109
5.2.5	Copper	109
5.2.6	Brass	112
5.3	Industrial Applications of Water-Soluble Polymeric Corrosion Inhibitors	113
5.4	Conclusions	116
	Acknowledgments	116
	References	117
6	High-Temperature Polymeric Corrosion Inhibitors	125
	<i>Jiyaul Haque, Mumtaz A. Quraishi, and Wan M.N.B. Wan Nik</i>	
6.1	Introduction	125
6.2	Polymer as Corrosion Inhibitor for High-Temperature Oil-Well Acidization	126
6.3	Polymer as Corrosion Inhibitor for High-Temperature Sour and Sweet Environment	131
6.4	Polymer as Corrosion Inhibitor for High-Temperature Naphthenic Acids Environment	133
6.5	Computational Studies of Polymeric Corrosion Inhibitors	134
6.6	Conclusions and Outlook	138
	Acknowledgements	139
	References	139
7	Polyurethane Corrosion Inhibitor	143
	<i>Mohammad M. Rahman</i>	
7.1	Introduction	143
7.2	Polyurethane (PU)	144
7.2.1	PU Synthesis	145
7.2.2	Structure	147
7.3	Polymer as an Inhibitor	147
7.4	PU as Corrosion Inhibitor (PUCI)	148
7.4.1	Plant-Resourced PUCI	148
7.4.2	Nanocomposite	150
7.4.3	Triblock Copolymers	152
7.4.4	Polyurea-Based PUCI	152
7.4.5	Sulfonated-Based PUCI	153
7.4.6	Waterborne PUCI	153

7.5	Mechanism of PUCI Inhibition	154
7.6	Conclusions and Perspectives	155
	References	156
8	Dual-Purpose Kinetic Hydrate and Corrosion Inhibitors	161
	<i>Muhammad I. Ulhaq</i>	
8.1	Introduction	161
8.2	Corrosion Inhibitors (CIs)	164
8.3	Kinetic Hydrate Inhibitors (KHIs)	167
8.4	Dual-Purpose Chemicals	170
8.5	Dual-Purpose Corrosion Inhibitor and KHIs (GHCI)s	170
8.5.1	Mechanism of Action of GHCI)s	173
8.5.2	Performance Testing and Evaluation of GHCI)s	175
8.5.3	Factors Controlling the Performance of GHCI)s	176
8.5.3.1	Size/Molecular Weight of GHCI)s	176
8.5.3.2	Chain Length Specific to Corrosion Inhibitor	177
8.5.3.3	Charge Distribution of Corrosion Inhibitors	177
8.5.3.4	Operational Conditions	179
8.6	Conclusion and Future Prospects	180
	Acknowledgments	180
	List of abbreviation	180
	References	181
9	Polymers as Corrosion Inhibitors for Sweet Environment	193
	<i>Dheeraj S. Chauhan, Vandana Srivastava, Yuanhua Lin, and Mumtaz A. Quraishi</i>	
9.1	Introduction	193
9.2	An Overview of Corrosion	194
9.2.1	Corrosion and Its Economic Impact	194
9.2.2	Corrosion Inhibitors	195
9.3	Sweet Corrosion	195
9.3.1	Mechanism Details of CO ₂ Corrosion	195
9.3.2	Key Parameters Governing Sweet Corrosion	196
9.3.2.1	Temperature	196
9.3.2.2	CO ₂ Partial Pressure	197
9.3.2.3	pH	197
9.3.3	Survey of Literature on Sweet Corrosion Inhibitors	197
9.4	Polymers as Sweet CI	205
9.4.1	Significance of Polymers as Sweet CI	205
9.4.2	Literature Survey of Polymers as Sweet CI	205
9.4.3	Modified Polymers as Sweet CI	212
9.5	Computational Modeling of Polymeric Inhibitors for Sweet Corrosion	212
9.6	Mechanism of Adsorption and Inhibition	214

9.7	Conclusions and Prospects	215
	References	216
10	Green Polymeric Inhibitors for Corrosion of Metals in Alkaline Media	221
	<i>Refat M. Hassan (El-Moushy)</i>	
10.1	Definitions of Corrosion	221
10.1.1	Influence of Corrosion on the Economy Sector	221
10.2	Main Reasons for Metals Corrosion	222
10.3	Theories of Corrosion	222
10.3.1	Electrochemical Theory	223
10.4	General Types of Corrosions	224
10.4.1	Galvanic Corrosion	225
10.4.2	Uniform Corrosion	225
10.4.3	Other Types of Corrosion	225
10.4.3.1	General and Local Electrochemical Corrosion	226
10.4.3.2	Crevice Corrosion	226
10.4.3.3	Intergranular Corrosion	227
10.4.3.4	Pitting Corrosion	227
10.4.3.5	Stress Corrosion Cracking (SCC)	228
10.4.3.6	Fretting Corrosion	228
10.4.3.7	Erosion–Corrosion	228
10.4.3.8	Stray Current Corrosion	228
10.4.3.9	Cavitation Corrosion	229
10.5	Corrosion Reactions of Al in Alkaline Media	229
10.6	Techniques for Prevention and Protection of Metals from Corrosion	230
10.6.1	Green Polymeric Inhibitors for Inhibition of Al Metal Dissolution in Alkaline Media	230
10.6.2	Natural Polymers	231
10.6.2.1	Polysaccharides	231
10.6.2.2	Solubility of Polysaccharides	231
10.6.2.3	Behavior of Water-Soluble Polymeric Macromolecules in Alkaline Media	232
10.6.2.4	Types of Polysaccharides	233
10.6.3	Synthetic Polymers	234
10.6.3.1	Poly (Vinyl Alcohol) (PVA)	234
10.7	Applied Methodologies for Measurements of Corrosion Rates	235
10.7.1	Methodology Techniques	235
10.7.1.1	Hydrogen Gas Evolution (Gasometric Technique)	235
10.7.1.2	Weight-loss Method	236
10.8	Factors Affecting the Corrosion Process	236
10.8.1	Nature of the Metal	236
10.8.2	Nature of the Corroding Environment	237
10.8.2.1	Dependence of Corrosion Rates on Nature and Concentration of Corrosive Media	237

10.8.2.2	Dependence of Corrosion Rates on Nature and Concentration of Inhibitors	239
10.8.2.3	Dependence of Corrosion Rate on Temperature	241
10.8.3	Corrosion Mechanisms	242
10.8.4	Absorption Isotherm Models Identification	243
10.8.5	Electrochemical Measurements	246
10.9	Conclusion	246
	Acknowledgment	247
	References	247
11	Polymeric Corrosion Inhibitors for Acid Media	257
	<i>Nurudeen A. Odewunmi, Mohammad A. Jafar Mazumder, and Shaikh A. Ali</i>	
11.1	Background	257
11.2	Outward and Inward Acid Corrosion	258
11.3	Organic and Inorganic Corrosion Inhibitor in Acid Media	259
11.3.1	Challenges of the Organic and Inorganic Components in Corrosion Inhibitor	260
11.3.2	Polymeric Corrosion Inhibitor in Acidic Media	261
11.4	Natural Polymeric Materials	262
11.5	Essential Oils	262
11.5.1	Terpenes and Isoprene	262
11.5.2	Tannins and Flavonoids	262
11.6	Carbohydrates (CHO)	263
11.6.1	Starch	264
11.6.2	Cellulose	265
11.6.3	Pectin	268
11.6.4	Exudates' fluids	269
11.6.5	Carrageenan	269
11.6.6	Dextrin	270
11.6.7	Alginates	271
11.6.8	Chitosan	271
11.7	Natural Proteins	272
11.7.1	Soy Polymer	273
11.7.2	Casein	273
11.7.3	Zein	274
11.7.4	Hydrolysate from Shrimp By-products	274
11.8	Synthetic Polymeric Materials	275
11.8.1	Polyglycols	275
11.8.2	Polyamines Derivatives	277
11.8.2.1	Polyethyleneimine (PEI)	277
11.8.2.2	Polyaniline (PANI) and Polydiamines (PDAs)	278
11.8.2.3	Polydopamine (PDM)	279
11.8.3	Polyamides Derivatives	279
11.8.4	Polyvinyl Derivatives	282
11.8.5	Polyzwitterion	286

11.9	Conclusion	289
	Acknowledgments	290
	References	290
12	Polymeric Corrosion Inhibitors for Microbiologically Influenced Corrosion	305
	<i>Chaitanya Kumar, Mohan Yama, and Jaya Rawat</i>	
12.1	Introduction to Microbiologically Influenced Corrosion (MIC)	305
12.2	Microbes in MIC	306
12.2.1	Sulfur Reducing Bacteria	306
12.2.2	Metal Oxidizing Bacteria (MOB)	306
12.2.3	Acid Producing Bacteria (APB)	307
12.3	Biofilms	307
12.3.1	Biofilm Studies and Characterization	308
12.4	MIC Issues in Industry: Oil and Gas	309
12.4.1	Pipeline Internal Corrosion	309
12.4.2	Water Network Systems	309
12.4.3	Hydrocarbon Product Storage Tanks	309
12.5	Corrosion Inhibitors for MIC	310
12.5.1	Inorganic Corrosion Inhibitors	310
12.5.2	Organic Corrosion Inhibitors	310
12.5.3	Green Corrosion Inhibitors	311
12.6	Polymeric Corrosion Inhibitors	312
12.6.1	Polymeric Corrosion Inhibitors for Microbial Corrosion	312
12.6.1.1	Corrosion Inhibition by Extracellular Polymeric Substances of Biofilms	316
12.7	Conclusions	317
	References	317
13	Smart Polymers Coating for Upstream Oil and Gas Industry to Slow Down the Corrosion	331
	<i>Rabia Nazar, Umer Mehmood, Hassan Ahmed, Aimen Imran, and Syed A. Raza</i>	
13.1	Introduction	331
13.1.1	Corrosion in the Primary Manufacturing Processes	331
13.2	Mechanism of Corrosion	334
13.2.1	Electrochemical Nature of Corrosion	334
13.3	Kinds of Corrosion in Industry	337
13.3.1	Electrochemical Corrosion	337
13.3.1.1	Corrosion due to Galvanic Reaction	337
13.3.1.2	Pitting Corrosion	337
13.3.2	Mechanical Corrosion	338
13.3.2.1	Stress Corrosion Cracking (SCC)	338
13.3.3	Chemical Corrosion	339
13.3.3.1	H ₂ S Corrosion	339

13.3.3.2	CO ₂ Corrosion	339
13.3.3.3	Oxygen Corrosion	340
13.4	Conventional Corrosion Prevention Methods	341
13.4.1	Tar Coatings	341
13.4.2	Alloyed Steel (Stainless)	341
13.4.3	Cathodic Protection	342
13.4.4	Galvanic Coatings	342
13.4.5	Polyolefin Coatings	342
13.4.6	Fusion Bonded Epoxy (FBE) Coating	343
13.5	Smart Coatings	343
13.5.1	Polymer Composite Coating	343
13.5.2	Conducting Polymer Coating	344
13.5.2.1	Polyaniline	344
13.5.2.2	Polypyrrole	344
13.5.2.3	Polycarbazole and its Derivatives	344
13.5.3	Self-healing Polymers for Coatings	345
13.5.3.1	Synthesis of Micro/Nano-Capsule	346
13.5.3.2	Mechanism of Self-healing Polymers	346
13.6	Conclusion	349
	Acknowledgment	349
	References	349

14 Surface Characterization Techniques in Corrosion Inhibition Research

Ambrish Singh, Kashif R. Ansari, Shivani Singh, Mumtaz A. Quraishi, and Yuanhua Lin

14.1	Introduction	353
14.2	Method of Weight Loss	354
14.2.1	Concentration of Inhibitor	355
14.2.2	Temperature Effect and Parameters of Activation	355
14.3	Parameters of Adsorption	357
14.3.1	Isotherms	357
14.3.2	Energy of Adsorption	359
14.4	Electrochemical Techniques	360
14.4.1	Open-Circuit Potential Curves	360
14.4.2	Electrochemical Impedance Spectroscopy	361
14.4.3	Potentiodynamic Polarization	362
14.4.3.1	Kinetics of Corrosion	363
14.4.4	Electrochemical Frequency Modulation Trend (EFMT)/Electrochemical Frequency Modulation Trend (EFM)	365
14.4.5	Linear Polarization Resistance	365
14.5	Surface Analytical Techniques	367
14.5.1	Scanning Electron Microscopy	367
14.5.2	Energy-Dispersive X-ray Spectroscopy	368
14.5.3	Water Contact Angle	368
14.5.4	Atomic Force Microscopy	369

14.5.5	X-Ray Photoelectron Spectroscopy	369
14.5.6	X-Ray Diffraction	371
14.5.7	Scanning Electrochemical Microscopy (SECM)	372
14.5.8	Scanning Kelvin Probe (SKP) Method	373
14.5.9	Scanning Vibrating Electrode Technique (SVET)	373
14.5.10	Time-of-Flight Secondary Ion Mass Spectrometry	374
14.5.11	Fourier-Transform Infrared Spectroscopy	375
14.6	Conclusion	378
	Acknowledgment	378
	Important Websites	378
	References	378

15 Guidelines for Designing Corrosion Inhibitors for Oil and Gas Production 383

Nayef M. Alanazi and Muhammad I. Ulhaq

15.1	Introduction	383
15.2	Classification of Corrosion	384
15.2.1	Crevice and Pitting Corrosions	384
15.2.2	Stress-Corrosion Cracking (SCC)	384
15.2.3	Fretting and Erosion-Corrosion	384
15.2.4	Uniform Corrosion	385
15.3	Corrosion Inhibitors	385
15.3.1	Sour Corrosion Inhibitor	386
15.3.1.1	Amine-Based Inhibitor	387
15.3.1.2	Imidazoline-Based Inhibitor	388
15.3.1.3	Gemini Surfactants-Based Inhibitor	388
15.3.1.4	Polymer-Based Inhibitor	390
15.3.2	Sweet Corrosion Inhibitor	390
15.3.2.1	Imidazolines-Based Inhibitor	391
15.3.2.2	Amines-Based Inhibitor	392
15.3.2.3	Amides/Amido-Based Inhibitor	392
15.3.2.4	Aldehydes/Carboxylates-Based Inhibitor	393
15.4	Corrosion Inhibitor Management	393
15.4.1	Identify Application Window	394
15.4.2	Define Corrosion Inhibition Test/Validation Program	394
15.4.3	Selection of Corrosion Inhibitor	396
15.4.4	Assurance of Corrosion Inhibitor (Laboratory Testing/Field Trial)	397
15.4.5	Implementation and Surveillance of Corrosion Inhibitor Application	398
15.5	Safety on Designing Corrosion Inhibitor	399
15.6	Conclusions	399
	Acknowledgment	400
	List of Abbreviations	400
	References	400