

Contents

- 1 *History, Structural Formulation of the Field Through Elementary Steps, and Future Perspectives, 1***
 - 1.1** Historical Notes, 1
 - 1.2** Current Polymer Processing Practice, 7
 - 1.3** Analysis of Polymer Processing in Terms of Elementary Steps and Shaping Methods, 14
 - 1.4** Future Perspectives: From Polymer Processing to Macromolecular Engineering, 18
- 2 *The Balance Equations and Newtonian Fluid Dynamics, 25***
 - 2.1** Introduction, 25
 - 2.2** The Balance Equations, 26
 - 2.3** Reynolds Transport Theorem, 26
 - 2.4** The Macroscopic Mass Balance and the Equation of Continuity, 28
 - 2.5** The Macroscopic Linear Momentum Balance and the Equation of Motion, 32
 - 2.6** The Stress Tensor, 37
 - 2.7** The Rate of Strain Tensor, 40
 - 2.8** Newtonian Fluids, 43
 - 2.9** The Macroscopic Energy Balance and the Bernoulli and Thermal Energy Equations, 54
 - 2.10** Mass Transport in Binary Mixtures and the Diffusion Equation, 60
 - 2.11** Mathematical Modeling, Common Boundary Conditions, Common Simplifying Assumptions, and the Lubrication Approximation, 60
- 3 *Polymer Rheology and Non-Newtonian Fluid Mechanics, 79***
 - 3.1** Rheological Behavior, Rheometry, and Rheological Material Functions of Polymer Melts, 80
 - 3.2** Experimental Determination of the Viscosity and Normal Stress Difference Coefficients, 94
 - 3.3** Polymer Melt Constitutive Equations Based on Continuum Mechanics, 100
 - 3.4** Polymer Melt Constitutive Equations Based on Molecular Theories, 122

4 *The Handling and Transporting of Polymer Particulate Solids*, 144

- 4.1 Some Unique Properties of Particulate Solids, 145
- 4.2 Agglomeration, 150
- 4.3 Pressure Distribution in Bins and Hoppers, 150
- 4.4 Flow and Flow Instabilities in Hoppers, 152
- 4.5 Compaction, 154
- 4.6 Flow in Closed Conduits, 157
- 4.7 Mechanical Displacement Flow, 157
- 4.8 Steady Mechanical Displacement Flow Aided by Drag, 159
- 4.9 Steady Drag-induced Flow in Straight Channels, 162
- 4.10 The Discrete Element Method, 165

5 *Melting*, 178

- 5.1 Classification and Discussion of Melting Mechanisms, 179
- 5.2 Geometry, Boundary Conditions, and Physical Properties in Melting, 184
- 5.3 Conduction Melting without Melt Removal, 186
- 5.4 Moving Heat Sources, 193
- 5.5 Sintering, 199
- 5.6 Conduction Melting with Forced Melt Removal, 201
- 5.7 Drag-induced Melt Removal, 202
- 5.8 Pressure-induced Melt Removal, 216
- 5.9 Deformation Melting, 219

6 *Pressurization and Pumping*, 235

- 6.1 Classification of Pressurization Methods, 236
- 6.2 Synthesis of Pumping Machines from Basic Principles, 237
- 6.3 The Single Screw Extruder Pump, 247
- 6.4 Knife and Roll Coating, Calenders, and Roll Mills, 259
- 6.5 The Normal Stress Pump, 272
- 6.6 The Co-rotating Disk Pump, 278
- 6.7 Positive Displacement Pumps, 285
- 6.8 Twin Screw Extruder Pumps, 298

7 *Mixing*, 322

- 7.1 Basic Concepts and Mixing Mechanisms, 322
- 7.2 Mixing Equipment and Operations of Multicomponent and Multiphase Systems, 354
- 7.3 Distribution Functions, 357
- 7.4 Characterization of Mixtures, 378
- 7.5 Computational Analysis, 391

8 *Devolatilization*, 409

- 8.1 Introduction, 409
- 8.2 Devolatilization Equipment, 411
- 8.3 Devolatilization Mechanisms, 413

- 8.4 Therm
- 8.5 Diffus
- 8.6 Boiling
- 8.7 Boiling
- 8.8 Ultras
- 8.9 Bubble
- 8.10 Bubble
- 8.11 Scanni
- Devolat

9 *Single Rotor*

- 9.1 Modelin
- 9.2 The Sin
- 9.3 The Sin
- 9.4 The Co-

10 *Twin Screw a*

- 10.1 Types o
- 10.2 Counte
- 10.3 Co-rotat

11 *Reactive Poly*

- 11.1 Classes
- Reactiv
- 11.2 Reactor
- 11.3 Mixing
- Polyme
- 11.4 Reactiv
- Compat
- 11.5 Polyme

12 *Die Forming*,

- 12.1 Capillar
- 12.2 Elastic
- 12.3 Sheet F
- 12.4 Tube, B
- 12.5 Wire Co
- 12.6 Profile

13 *Molding*, 753

- 13.1 Injection
- 13.2 Reactive
- 13.3 Compres

- 8.4 Thermodynamic Considerations of Devolatilization, 416
- 8.5 Diffusivity of Low Molecular Weight Components in Molten Polymers, 420
- 8.6 Boiling Phenomena: Nucleation, 422
- 8.7 Boiling-Foaming Mechanisms of Polymeric Melts, 424
- 8.8 Ultrasound-enhanced Devolatilization, 427
- 8.9 Bubble Growth, 428
- 8.10 Bubble Dynamics and Mass Transfer in Shear Flow, 430
- 8.11 Scanning Electron Microscopy Studies of Polymer Melt Devolatilization, 433
- 9 *Single Rotor Machines, 447***
 - 9.1 Modeling of Processing Machines Using Elementary Steps, 447
 - 9.2 The Single Screw Melt Extrusion Process, 448
 - 9.3 The Single Screw Plasticating Extrusion Process, 473
 - 9.4 The Co-rotating Disk Plasticating Processor, 506
- 10 *Twin Screw and Twin Rotor Processing Equipment, 523***
 - 10.1 Types of Twin Screw and Twin Rotor-based Machines, 525
 - 10.2 Counterrotating Twin Screw and Twin Rotor Machines, 533
 - 10.3 Co-rotating, Fully Intermeshing Twin Screw Extruders, 572
- 11 *Reactive Polymer Processing and Compounding, 603***
 - 11.1 Classes of Polymer Chain Modification Reactions, Carried out in Reactive Polymer Processing Equipment, 604
 - 11.2 Reactor Classification, 611
 - 11.3 Mixing Considerations in Multicomponent Miscible Reactive Polymer Processing Systems, 623
 - 11.4 Reactive Processing of Multicomponent Immiscible and Compatibilized Immiscible Polymer Systems, 632
 - 11.5 Polymer Compounding, 635
- 12 *Die Forming, 677***
 - 12.1 Capillary Flow, 680
 - 12.2 Elastic Effects in Capillary Flows, 689
 - 12.3 Sheet Forming and Film Casting, 705
 - 12.4 Tube, Blown Film, and Parison Forming, 720
 - 12.5 Wire Coating, 727
 - 12.6 Profile Extrusion, 731
- 13 *Molding, 753***
 - 13.1 Injection Molding, 753
 - 13.2 Reactive Injection Molding, 798
 - 13.3 Compression Molding, 811

14 *Stretch Shaping*, 824

14.1 Fiber Spinning, 824

14.2 Film Blowing, 836

14.3 Blow Molding, 841

15 *Calendering*, 865

15.1 The Calendering Process, 865

15.2 Mathematical Modeling of Calendering, 867

15.3 Analysis of Calendering Using FEM, 873

Appendix A *Rheological and Thermophysical Properties of Polymers*, 887

Appendix B *Conversion Tables to the International System of Units (SI)*, 914

Appendix C *Notation*, 918

Author Index, 929

Subject Index, 944

1 History of the Field: Steps, a

- 1.1 Historical Notes, 1
- 1.2 Current Polymer Processing, 1
- 1.3 Analysis of Polymer Processing Steps and Shaping Methods, 1
- 1.4 Future Perspectives: 1

Polymer processing is carried out on polymeric materials. This chapter deals with the conversion of polymers into useful shapes, not only shaping but also chemical and physical modifications and morphological changes. This chapter briefly reviews the history of the field, the reader to what we have learned from the polymer processing methods of the past, the future of the field, which is the final properties of polymers, and the final properties of polymers based on first molecular

1.1 HISTORICAL NOTES

Plastics and Rubber Manufacturing

Modern polymer processing began in the rubber industry and the process of rubber processing machinery. In 1792, a man named James Hargreaves, a winch inside a toothed wheel, was used in England, to reclaim scrap rubber. In 1820, John Goodyear, to confuse his competitors, moved to Massachusetts, developed a process for rubber processing, the *roll calender* for the continuous processing of rubber. This process is still being used in the rubber industry. John Goodyear, is credited with the invention of the Goodyear process, and Richard Brooman applied for a patent which was used in wire coating.