

Contents

Foreword xxv

Part I Natural Waxes 1

1	Introduction	3
1.1	General Survey of Waxes	3
1.2	Definitions of Waxes	3
1.2.1	Natural Recent Waxes	5
1.2.2	Mineral Hydrocarbon Waxes	5
1.2.3	Petroleum Waxes	5
1.2.4	Fully Synthetic Waxes	5
1.3	Brief History of Waxes	5
1.3.1	Waxes Used by Ancient Egyptians	7
1.3.1.1	The Mummification Process	7
1.3.1.2	Punic Wax	8
1.3.1.3	Nefertiti	9
1.3.2	Greeks, Romans, and Waxes	11
1.3.2.1	Bronze Casting	11
1.3.2.2	Wax Tablets in Ancient Times	11
1.3.2.3	Wax Tablets at Later Times	14
1.3.2.4	Candles	14
1.3.2.5	Waxes in Medicines and Cosmetics	15
1.3.2.6	Waxes as Cosmetics in Early Christianity	16
1.3.2.7	Wax Trading in the Middle Ages	16
1.3.3	Waxes from the Indians	17
1.4	Origin of Natural Waxes	18
1.4.1	Petroleum Waxes	18
1.4.2	Plant Waxes	19
1.4.3	Animal Waxes	19
	References	20

2	Waxes in Arts	23
2.1	Waxes in Paintings	23
2.2	Pre-encaustic Painting	24
2.3	The Faiyum Mummy Portraits	25
2.4	Greece and Rome	26
2.5	Post Roman Wax Paintings	27
2.6	Revival of Encaustic	28
2.7	Wax, Effigies, Sculptures, and Masks	30
2.7.1	Middle Ages	31
2.7.2	Modern Age	33
2.7.3	Popular Arts	33
2.8	Votive Figures in Religion	35
2.9	Wax as Processing Aid in Arts and Craft	37
2.9.1	Short History of Etching	38
2.9.2	Art Casting	39
2.9.3	History of Art Casting	41
2.10	Waxes, Crafts, and Arts in the New World	41
2.10.1	Pre-Columbian Art	42
2.10.2	Bronze and Gold Metallurgy in the New World	42
2.11	Wax Museums	44
2.12	Summary	45
	References	45
3	Photosynthesis of Plant Waxes	47
3.1	Chemical Composition of Plant Waxes	48
3.2	The Biochemical Pathway to Plant Waxes	48
3.3	Photosynthesis to Plant Waxes	49
3.4	Relevant Phases of Photosynthesis: The First Stage of Plant Wax Production	51
3.4.1	Energy Absorption	51
3.4.2	The Light Reaction Part I: Electron Transfer in Reaction Centers	51
3.4.3	The Light Part II: Transformation of Light Energy into Chemical Energy	52
3.4.4	Synthesis and Export of Stable Organic Compounds	53
3.5	Recent Research Results	55
3.6	From the Calvin Cycle to Wax	56
3.6.1	From Triose to Glucose	56
3.6.2	Glycolysis	56
3.6.3	Fatty Acid Synthesis	57
3.6.4	Elongation of Fatty to Wax Acid	59
3.7	Artificial Photosynthesis and Engineering Natural Waxes	60
3.7.1	G. Ciamician, a Pioneer in Photochemistry	60
3.7.2	Recent Developments	61
3.7.3	Conclusion	61
	References	62

Section I Natural Waxes 65

Reference 66

4 The Natural Animal Waxes 67**5 Insect Waxes 69**

5.1 Beeswax 69

5.1.1 Chemical Composition on Beeswax 70

5.1.1.1 Propolis 71

5.1.2 Antioxidant Effect 72

5.1.3 Antimicrobial and Virostatic Effects 73

5.1.4 Construction of the Wax Comb 74

5.1.5 Commercialization of Beeswax 74

5.1.6 Cleaning and Bleaching of Beeswax 75

5.1.6.1 Heating with Fuller's Earth or Charcoal 75

5.1.6.2 Sun Exposure 76

5.1.6.3 Chemical Treatment 76

5.1.7 Uses of Beeswax 77

5.1.7.1 Candles 77

5.1.7.2 Cosmetics 78

5.1.7.3 Creams and Body Lotions 81

5.1.7.4 Wood Preservatives 81

5.1.7.5 Shoe and Leather Care 82

5.1.8 Economic Aspects 83

5.1.9 Actual Challenges 84

5.1.9.1 Environment 84

5.1.9.2 Insects 84

5.1.9.3 Pesticides 85

5.1.10 Quality Control 85

References 87

6 Other Insect Waxes 89

6.1 Ghedda (Gedda) Wax 89

6.1.1 Properties 90

6.1.2 Chemical Composition 90

6.1.3 Comparison of European and Asian Beeswaxes 90

6.2 Chinese Insect Wax 92

6.2.1 Short Excursion into the Interesting Biology of These Insects 92

6.2.2 Properties 92

6.2.3 Chemical Composition 93

6.2.4 Applications 93

6.3 Shellac Wax 94

6.3.1 Cultivation 96

6.3.2 Isolation of Shellac Wax 96

6.3.3 Properties of Shellac Wax 97

6.3.4	Market	98
6.3.5	Registration Status	99
6.3.6	Applications	100
	References	101
7	Mammalian Animal Waxes	103
7.1	Introduction	103
7.2	Wool Wax	104
7.2.1	Wool Wax – Lanolin – Wool Fat or Grease: Definition of Terms	105
7.2.2	Wool Wax – Valuable By-product	106
7.2.3	Separation of Lanolin from Sheep's Wool	107
7.2.4	Composition of Wool Wax	108
7.2.5	Applications	110
7.2.6	Toxicology	111
7.2.7	Potential Classification of Wool Wax or Lanolin as an Allergenic Substance	112
7.3	Mammalian Marine Waxes	113
7.3.1	Spermaceti	113
7.3.1.1	Properties	115
7.3.1.2	Applications	115
7.3.2	Amber and Ambergris	115
7.3.2.1	Amber and Ambergris Occurrence	117
7.3.2.2	Legality Today	117
7.4	Mammalian Human Waxes: Earwax/Cerumen	117
7.4.1	General	117
7.4.2	The Position of Cerumen in the Realm of Waxes	118
7.4.3	Biosynthesis of Ear Wax	118
7.4.4	Appearance and Composition	119
7.4.5	Earwax in Oncology	120
7.4.6	Summary	121
7.5	Marine Waxes	121
7.5.1	Marine Animals Waxes	122
7.5.2	Composition of Marine Waxes	122
7.6	Other Marine Waxes	122
7.7	Bird Waxes	123
7.7.1	Biosynthesis and Composition of Bird Waxes	123
7.7.2	Conclusion	124
	References	124

Section II Natural Plant Waxes 127

8	Carnaúba Wax	129
8.1	Introduction	129
8.2	History	130
8.3	General Properties of Carnaúba Wax	132
8.4	Economic Aspects	133

8.5	Origin	133
8.6	Occurrence and Exploitation	134
8.7	Harvesting Carnaúba	135
8.8	Grinding	137
8.9	Micronization	137
8.10	Carnaúba-Wax-Based Emulsions	138
8.11	Types and Specifications	138
8.12	Uses and Applications of Carnaúba Wax Grades	140
8.12.1	Pharmaceuticals	140
8.12.2	Food	141
8.12.3	Citrus Fruit Coating	141
8.13	Cosmetics	142
8.14	Care Products	142
8.14.1	Shoe Polish	143
8.14.2	Solvent-Based Polishes	143
8.14.3	Floor and Stone Floor Care	144
8.14.4	Car Polish	144
8.15	Candles	144
8.16	Printing Inks	144
8.17	Plastics Industry	145
8.18	Varnishes/Coatings	145
8.19	Economic Outlook	145
8.20	Physical and Chemical Properties	146
8.21	Chemical Composition of Carnaúba Wax	146
8.22	Physiological and Toxicological Aspects of Carnaúba Wax	148
8.23	Registration Status	149
8.24	Policosanol in Carnaúba Wax	150
	References	150
9	Candelilla or the “Great Wax Rush”	153
9.1	History	153
9.2	Occurrence and Isolation	153
9.3	Working Up Candelilla	156
9.4	The Candelilla Wax Value Chain	157
9.5	Main Applications and Uses of Candelilla Wax	157
9.5.1	Cosmetics	158
9.5.2	Polishes	158
9.5.3	Candle, Hot Melt, Polymer Processing	159
9.5.4	Pharmaceutical Industry	159
9.5.5	Food Industry	159
9.6	Physical and Chemical Properties and Composition of Candelilla Wax	159
9.7	Economic Aspects	162
9.8	Comparison Between Candelilla and Sugarcane Wax	163
9.9	Registration Status	164
	References	165

10	Montan Wax	167
10.1	A General Description	167
10.2	The Future of Montan Wax	169
10.3	Formation and Occurrence of Montan Wax	169
10.4	The Origin of Montan Wax	169
10.5	Separation of Montan Wax from Lignite	171
10.6	Extraction	171
10.7	Details of Montan Wax Production	172
10.8	Properties and Composition	173
10.9	Montan Wax Components	174
10.10	Resins and Dark Residues	176
10.11	Applications for Crude Montan Wax	177
10.11.1	Preparation of Emulsions	177
10.11.2	Bitumen Industry	177
10.12	Refining and Derivatization	177
10.12.1	Deresinification	178
10.12.2	Bleaching	178
10.12.3	Distillation	178
10.12.4	Oxidation with Nitric and Sulfuric Acid	179
10.12.5	Oxidation with Chromic Acid or Chromates in Sulfuric Acid	179
10.13	Further Processing and Refining of Bleached Montan Wax	181
10.14	Derivatization	182
10.15	Uses and Economic Aspects	183
10.16	Selected Technical Applications for Montan Waxes	185
10.16.1	Historical Overview	185
10.16.2	Care and Polishing Industry	185
10.16.3	Behavior of Natural Waxes When Exposed to Solvents	185
10.16.4	Solubility of Waxes	186
10.16.5	Montan Waxes for Shoe Polishes	186
10.16.6	Montan Waxes for Polishes	187
10.16.7	Powder Coatings	187
10.16.8	Montan Wax for Rigid PVC Processing	188
10.16.9	Excursion into Calendering Films and Sheets	189
10.16.10	Rigid PVC Extrusion	189
10.16.11	Special Advantages of Rigid PVC Lubricants	191
10.16.12	Masterbatch	191
10.17	Registration Status	192
10.18	Montan Wax and Other Natural Wax Substitutes from Linear Alpha Olefins	192
10.18.1	What Are “Linear Alpha-olefins” (LAOs)?	193
10.18.2	Linear Alpha-Olefins	193
10.18.3	Linear Alpha-olefin Waxes	193
10.19	Modified Linear Alpha Olefin Waxes	194
10.19.1	Oxidation of Alpha-Olefins (Schematic)	194
10.19.2	Addition of MSA as Dienophile to Alpha Olefin (Schematic)	195

10.19.3	Grafting with Peroxides	195
10.19.4	LAO Copolymers with Maleic Anhydride	196
10.20	Production of Linear Alpha-olefins	196
10.20.1	The Starting Point: The Ziegler “Aufbau Reaction”	197
10.20.2	Shell Higher Olefin Process (SHOP)	198
10.20.3	INEOS: Ethyl Process	199
10.20.4	Chevron Phillips: Gulfene Process	199
10.20.5	Other LAO Processes	199
10.20.6	The Idemitsu Petrochemical Process	200
10.20.7	SABIC-Linde α -Sablin® Process	200
10.20.8	Sasol Fischer–Tropsch Alpha-Olefins	200
10.21	Summary of Applications of Alpha-Olefins	200
10.22	Short Overview of Technical Applications of Linear Alpha-olefin Waxes	201
10.23	Peat Wax	202
10.23.1	Short Description	202
10.23.2	Registration Status	203
10.24	Ozokerite Wax	203
10.24.1	Sources	203
10.24.2	Properties	203
10.24.3	Mining	204
10.24.4	Registration Status	205
	References	205
11	Sugarcane Wax	209
11.1	Introduction–General Considerations	209
11.2	Occurrence and Isolation	209
11.3	Production of Sugarcane Worldwide (2018)	210
11.4	Composition of Sugarcane Wax	211
11.5	Separation of Sugarcane Wax	211
11.5.1	Value Chain of Sugar: The Indian Company Godavari Biorefineries Ltd.	211
11.6	Delivery Forms and Composition	213
11.7	Production	214
11.8	Further Applications of Sugarcane Wax	215
11.9	Medical and Dietary Aspects of Sugarcane Wax	216
11.10	Description of Policosanol	216
11.10.1	Separation of Policosanol from Sugarcane Wax	217
11.10.2	Potential Medical Effects of Policosanol	219
11.10.3	The “Positive” Studies	219
11.10.4	Controversial Comments	220
11.11	Rice Bran Wax	221
11.11.1	Applications	222
11.11.2	Registration Status	223
	References	223

12	Japan Wax	227
12.1	General Reflections About Japan Wax	227
12.2	Refining Japan Wax	228
12.3	Chemical Composition of Japan Wax	229
12.4	Uses of Japan Wax	229
12.5	Economy	230
12.6	Registration Status	230
12.7	Castor Wax or Ricinus Wax	231
12.7.1	General Description	231
12.7.2	Chemical Composition of Castor Oil	231
12.7.3	Origin	233
12.7.4	Production Process of Hydrogenated Castor Oil Wax: Castor Wax	233
12.7.5	Uses and Applications	234
12.7.5.1	Plastics Industry	234
12.7.5.2	Lubricants Industry	235
12.7.5.3	Cosmetics Industry	235
12.7.5.4	Ink and Coating Industry	235
12.7.5.5	Miscellaneous	236
12.7.6	Registration Status	236
12.8	<i>Ricinus communis</i> Linnaeus: "The Umbrella Murder Case"	236
	References	237
13	Palm Wax	239
13.1	General Considerations	239
13.2	Origin of Palm Oils	240
13.3	Agriculture of Oil Palm Trees	241
13.4	Extraction of Palm Oil	241
13.5	Palm Kernel Oil	241
13.5.1	From Palm Oil to Palm Wax	242
13.6	Outlook	243
	References	243
14	Wax of Manzanita Leaves	245
14.1	A General	245
14.2	Potential Medical Effects	247
14.3	Manzanita Roots and Smoking Pipes	247
	References	248
15	Waxes of Citrus Fruits and Leaves	249
15.1	Chemical Composition	249
15.1.1	Hydrocarbon Length Distribution in Citrus Fruits and Leaves	250
15.2	Primary Alcohol Carbon Length Distribution in Citrus Fruits and Leaves	252
15.3	Fatty Acids and Wax Acids Length Distribution	253
15.4	Waxes from Larrea Leaves and Stems	256

15.5	Sunflower Wax	259
15.5.1	A General	259
15.5.2	The Winterization Process	260
15.5.3	Properties of Sunflower Wax	260
15.5.4	Composition of Sunflower Wax	261
15.5.5	Uses and Applications	261
15.5.6	Registration Status	262
15.6	Soy (or Soybean) Wax	262
15.6.1	Description and Use	262
15.6.2	Properties	263
15.7	Other Waxes from Hydrogenated Oils	263
15.8	Tea Wax	264
15.8.1	Technical Data	264
15.8.2	Registration Status	264
15.9	Jasmine Wax	265
15.9.1	Technical Data	265
15.9.2	Registration Data	265
15.10	Rose Wax	265
15.10.1	Technical Data	266
15.10.2	Registration Data	266
	References	266

Part II Synthetic Waxes 269

16	Synthetic Waxes	271
16.1	Introduction	271
16.2	The Building Blocks of Synthetic Waxes: Monomers, Oligomers, and Polymers	272
16.2.1	Monomer Molecule	273
16.2.2	Oligomer Molecule	273
16.2.3	Macromolecules – Polymer Molecules	274
16.3	Short Introduction to Molar Mass and Distributions	275
16.3.1	Summary	279
16.4	The Chemical Structure of Synthetic Polymer and Chemically Related Waxes	280
16.5	Molecular Structure of Synthetic and Petroleum Waxes	281
16.5.1	Hermann Staudinger and the Beginning of the Polymer Age	282
16.6	Discrimination Between Waxes and Plastics – A Brief Excursion into Polymer Physics	284
16.6.1	Regulations	287
	References	287
17	Polyolefin Waxes	289
17.1	General	289
17.1.1	Polyethylene – the Early Beginning	290

17.1.2	Another Early Approach to Polyethylene	291
17.1.3	Polyethylene Waxes	293
17.1.4	Polyethylene Waxes Produced by Polymerization	294
17.1.4.1	Polyethylene Waxes Produced by Low-pressure Polymerization	294
17.1.4.2	Polyethylene Made by Phillips Catalysts	295
17.1.4.3	Ziegler–Natta: The invention	295
17.1.5	Olefin Polymerization	296
17.1.5.1	The Reaction Mechanism	297
17.2	Industrial Production of Ethylene Polymers: Plastics and Waxes	299
17.2.1	High-Pressure Polymerization	300
17.2.1.1	Low-Density Polyethylene High-Pressure Waxes	300
17.2.1.2	Waxes Made by Free Radical Polymerization	301
17.2.1.3	The Free-Radical Polymerization Production Processes	302
17.2.2	High-Pressure LDPE Wax Producers	306
17.2.3	Low-Pressure Ziegler–Natta Polymerization	306
17.2.3.1	Ziegler–Natta PO Wax Plants	308
17.2.4	Low-Pressure Metallocene Polymerization	309
17.2.4.1	Metallocene Waxes	309
17.2.4.2	Waxes Produced with Metallocene-MAO Catalyst Systems	312
17.2.5	The Chemistry of Metallocene Polymerization	312
17.2.5.1	Reaction Mechanism	313
17.2.5.2	Thermal Degradation of Polyolefins	313
17.2.5.3	Waxes as Byproducts of Polyolefin Synthesis	314
17.2.5.4	Scrap Waxes	315
17.3	Market and Economics	316
17.4	Use and Applications	316
17.4.1	Polyethylene Waxes for PVC Plastics	316
17.4.2	Wood-Plastic Composites	319
17.4.2.1	History	319
17.4.2.2	WPCs Today	320
17.4.3	Waxes for Adhesives	321
17.4.3.1	The Special Contribution of Polyethylene Waxes to Adhesives	322
17.4.3.2	Water-Based Adhesives	323
17.4.3.3	Vegetable Adhesives	324
17.4.3.4	Resin Adhesives	324
17.4.4	Waxes for Natural Glue	327
17.4.4.1	Animal or Protein Adhesive	328
17.4.4.2	History of Natural glue	329
17.4.4.3	Modern Use of Animal Glue	330
17.4.5	Natural Rubber-Based Adhesives	331
17.4.6	Hot Melt Adhesives	332
17.4.6.1	Fast Setting Hot Melts	332
17.4.6.2	Delayed Setting Hot Melts	332
17.4.6.3	Pressure-Sensitive Hot Melt Adhesives (HMPSA)	332
17.4.6.4	Remoistenable Glue	333

17.4.6.5	Polyamide Glues	333
17.4.6.6	Reactive Adhesives	333
17.4.6.7	Solvent-Based Adhesives	333
17.4.6.8	PE Waxes for Packaging Adhesives	334
17.4.6.9	PE Waxes for Furniture and Building Adhesives and Primers	334
17.4.6.10	PE Waxes for Textile and Leather Adhesives	335
17.4.6.11	Repairs of Old Art Textile Pictures and Historical Garments with Adhesives	336
17.4.6.12	PE Waxes for Artificial Turf	336
17.4.6.13	Coatings for Corrugated Boards	337
17.4.6.14	Hot Melt Coatings in the Pharmaceutical Industry	338
17.4.6.15	The Relevance of Hot Melt Adhesives for the Wax Market	339
17.4.6.16	PE Waxes for Road Marking	340
17.4.6.17	Polyethylene Waxes for Cable Filling	341
17.4.6.18	Wax-Based Cavity Sealing for Cars	342
17.4.6.19	Underbody Protection for Cars with Waxes	342
17.4.6.20	PE Waxes for Coatings	343
17.4.6.21	Micronized PE Waxes	344
17.4.7	PE Waxes for Textile Applications	378
17.4.7.1	History of Batik and African Prints	378
17.4.7.2	African Printing	379
17.4.7.3	Wax Prints on Fabrics Today	381
17.4.8	PE Waxes for Cotton	382
17.4.8.1	History of Waxed Cotton	382
17.4.8.2	PE Waxes for Cotton Today	383
17.4.8.3	PE Waxes as Needle Lubricants for Textile Production	384
17.4.8.4	PE Waxes for Leather Care Products	384
17.4.8.5	Instructions for a High Gloss Polish for Leather, Especially for Leather Shoes	386
17.4.9	PE Waxes for Masterbatch	387
17.4.10	PE Waxes as Lubricants in Plastics Processing	389
17.4.11	PE Waxes as Lubricants in Metalworking	390
17.4.12	Polyolefin Waxes as Release Agents	391
17.4.13	PE Waxes for Powder Metallurgy	392
17.4.13.1	An Example for Powder Metallurgy	394
17.4.14	PE Waxes for Injection Molding	394
17.4.15	Waxes and Fertilizers	397
17.4.15.1	History	397
17.4.15.2	PE Waxes for Fertilizers	399
17.4.15.3	Practical Application of Waxes in Fertilizers	399
17.4.16	Waxes as Agents for Pyrotechnics and Explosives	400
17.4.16.1	Short History of Explosives and Fireworks	401
17.4.16.2	The Chemistry of Fireworks	403
17.4.17	Waxes as Phlegmatization Agents for Powerful Explosive Chemicals	405

17.4.18	Dynamite	407
17.4.19	Fireworks Today	410
17.4.20	PE Waxes as Fibrously Felted Wax Wool for Oil and Solvent Binder	411
17.4.20.1	Polymer Absorbents	411
17.4.20.2	Waxes as Super Absorbents	411
17.4.20.3	Practical Issues	412
17.4.20.4	Production Process	413
17.4.20.5	Applications	414
	References	425
18	Polypropylene Waxes	433
18.1	General Overview	433
18.2	History of Polypropylene Plastics and Waxes	434
18.2.1	History: Phillips Petroleum	434
18.2.2	History: Giulio Natta	435
18.3	Polypropylene Plastics and Waxes: A Symbiotic Relationship	436
18.4	Chirality and Tacticity: Principles	437
18.4.1	Chirality	438
18.4.2	Tacticity	438
18.4.2.1	Isotactic Polypropylene Chains	439
18.4.2.2	Syndiotactic Polypropylene Chains	439
18.4.2.3	Atactic Polypropylene Chains	440
18.4.3	Tacticity of Industrial Polypropylene Waxes	440
18.5	PP Wax Polymerization Reactions and Processes	441
18.5.1	Reaction Mechanisms	441
18.5.2	Phillips Catalysts	442
18.5.3	Reaction Mechanisms	442
18.5.4	Production of PP Plastics and Waxes	442
18.5.5	The Giulio Natta Route to Polypropylene	443
18.5.6	Metallocene Catalyst Systems	444
18.6	Polyethylene and Polypropene Plastics and Waxes: A Comparison	444
18.7	Properties of Polypropylene Waxes	446
18.7.1	Isotactic PP Waxes	446
18.7.2	Copolymer PP-PE Waxes	447
18.7.3	Syndiotactic PP Waxes	448
18.8	Atactic Polypropylene Wax-like Materials (APO/APAO)	448
18.9	Applications of Polypropylene Waxes	449
18.9.1	General	449
18.9.2	Low Viscosity PP Waxes with Low Drop Point	450
18.9.3	Medium Viscosity PP Waxes with High Drop Point	450
18.9.4	Low Viscosity PP Waxes with High Drop Point	450
18.9.5	Selected Applications of PP Waxes	450
18.9.6	Dispersing Aid	451
18.9.7	Waxes for Different Hot Melt Adhesives	451
18.9.8	Inks and Coatings	452

18.9.9	Anti-slip Additives for Wood Coatings	452
18.9.10	PP Wax as Matting Agent for Powder Coatings	452
18.9.11	Artificial Grass and Turf	452
18.9.12	PP Wax for Masterbatch	453
18.9.13	PP Wax Made by “Canadian Clean Technology” Company Green Mantra	453
18.10	Regulatory Aspects	454
18.11	Economic Aspects	454
	References	455
19	Petroleum and Related Crude Oil-Based Waxes	457
19.1	Definitions	457
19.2	Introduction to Paraffin Waxes	458
19.3	History	459
19.4	Petroleum Wax Production from Crude Oil	460
19.4.1	General	461
19.4.2	The First Petroleum Refineries	461
19.5	Refinery Process	462
19.5.1	Separation	462
19.5.2	Conversion	464
19.5.2.1	Cracking	465
19.5.2.2	Steam cracking	465
19.5.2.3	Catalytic Cracking	467
19.5.2.4	Fluid Catalytic Cracking (FCC)	467
19.5.2.5	Hydrocracking	468
19.5.2.6	Visbreaking	468
19.5.2.7	Coking	469
19.5.2.8	Delayed Coking	469
19.5.2.9	Fluid Coking	469
19.5.3	Combining Processes	470
19.5.3.1	Polymerization	470
19.5.3.2	Alkylation	470
19.5.3.3	Isomerization	471
19.5.3.4	Reforming	471
19.5.4	Dewaxing	472
19.5.4.1	Cold Press Process	472
19.5.4.2	Dewaxing Without Solvent	473
19.5.4.3	Solvent Dewaxing	473
19.5.4.4	Urea Dewaxing Process	474
19.5.4.5	Catalytic Dewaxing Process	475
19.5.5	Wax Sweating Process	476
19.5.6	Acid Treatment Process	476
19.5.7	Wax Recrystallization Process	477
19.5.8	De-oiling Process for Crude Waxes	478
19.5.8.1	Advantages of the Sulzer-Sasol Process	479

19.5.8.2	Other New De-oiling Concepts	480
19.5.8.3	Solvent De-oiling Process	481
19.5.8.4	Pulping De-oiling Process	481
19.5.8.5	Crystallization De-oiling Process	482
19.5.8.6	Spray De-oiling Process	482
19.5.9	Refining De-oiled Slack Waxes	482
19.5.9.1	Refining with Adsorbents (Decolorizing)	484
19.5.9.2	Refining with Percolation Process	484
19.5.9.3	Refining with Hydrotreating	485
19.6	Petroleum Waxes are in Order of Refining	486
19.6.1	Slack Wax (Petroleum)	487
19.6.1.1	Regulatory Status	488
19.6.1.2	Applications	488
19.6.2	Slack Wax (Petroleum), Clay-Treated	489
19.6.2.1	ECHA Definition (2021)	489
19.6.2.2	Regulatory Status	489
19.6.3	Slack Wax (Petroleum), Hydrotreated	489
19.6.3.1	ECHA Definition (2021)	489
19.6.3.2	Applications	489
19.6.3.3	Regulatory Status	489
19.6.4	De-oiled Slack Wax, Paraffin Waxes and Hydrocarbon Waxes	490
19.6.4.1	EPA Definition (2021)	490
19.6.4.2	Applications	490
19.6.4.3	Regulatory Status	490
19.6.5	Crude Soft Waxes/Foots Oil (Petroleum)	491
19.6.5.1	ECHA Definition (2021):	491
19.6.5.2	Applications	491
19.6.5.3	Regulatory	491
19.6.6	Semirefined, Filtered (Decolorized)	491
19.6.7	Fully Refined Waxes	492
19.6.8	Filtered (Decolorized) Waxes, Clay Treated	492
19.6.8.1	TSCA Definition (2019)	492
19.6.8.2	Regulations	492
19.6.9	Microcrystalline Waxes	493
19.6.9.1	EPA Definition (2021)	493
19.6.9.2	Types of Microcrystalline Waxes	493
19.6.9.3	Some Applications of Microwaxes in Detail	494
19.6.10	Application of Petroleum Waxes in Principal	495
19.6.11	General Physical and Chemical Properties of Microcrystalline Waxes	496
19.6.11.1	Regulatory Status	497
19.6.12	Petroleum Jelly, Petrolatum or Vaseline	497
19.6.12.1	ECHA Definition	497
19.6.12.2	History	497
19.6.12.3	Regulatory Status	498

19.6.13	Applications of Petrolatum	499
19.6.13.1	Skin Protection	499
19.6.13.2	Hair Protection	500
19.6.13.3	Outdoor Sports	500
19.6.13.4	Sexual Lubricants	501
19.6.13.5	Water Protective Coating	501
19.6.13.6	Finishing	501
19.6.13.7	Special Lubrication Uses	501
19.6.13.8	Other Applications	502
19.6.14	Health-related Discussion for Petrolatum (Petroleum Jelly, Vaseline)	502
19.6.14.1	Oil-based Waxes and Human Health	504
19.6.15	Environmental Aspects: Biodegradation of Waxes Based on Crude Oil	504
19.6.15.1	Paraffin Waxes	504
19.6.15.2	Environmental Fate of Crude Oil waxes: Short Summary	506
19.6.15.3	Other Environmental Issues	506
19.6.16	Global Consumption of Petroleum Waxes	506
19.6.17	Some Key Players in the Petroleum Wax Market (2021)	507
	References	507
20	Fischer–Tropsch Synthesis (FTS) and Waxes	515
20.1	Introduction	515
20.2	History	516
20.3	Fischer–Tropsch Reaction Mechanism	517
20.4	Fischer–Tropsch Synthesis (FTS)	518
20.4.1	Biomass-to-Liquids (BTL)	519
20.4.2	Coal-to-Liquids (CTL)	520
20.4.3	Gas-to-Liquids (GTL)	521
20.4.4	GTL/FTS Plants: Overview	522
20.4.5	GTL/Fischer–Tropsch Plants under Operation and Planning	522
20.5	Fischer–Tropsch Waxes – Key Manufacturers	523
20.6	FT Waxes: Chemical and Physical Properties	523
20.6.1	FT Waxes – Properties of Selected Wax Grades from Sasol and Shell	524
20.7	Oxidized FT Waxes	524
20.7.1	History	524
20.7.2	Mechanism of Paraffin Oxidation	524
20.7.3	Oxidized Waxes Today	525
20.7.4	Application of Wax Oxidates	525
20.8	Liquid Applications of Waxes	526
20.8.1	Fischer–Tropsch and Other Waxes for Hot Melt Adhesive (HMA)	526
20.8.1.1	History of a Natural Adhesive Used by the Iceman “Ötzi”	527
20.8.1.2	Other Industrial Applications of FT Waxes for Hot Melt Adhesives	528
20.8.1.3	Private Use of HMAs	530
20.8.2	FT Waxes and Other Waxes for Inks, Paints, and Coatings	531

20.8.2.1	Grinding	531
20.8.2.2	Spraying of Waxes	537
20.8.3	Emulsions	539
20.8.3.1	Solutions, Dispersions, Emulsions, Colloids, and Suspensions	539
20.8.3.2	Preparation of Emulsions and Dispersions with Oxidized Waxes	540
20.8.3.3	Surfactant Systems of Emulsions	541
20.8.3.4	Oxidized Waxes for Water Based Emulsions	542
20.8.4	FT Wax for Coatings and Printing Inks	547
20.8.4.1	The Blooming Mechanism	548
20.8.4.2	The Ball Bearing Mechanism	548
20.8.4.3	Comparison of the Proposed Mechanisms	548
20.8.5	FT Waxes for the Cosmetic and Pharmaceutical Industries	548
20.8.6	FT – Waxes for PVC or Plastic Processing	549
20.8.7	FT Waxes for Rubber and Tire	549
20.8.8	FT Waxes for Textiles and Fibers	550
20.8.9	FT Waxes for Leather and Fabric Impregnation	550
20.8.10	FT Waxes for Paper	551
20.8.11	FT Waxes and Paraffins for Wood Treatment	551
20.8.12	Waxes for Matches	552
20.8.12.1	History	552
20.8.12.2	Matches in Germany in the 20th History: An Episode	555
20.8.12.3	Modern Matches	555
20.8.13	Paraffins and waxes for Sticky Flypaper	556
20.8.14	Waxes for Pencils and Crayons	557
20.8.14.1	History	557
20.8.14.2	FT-Paraffin and waxes for Pencils	558
20.8.14.3	FT Paraffin and Waxes for Production of Crayons	558
20.8.15	FT Waxes for Candles	559
20.8.16	Waxes for Road Construction	561
20.8.16.1	History	561
20.8.16.2	Waxes in Modern Road Construction	563
20.8.16.3	The Influence of Waxes on Bitumen Properties	564
20.8.16.4	Waxes for Road Repair and Recycling	565
20.8.16.5	Appendix	566
20.9	Regulatory Compliance	567
20.9.1	Regulatory	567
	References	568
21	Amide Waxes	573
21.1	General	573
21.2	History of Amide Waxes	574
21.3	<i>N,N'</i> -Ethylenebis(stearamide): EBS	574
21.3.1	Production	575
21.3.2	Dust	575
21.3.3	Market	576

21.4	Applications	576
21.4.1	Amide Wax EBS for Road Construction	577
21.4.2	Amide Wax Ethylene (bis)Stearamide (EBS) as a Rheology Agent Mixed with Hydrogenated Castor Oil (EBS and HCO)	579
21.4.3	Registration Status for Hydrogenated Castor Oil with Amide Wax	581
21.4.4	Amide Waxes (EBS) as Additives in Plastics Processing	581
21.4.4.1	Blown Film Production	582
21.4.4.2	Compatibility	582
21.4.4.3	Nucleating Agents	582
21.4.4.4	Crystallization	583
21.4.4.5	Addition of Nucleating Agents	584
21.4.5	Rubber Processing	584
21.4.6	Amide Waxes <i>N,N'</i> -Ethylene-bis-Stearamide and Other Waxes for Coatings and Printing Inks	585
21.4.6.1	Slip Aid	586
21.4.6.2	Abrasion Resistance	586
21.4.6.3	Anti-blocking	586
21.4.6.4	Matting Agent	587
21.4.6.5	Water Repellency	587
21.4.6.6	Texturizer	587
21.4.7	Amide Waxes (EBS) for the Fiber Industry	587
21.4.8	Regulatory	588
21.5	Stearamide Wax	588
21.5.1	General	588
21.5.2	Applications	589
21.5.2.1	Thermal Paper	589
21.5.2.2	Polyolefin Films	589
21.5.2.3	Chemical Industry	589
21.5.2.4	Miscellaneous	589
21.5.3	Regulatory	590
21.6	Erucamide Wax	590
21.6.1	General	590
21.6.2	Applications	590
21.6.3	Ink Industry	591
21.6.4	Slip Additive	591
21.6.5	Miscellaneous	591
21.6.6	Regulatory	592
21.7	Oleamide Wax	592
21.7.1	General	592
21.7.2	Oleamide of Natural Origin	593
21.7.3	Applications	593
21.7.3.1	Plastics Industry	593
21.7.3.2	Cosmetic Industry	593
21.7.3.3	Cable Industry	593
21.7.3.4	Ink Industry	593

21.7.4	Regulatory	594
21.8	Comparison of Anti-blocking and Slip Properties Between Erucamide, Stearamide, and Oleamide Waxes	594
21.9	<i>N,N'</i> -Ethylene-bis-Oleamide (EBO)	596
21.9.1	General	596
21.9.2	Production	596
21.9.3	Applications	597
21.9.4	Plastics	597
21.9.5	Regulatory Status	597
	References	598

22	Polytetrafluoroethylene (PTFE) Waxes	601
22.1	Introduction	601
22.1.1	Summary	601
22.1.2	History	602
22.1.3	General Properties of PTFE Waxes and Plastics	602
22.1.4	Production of TFE Monomer	604
22.1.5	Polymerization of TFE to PTFE Plastic and Waxes	604
22.1.6	Production Methods	604
22.1.7	Recycling of PTFE Plastic and Wax	605
22.1.8	The PTFE World Market	607
22.1.9	Selection of PTFE/Micronized PTFE Wax Suppliers	607
22.1.10	Physico-chemical Properties	607
22.1.11	Applications of PTFE	608
22.1.11.1	PTFE Waxes for Inks and Coatings	609
22.1.11.2	Surface Texturing through Powder Coatings	609
22.1.11.3	Lubricants	610
22.1.11.4	Protection Against Chemicals	610
22.1.11.5	Ski Wax	610
22.1.11.6	Sailing	610
22.1.12	Environmental and Health Issues	610
22.1.13	Greenhouse Emissions	611
22.1.14	Summary	612
22.1.15	Workplace Hazards	612
22.1.16	Fluorinated Chemicals of Concern	613
22.1.16.1	The Ozone Hole	613
22.1.16.2	PFOA and PFAS	613
22.2	Resume	614
22.2.1	Regulatory	615
	References	615

Appendix A	Final Tables A.I–A.V: Listing of Aliphatic Compounds in Waxes	617
	References	637

Appendix B Candles – A Most Popular Application Area for Waxes 639

- B.1 Short Summary 639
- B.2 Candles in Religion 642
- B.3 Candles in Modern Science 646
- References 647

Appendix C Test Methods for Characterizing Waxes 649

- C.1 Test Methods for Waxes 649
- C.2 Safety Data Sheets 651

Epilogue: The Future of Waxes 653

Index 655