

HANSER

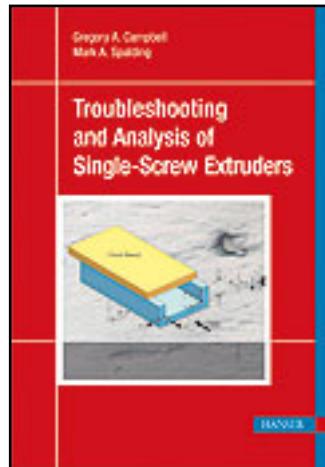


Table of Contents

Gregory A. Campbell, Mark A. Spalding

Analyzing and Troubleshooting Single-Screw Extruders

ISBN (Buch): 978-3-446-41371-9

ISBN (E-Book): 978-3-446-43266-6

For further information and order see

<http://www.hanser-fachbuch.de/978-3-446-41371-9>

or contact your bookseller.

Contents

Preface	V
Acknowledgements	VII
1 Single-Screw Extrusion: Introduction and Troubleshooting ..	1
1.1 Organization of this Book	3
1.2 Troubleshooting Extrusion Processes	5
1.2.1 The Injection Molding Problem at Saturn	6
1.3 Introduction to Screw Geometry	6
1.3.1 Screw Geometric Quantitative Characteristics	8
1.4 Simple Flow Equations for the Metering Section	11
1.5 Example Calculations	15
1.5.1 Example 1: Calculation of Rotational and Pressure Flow Components	15
1.5.2 Example 2: Flow Calculations for a Properly Operating Extruder	17
1.5.3 Example 3: Flow Calculations for an Improperly Operating Extruder	18
1.5.4 Metering Channel Calculation Summary	20
Nomenclature	20
References	22
2 Polymer Materials	23
2.1 Introduction and History	24
2.1.1 History of Natural Polymers	25
2.1.2 The History of Synthetic Polymers	26
2.2 Characteristics of Synthetic Polymers	28
2.3 Structure Effects on Properties	31
2.3.1 Stereochemistry	34
2.3.2 Melting and Glass Transition Temperatures	35
2.3.3 Crystallinity	37

2.4	Polymer Production and Reaction Engineering	40
2.4.1	Condensation Reactions	40
2.4.2	Addition Reactions	43
2.5	Polymer Degradation	46
2.5.1	Ceiling Temperature	49
2.5.2	Degradation of Vinyl Polymers	51
2.5.3	Degradation of Condensation Polymers	53
	References	54
3	Introduction to Polymer Rheology for Extrusion	57
3.1	Introduction to the Deformation of Materials	57
3.2	Introduction to Basic Concepts of Molecular Size	58
3.2.1	Size Distribution Example	59
3.2.2	Molecular Weight Distributions for Polymers	60
3.3	Basic Rheology Concepts	63
3.4	Polymer Solution Viscosity and Polymer Molecular Weight	67
3.4.1	Sample Calculation of Solution Viscosity	71
3.5	Introduction to Viscoelasticity	72
3.6	Measurement of Polymer Viscosity	80
3.6.1	Capillary Rheometers	80
3.6.2	Cone and Plate Rheometers	91
3.6.3	Melt Index and Melt Flow Rate	94
3.7	Viscosity of Polymers as Functions of Molecular Character, Temperature, and Pressure	97
3.8	Models for Non-Newtonian Flow	103
	Nomenclature	105
	References	107
4	Resin Physical Properties Related to Processing	109
4.1	Bulk Density and Compaction	110
4.1.1	Measurement of Bulk Density	111
4.1.2	Measuring the Compaction Characteristics of a Resin	112
4.2	Lateral Stress Ratio	115
4.2.1	Measuring the Lateral Stress Ratio	116
4.3	Stress at a Sliding Interface	118
4.3.1	The Screw Simulator and the Measurement of the Stress at the Interface	119

4.4	Melting Flux	121
4.5	Heat Capacity	123
4.6	Thermal Conductivity and Heat Transfer	124
4.7	Melt Density	125
	Nomenclature	127
	References	127
5	Solids Conveying	131
5.1	Description of the Solid Conveying Process	132
5.2	Literature Review of Smooth-Bore Solids Conveying Models	134
5.2.1	Darnell and Mol Model	137
5.2.2	Tadmor and Klein Model	138
5.2.3	Clarkson University Models	139
5.2.4	Hyun and Spalding Model	142
5.2.5	Moysey and Thompson Model	143
5.3	Modern Experimental Solids Conveying Devices	143
5.3.1	Solids Conveying Devices at Clarkson University	144
5.3.2	The Solids Conveying Device at Dow	158
5.4	Comparison of the Modified Campbell-Dontula Model with Experimental Data	168
5.4.1	Solids Conveying Example Calculation	172
5.5	Grooved Bore Solids Conveying	174
5.5.1	Grooved Barrel Solids Conveying Models	178
5.6	Solids Conveying Notes	180
	Nomenclature	183
	References	185
6	The Melting Process	189
6.1	Compression Ratio and Compression Rate	191
6.2	The Melting Process	193
6.2.1	The Melting Process as a Function of Screw Geometry	194
6.2.2	Review of the Classical Literature	199
6.2.3	Reevaluation of the Tadmor and Klein Melting Data	200
6.3	Theory Development for Melting Using Screw Rotation Physics	203
6.3.1	Melting Model for a Conventional Transition Section Using Screw Rotation Physics	204
6.3.2	Melting Models for Barrier Screw Sections	218

6.4	Effect of Pressure on Melting Rate	227
6.5	One-Dimensional Melting	228
6.5.1	One-Dimensional Melting Model	232
6.6	Solid Bed Breakup	234
6.7	Melting Section Characteristics	238
	Nomenclature	240
	References	242
7	Fluid Flow in Metering Channels	247
7.1	Introduction to the Reference Frame	247
7.2	Laboratory Observations	250
7.3	Literature Survey	254
7.4	Development of Linearized Flow Analysis	259
7.4.1	Example Flow Calculation	274
7.5	Numerical Flow Evaluation	277
7.5.1	Simulation of a 500 mm Diameter Melt-Fed Extruder	279
7.5.2	Extrusion Variables and Errors	281
7.5.3	Corrections to Rotational Flow	287
7.5.4	Simulation of the 500 mm Diameter Extruder Using F_c	292
7.6	Frame Dependent Variables	293
7.6.1	Example Calculation of Energy Dissipation	296
7.7	Viscous Energy Dissipation and Temperature of the Resin in the Channel	297
7.7.1	Energy Dissipation and Channel Temperature for Screw Rotation	303
7.7.2	Energy Dissipation and Channel Temperature for Barrel Rotation	307
7.7.3	Temperature Increase Calculation Example for a Screw Pump	308
7.7.4	Heat Transfer Coefficients	313
7.7.5	Temperature Calculation Using a Control Volume Technique .	314
7.7.6	Numerical Comparison of Temperatures for Screw and Barrel Rotations	317
7.8	Metering Section Characteristics	319
	Nomenclature	321
	References	325

8 Mixing Processes for Single-Screw Extruders	329
8.1 Common Mixing Operations for Single-Screw Extruders	330
8.1.1 Common Mixing Applications	331
8.2 Dispersive and Distributive Mixing Processes	333
8.3 Fundamentals of Mixing	335
8.3.1 Measures of Mixing	336
8.3.2 Experimental Demonstration of Mixing	338
8.4 The Melting Process as the Primary Mechanism for Mixing	346
8.4.1 Experimental Analysis of the Melting and Mixing Capacity of a Screw	349
8.4.2 Mixing and Barrier-Flighted Melting Sections	352
8.5 Secondary Mixing Processes and Devices	353
8.5.1 Maddock-Style Mixers	354
8.5.2 Blister Ring Mixers	359
8.5.3 Spiral Dam Mixers	361
8.5.4 Pin-Type Mixers	362
8.5.5 Knob Mixers	363
8.5.6 Gear Mixers	364
8.5.7 Dynamic Mixers	364
8.5.8 Static Mixers	367
8.6 Mixing Using Natural Resins and Masterbatches	374
8.7 Mixing and Melting Performance as a Function of Flight Clearance ...	375
8.8 High Pressures During Melting and Agglomerates	376
8.9 Effect of Discharge Pressure on Mixing	376
8.10 Shear Refinement	377
8.11 Direct Compounding Using Single-Screw Extruders	379
Nomenclature	380
References	382
 9 Scaling of Single-Screw Extrusion Processes	387
9.1 Scaling Rules	388
9.2 Engineering Design Method for Plasticating Screws	389
9.2.1 Process Analysis and Simulations	393
9.3 Scale-Up from a 40 mm Diameter Extruder to an 80 mm Diameter Machine for a PE Resin	393
9.4 Rate Increase for an 88.9 mm Diameter Extruder Running a HIPS Resin	397
Nomenclature	404
References	405

10 Introduction to Troubleshooting the Extrusion Process	407
10.1 The Troubleshooting Process	408
10.2 Hypothesis Setting and Problem Solving	411
10.2.1 Case Study for the Design of a New Resin	412
10.2.2 Case Study for a Surface Blemish	414
10.2.3 Case Study for a Profile Extrusion Process	415
10.3 Equipment and Tools Needed for Troubleshooting	416
10.3.1 Maddock Solidification Experiment	418
10.4 Common Mechanical Problems	419
10.4.1 Flight Clearance and Hard Facing	419
10.4.2 Barrel and Screw Alignment	421
10.4.3 Extruder Barrel Supports	422
10.4.4 First-Time Installation of a Screw	424
10.4.5 Screw Breaks	425
10.4.6 Protection from High-Pressure Events	427
10.4.7 Gearbox Lubricating Oil	429
10.4.8 Particle Seals and Viscoseals	429
10.4.9 Screw Cleaning	431
10.5 Common Electrical and Sensor Problems	431
10.5.1 Thermocouples	432
10.5.2 Pressure Sensors	432
10.5.3 Electronic Filters and Noise	433
10.6 Motors and Drive Systems	435
10.6.1 Motor Efficiencies and Power Factors	437
10.7 Typical Screw Channel Dimensions	438
10.8 Common Calculations	439
10.8.1 Energy Dissipated by the Screw	439
10.8.2 Screw Geometry Indices	440
10.9 Barrel Temperature Optimization	442
10.10 Screw Temperature Profile	445
10.11 The Screw Manufacturing and Refurbishing Process	454
10.12 Injection-Molding Plasticators	462
10.12.1 Calculations for Injection-Molding Plasticators	464
10.13 New Equipment Installations	464
10.13.1 Case Study: A Large Diameter Extruder Purchase	468
10.13.2 Case Study: Extruder and Line Purchase for a New Product	469
10.13.3 Summary for New Equipment Installations	470
Nomenclature	471
References	473

11 Contamination in the Finished Product	477
11.1 Foreign Contaminants in the Extrudate	477
11.1.1 Melt Filtration	478
11.1.2 Metal Fragments in the Extrudate	482
11.1.3 Gas Bubbles in a New Sheet Line	483
11.2 Gels in Polyolefin Resins	484
11.2.1 Protocols for Gel Analysis	485
11.3 Resin Decomposition in Stagnant Regions of a Process	491
11.4 Improper Shutdown of Processing Equipment	493
11.5 Equipment Purging	494
11.6 Oxygen Exclusion at the Hopper	496
11.7 Flight Radii Size	496
11.8 Drying the Resin	499
11.9 Color Masterbatches	500
11.10 Case Studies for Extrusion Processes with Contamination in the Product	501
11.10.1 Intermittent Crosslinked Gels in a Film Product	501
11.10.2 Small Gels in an LLDPE Film Product	507
11.10.3 Degassing Holes in Blow-Molded Bottles	510
11.11 Contamination in Injection-Molded Parts	513
11.11.1 Splay Defects for Injection-Molded Parts	513
11.12 Injection-Molding Case Studies	516
11.12.1 Injection-Molded Parts with Splay and Poor Resin Color Purge	516
11.12.2 Black Color Streaks in Molded Parts: Case One	520
11.12.3 Black Streaks in Molded Parts: Case Two	525
11.12.4 Silver Streaks in a Clear GPPS Resin Injection-Molded Packaging Part	529
11.12.5 The Injection-Molding Problem at Saturn	536
Nomenclature	537
References	538
12 Flow Surging	541
12.1 An Overview of the Common Causes for Flow Surging	542
12.1.1 Relationship Between Discharge Pressure and Rate at the Die	542
12.2 Troubleshooting Flow Surging Processes	543
12.3 Barrel Zone and Screw Temperature Control	544
12.3.1 Water- and Air-Cooled Barrel Zones	545

12.4	Rotation- and Geometry-Induced Pressure Oscillations	546
12.5	Gear Pump Control	548
12.6	Solids Blocking the Flow Path	551
12.7	Case Studies for Extrusion Processes That Flow Surge	551
12.7.1	Poor Barrel Zone Temperature Control	551
12.7.2	Optimization of Barrel Temperatures for Improved Solids Conveying	554
12.7.3	Flow Surging Due to High Temperatures in the Feed Section of the Screw	556
12.7.4	Flow Surging Due to High Temperatures in the Feed Casing ..	563
12.7.5	Flow Surging Due to a Poorly Designed Barrier Entry for GPPS Resin	565
12.7.6	Solid Blockage at the Entry of a Spiral Mixer	568
12.7.7	Flow Surging Caused by a Worn Feed Casing and a New Barrel	574
12.7.8	Flow Surging for a PC Resin Extrusion Process	583
	Nomenclature	587
	References	588
13	Rate-Limited Extrusion Processes	591
13.1	Vent Flow for Multiple-Stage Extruders	593
13.2	Screw Wear	595
13.3	High-Performance and Barrier Screws for Improved Rates	597
13.4	Case Studies That Were Rate Limited	597
13.4.1	Rate Limitation Due to a Worn Screw	597
13.4.2	Rate Limitation Due to Solid Polymer Fragments in the Extrudate	598
13.4.3	Rate Limited by the Discharge Temperature for a Pelletizing Extruder	603
13.4.4	Large Diameter Extruder Running PS Resin	610
13.4.5	Rate Limited by Discharge Temperature and Torque for Starch Extrusion	614
13.4.6	Vent Flow for a Two-Stage Screw Running a Low Bulk Density PS Feedstock	617
13.4.7	Increasing the Rate of a Large Part Blow-Molding Process	619
	Nomenclature	623
	References	624

14 Barrier and High-Performance Screws	625
14.1 Barrier Screws	627
14.2 Wave Dispersion Screws	633
14.2.1 Double Wave Screw	633
14.2.2 Energy Transfer Screws	635
14.2.3 Variable Barrier Energy Transfer Screws	641
14.2.4 Distributive Melt Mixing Screws	645
14.2.5 Fusion Screws	649
14.3 Other High-Performance Screw Designs	650
14.3.1 Stratablast Screws	650
14.3.2 Unimix Screws	652
14.4 Calculation of the Specific Rotation Rate	653
Nomenclature	653
References	654
15 Melt-Fed Extruders	657
15.1 Simulation Methods	657
15.2 Compounding Processes	658
15.2.1 Common Problems for Melt-Fed Extruders on Compounding Lines	660
15.3 Large-Diameter Pumping Extruders	661
15.3.1 Loss of Rate Due to Poor Material Conveyance in the Feed Section	670
15.3.2 Operation of the Slide Valve	672
15.3.3 Nitrogen Inerting on Vent Domes	673
15.4 Secondary Extruders for Tandem Foam Sheet Lines	674
15.4.1 High-Performance Cooling Screws	678
Nomenclature	681
References	682
Appendix A1	
Polymer Abbreviation Definitions	685
Appendix A3	
Rheological Calculations for a Capillary Rheometer and for a Cone and Plate Rheometer	687
A3.1 Capillary Rheometer	687
A3.2 Cone and Plate Rheometer	691
References	693

Appendix A4

Shear Stress at a Sliding Interface and Melting Fluxes for Select Resins	695
A4.1 Shear Stress at a Sliding Interface for Select Resins	695
A4.2 Melting Fluxes for Select Resins	699
References	702

Appendix A5

Solids Conveying Model Derivations and the Complete LDPE Solids Conveying Data Set	705
A5.1 Channel Dimensions, Assumptions, and Basic Force Balances	705
A5.2 Campbell-Dontula Model	707
A5.2.1 Modified Campbell-Dontula Model	708
A5.3 Hyun-Spalding Model	710
A5.4 Yamamuro-Penumadu-Campbell Model	712
A5.5 Campbell-Spalding Model	714
A5.6 The Complete Dow Solids Conveying Data Set	714
References	719

Appendix A6

Melting Rate Model Development	721
A6.1 Derivation of the Melting Performance Equations for a Conventional Channel	721
A6.2 Effect of Static Pressure on Melting	732
References	732

Appendix A7

Flow and Energy Equation Development for the Metering Channel	733
A7.1 Transformed Frame Flow Analysis	733
A7.1.1 x -Directional Flow	735
A7.1.2 z -Directional Flow	736
A7.1.3 z -Directional Flow for Helix Rotation with a Stationary Screw Core and Barrel	742
A7.1.4 z -Directional Flow Due to a Pressure Gradient	744
A7.2 Viscous Energy Dissipation for Screw Rotation	749
A7.2.1 Viscous Energy Dissipation for Screw Rotation: Generalized Solution	749

A7.2.2 Viscous Energy Dissipation for Screw Rotation for Channels with Small Aspect Ratios ($H/W < 0.1$)	755
A7.3 Viscous Energy Dissipation for Barrel Rotation	757
A7.3.1 Viscous Energy Dissipation for Barrel Rotation: Generalized Solution	758
A7.3.2 Viscous Energy Dissipation for Barrel Rotation for Channels with Small Aspect Ratios ($H/W < 0.1$)	761
References	762
Author	763
Subjekt	769