

---

---

# CONTENTS

Contributors *xiii*

Introduction *xv*

## **1 / Choosing the Coating Method**

*EDWARD D. COHEN*

- 1.1 Coating Components and Structures 1
- 1.2 Coating Technologies 5
- 1.3 Coating Methods 6
  - 1.3.1 Single Layer Methods 6
  - 1.3.2 Multilayer Coating Methods 9
- 1.4 Selecting a Coating Method:  
Basic Considerations 10
  - 1.4.1 Number of Layers 11
  - 1.4.2 Wet Layer Thickness 11
  - 1.4.3 Viscosity (and Viscoelasticity) 11
  - 1.4.4 Coating Weight Accuracy 12
  - 1.4.5 Coating Support 12
  - 1.4.6 Coating Speed 12
  - 1.4.7 Other Factors 13
  - 1.4.8 Drying 13
- 1.5 Choosing the Coating Method 13
- 1.6 Information Sources 19
- 1.7 Coating Facilities 19
- Literature 21

## **2 / Fluid Handling and Preparation**

*PETER M. SCHWEIZER*

- 2.1 Introduction 23
- 2.2 Purpose of Fluid Handling and Preparation 25
  - 2.2.1 Statistical Considerations 28
- 2.3 Fluid Displacement 29
  - 2.3.1 Purpose of Fluid Displacement 30
  - 2.3.2 Operating Modes of Displacement  
Systems 30
  - 2.3.3 Displacement Characteristics 31
  - 2.3.4 Net Positive Suction Head (NPSH)  
Value 31
  - 2.3.5 Power Requirement 32

2.4	Flow Measurement	33
2.4.1	Types of Flow Measurement	33
2.4.2	Measurement Principles	33
2.4.3	Accuracy of Flow Rate Measurements	34
2.4.4	Measurement of Two-Phase Flows	35
2.5	Gas Removal	35
2.5.1	Principal Aspects of Gas Removal	35
2.5.2	Solubility of Gases in Liquids	35
2.5.3	Bubble Removal	36
2.5.4	Practical Implications and Applications	37
2.5.5	Bubble Removal from Solid Walls	39
2.6	Filtration	40
2.6.1	Filtration Mechanisms	40
2.6.2	Filter Types	41
2.6.3	Filter Life	42
2.6.4	Requirements for Filter Specification	42
2.6.5	Filtration Problems	43
2.7	Online Injection and Homogenization	43
2.7.1	Purpose	43
2.7.2	Online Injection	43
2.7.3	Homogenization	44
2.7.4	Mixing Homogeneity	44
2.7.5	Pressure Drop	46
2.8	Temperature Control	46
2.8.1	Isothermal Operating Conditions	46
2.8.2	Temperature Change of the Coating Solution during Flow along the Distribution Cavity	47
2.8.3	Temperature Control Requirements	50
2.8.4	Temperature Control Systems	50
2.9	System Perturbations	51
2.9.1	Example	54
2.10	Residence Time	54
2.10.1	Mean (Average) Residence Time	55
2.10.2	Residence Time Spectrum	55
2.10.3	Transfer Function	56
2.11	Systems Cleaning	57
2.11.1	Mechanisms of Cleaning	57
2.11.2	Practical Aspects	59
	Literature	61

### **3 / Roll Coating**

*DENNIS J. COYLE*

3.1	Introduction	63
3.2	Classification of Roll Coating Flows	64
3.3	Analysis of Roll Coating Flows	69

3.3.1	Goals of Analysis	69
3.3.2	Lubrication Theory	70
3.3.3	Asymptotic Analysis	71
3.3.4	Finite Element Analysis	72
3.4	Forward Roll Coating	72
3.4.1	Introduction	72
3.4.2	Mechanisms of Flow	73
3.4.3	Analysis of the Flow	73
3.4.4	Flow Fields	74
3.4.5	Non-Newtonian Effects	78
3.4.6	Conclusions	79
3.5	Ribbing Instability	79
3.5.1	Introduction	79
3.5.2	The Mechanism of Ribbing	81
3.5.3	Critical Conditions for the Onset of Ribbing	82
3.5.4	Non-Newtonian Effects	84
3.5.5	Conclusions	85
3.6	Reverse Roll Coating	86
3.6.1	Introduction	86
3.6.2	Fluid Flow in the Metering Gap	86
3.6.3	Flow Instabilities	90
3.6.4	Non-Newtonian Effects	93
3.6.5	Conclusions	94
3.7	Deformable Rolls	94
3.7.1	Introduction	94
3.7.2	The Mechanics of Deformable Nip Flow	95
3.7.3	Analysis of Deformable Nip Flow	97
3.7.4	Results and Discussion	98
3.7.5	Conclusions	102
3.8	Gravure Coating	103
3.8.1	Introduction	103
3.8.2	Flexible Blade Doctoring	105
3.8.3	Coating Transfer (Pick-Out)	107
3.8.4	Conclusions	108
	Literature	109

## 4 / Premetered Coating

*EDGAR B. GUTOFF*

4.1	Review of Premetered Coaters	117
4.1.1	Slot or Extrusion Coaters	118
4.1.2	Slide or Cascade Coaters	119
4.1.3	Curtain Coaters	120
4.2	Surface Tension and Wettability	122
4.2.1	Introduction	122
4.2.2	Origin of Surface Tension	123

- 4.2.3 Effects of Surfactants and Dynamic Surface Tension 124
- 4.2.4 Capillary Pressure 124
- 4.2.5 Shape of the Coating Bead on a Slide Coater 125
- 4.3 Shear and Elongation Rates 127
- 4.4 Contact Angles and Spreading 129
  - 4.4.1 Static Contact Angles and Spreading Coefficient 129
  - 4.4.2 Surface Tension Requirements in Multilayer Coatings 130
  - 4.4.3 Surface Tension-Driven Defects 131
  - 4.4.4 Contact Angles on a Moving Web 133
- 4.5 Low Flow Limits of Coatability 141
  - 4.5.1 Introduction and Background 141
  - 4.5.2 More Data on Low Flow Limits in Slide Coating 142
  - 4.5.3 Balance of Forces 145
  - 4.5.4 Explanation of Factors Affecting the Limits of Coatability 149
  - 4.5.5 Multilayer Coatings and Carrier Coatings 150
  - 4.5.6 Low Flow Limits in Slot Coating 151
- 4.6 Instabilities in Slide Coating 156
  - 4.6.1 Wave Formation 156
  - 4.6.2 Chatter 161
  - 4.6.3 Ribbing 162
  - 4.6.4 Streaks 163

Literature 164

## **5 / Air Knife Coating**

*NEIL I. STEINBERG*

- 5.1 Overview 169
- 5.2 Typical Operating Range 170
- 5.3 Mechanism 170
  - 5.3.1 Qualitative Description 170
  - 5.3.2 Basic Laminar Film Flow 171
- 5.4 A Coating Thickness Correlation 175
  - 5.4.1 The Momentum Balance 175
  - 5.4.2 Correlation of Experimental Photographic Coatings 176
- 5.5 Defects and Flow Stability 186

Literature 192

## **6 / Drive Systems for Off-Machine Coaters**

*GERALD I. KHEBOIAN*

- Abbreviations and Definitions 193
- 6.1 Writing Specifications 194

- 6.1.1 The Project Team 195
- 6.1.2 Terminology 196
- 6.2 Selecting a Winding Machine for a Coating Operation 200
  - 6.2.1 A Constant Tension System for the #24 Winder 205
- 6.3 The Master or Lead Section and Factors That Reduce Its Effectiveness on a Coating Machine 206
  - 6.3.1 Problems with Maintaining the Effectiveness of a Lead Section 207
  - 6.3.2 Defects That Cause Operators to Bypass Sections or Open Nips 209
- 6.4 Influence of Unwind and Winder on Web Control 210
- 6.5 A Speed Monitoring System 210
- 6.6 Tension in a Coating Machine 211
  - 6.6.1 Differential Tension 211
  - 6.6.2 Tension Zone 212
  - 6.6.3 Typical Tension Values 212
  - 6.6.4 Typical Problem of Establishing Tension for a Critical Process 212
  - 6.6.5 Stall Tension 213
  - 6.6.6 Selecting a Tension Indicating System 214
  - 6.6.7 Need for Tension Control 215
- 6.7 Effects of Wiring Practices on Tension Control 217
- 6.8 When to Use Pure Speed Control 218
- 6.9 Types of Tension Control Systems 219
  - 6.9.1 Motor Current Regulation 220
  - 6.9.2 Use of a Current Regulator to Control Winder Tension 222
  - 6.9.3 Use of a Current Controller on Constant-Diameter Sections 222
  - 6.9.4 Dancer Roll Control 223
  - 6.9.5 Tension Regulation with Force Transducers 224
  - 6.9.6 Tension Control Systems—Advantages and Disadvantages 225
  - 6.9.7 Tension Control of Constant Diameter Sections 226
- 6.10 Isolation 226
  - 6.10.1 Isolation and the Need for Tension Control 227
- 6.11 Sections That Can Control Tension 227
  - 6.11.1 Sections That Provide Limited or No Tension Control 228
  - 6.11.2 How to Deal with Sections with Limited Ability to Control Tension 228
  - 6.11.3 Typical Speed Trim Values for Constant Diameter Sections 229

- 6.12 Integral versus Proportional Control 230
- 6.13 The Need for Motoring and Regeneration 230
  - 6.13.1 Characteristics of Power Units 231
  - 6.13.2 Effect of Gear Reducers on Power Supply Selection 232
- 6.14 Sizing Power Supplies for Off-Machine Coater Drives 233
  - 6.14.1 Power Unit Overload Capacity 233
  - 6.14.2 Getting the Most from the Power Supply 234
  - 6.14.3 Continuous or Intermittent Processes 235
- 6.15 Web 235
  - 6.15.1 Causes of Wrinkles in the Base Web 235
  - 6.15.2 Web Attributes 237
- 6.16 Web Guides and Web Spreaders 238
  - 6.16.1 Unwind Guiding 239
  - 6.16.2 Rewind Guiding 239
  - 6.16.3 Intermediate Guiding 239
  - 6.16.4 Web Spreaders 240
  - 6.16.5 Spreader Roller Applications 241
- 6.17 Defects—Sources and Solutions 243
  - 6.17.1 Sources of Coating Chatter 243
  - 6.17.2 Backlash within a Gearbox, a Geared Coupling, or Timing Belts 243
  - 6.17.3 Chatter Caused by the Roll 244
  - 6.17.4 Roll Unbalance 244
  - 6.17.5 Nonconcentric Roll 244
  - 6.17.6 Effects of Coupling Selection on Feedback Devices 246
  - 6.17.7 Other Factors That Affect Coating Quality 246
- 6.18 Application Considerations for Off-Machine Coater Sections 247
  - 6.18.1 Unwind Stand 247
  - 6.18.2 Types of Center Unwinds 248
  - 6.18.3 Need for a Drive Motor on Unwind Stands 249
  - 6.18.4 Preference for Large Diameter Cores on Any Type of Unwind 249
  - 6.18.5 Wound Roll Defects Make Acceleration and Splicing Difficult 250
  - 6.18.6 Selecting Horsepower for Unwind Drives 250
  - 6.18.7 Draw Rolls 251
  - 6.18.8 Coaters 255
  - 6.18.9 Dryers 255
  - 6.18.10 Dryer Doctor Loading 256
  - 6.18.11 Dryer Tension 256

6.18.12	Small Dryer Sections as Lead Sections	257
6.18.13	Dryer Condensation Problems	257
6.18.14	Coating Web Defects due to Web Wrinkling	257
6.18.15	Flotation and Air Impingement Dryers	257
6.18.16	Calender	258
6.18.17	Rewind: The Web's Exit Point	258
6.18.18	Centerwind Windups	259
6.18.19	Taper Tension Systems for Center-Drive Unwinds and Rewinds	261
6.18.20	Transient Conditions Can Cause Winding Problems	261
6.18.21	Role of Quality Assurance in Improved Machine Performance	262
6.19	Summary	263
6.19.1	Power Requirements	263
6.19.2	Use of NRL and RDC Constants	264
	Literature	265

## 7 / Thin Film Drying

*EDWARD D. COHEN*

7.1	Introduction	267
7.2	Basic Principles	268
7.2.1	Coating-Drying Interactions	268
7.2.2	Basic Equations	269
7.2.3	Psychrometric Definitions	272
7.3	Drying Regimes	274
7.3.1	Predryer	275
7.3.2	Constant Rate	275
7.3.3	Falling Rate	276
7.3.4	Equilibration	277
7.4	Hardware	277
7.4.1	Air Convection Dryers	278
7.4.2	Selecting a Dryer Type	284
7.4.3	Other Energy Sources	285
7.5	Dryer Control	286
7.6	Drying Defects	287
7.6.1	Defects Caused by Motion of Air	287
7.6.2	Defects Caused by Surface Forces	289
7.6.3	Other Dryer-Related Defects	290
	Literature	296

Nomenclature 299

Contributors 303

Index 305