

Contents

Acknowledgments	V
Preface	VII
List of Acronyms	IX
1 Requirements for Efficient Troubleshooting	1
1.1 Instrumentation	1
1.2 Understanding the Extrusion Process	2
1.3 Collection and Analysis of Historical Data (Time Line)	4
1.4 Team Building	5
1.5 Condition of the Equipment	6
1.6 Information about the Feed Stock	6
1.7 Problem-Solving Techniques	8
1.8 Collection and Interpretation of Extrusion Process Data	9
1.8.1 Introduction	9
1.8.2 Vital Signs of the Extrusion Process	9
1.8.2.1 Melt Pressure	10
1.8.2.2 Melt Temperature	16
1.8.2.3 Training	25
1.8.3 Conclusions	25
2 Tools for Troubleshooting	27
2.1 Temperature Measurement Devices	27
2.2 Data Acquisition Systems	28
2.2.1 Portable Data Collectors/Machine Analyzers	29
2.2.2 Fixed-Station Data Acquisition Systems	30
2.3 Light Microscopy	33

2.4	Thermochromic Materials	34
2.5	Thermal Analysis, IR Spectroscopy, and Rheometry	35
2.5.1	Differential Thermal Analysis and Differential Scanning Calorimetry	35
2.5.2	Thermogravimetric Analysis	37
2.5.3	Fourier Transform Infrared Spectroscopy	38
2.5.4	Thermomechanical Analysis	39
2.5.5	Torque Rheometry	40
2.5.6	High Pressure Capillary Rheometry	41
2.5.7	Rotational Rheometry	43
2.5.8	Other Thermal Characterization Techniques	46
2.6	Miscellaneous Tools	46
2.6.1	Infrared Thermography	47
2.6.2	The Smartphone	48
2.6.3	Power Measurements	49
3	Systematic Troubleshooting	51
3.1	Upsets versus Development Problems	51
3.2	Machine-Related Problems	51
3.2.1	The Drive System	52
3.2.2	The Feed System	53
3.2.3	The Heating and Cooling System	53
3.2.4	How Screw Design Can Affect Extruder Performance	54
3.2.5	Wear Problems	65
3.2.5.1	Wear Mechanisms	66
3.2.5.2	Test Methods for Wear	67
3.2.5.3	Causes of Wear	72
3.2.5.4	Solutions to Wear Problems	77
3.2.5.5	Rebuilding Worn Screws and Barrels	83
3.2.6	Screw Binding	87
3.2.6.1	Extrusion of Fluoropolymers	88
3.2.6.2	The Mechanics of Screw Binding	88
3.2.6.3	Changes in Clearance Due to Temperature Differences	88
3.2.6.4	Analysis of Temperature Distribution in Extruder Screws	91
3.2.6.5	Change in Clearance Due to Compressive Load	92
3.2.6.6	Results from Analysis	92
3.3	Polymer Degradation	93
3.3.1	Types of Degradation	93
3.3.1.1	Thermal Degradation	94

3.3.1.2	Mechanical Degradation	94
3.3.1.3	Chemical Degradation	96
3.3.2	Degradation in Extrusion	97
3.3.2.1	Residence Time Distribution	97
3.3.2.2	Temperature Distribution Simple Calculations	101
3.3.2.3	Temperature Distribution Numerical Calculations	107
3.3.2.4	Reducing Degradation	114
3.4	Extrusion Instabilities	115
3.4.1	Frequency of Instability	116
3.4.1.1	High-Frequency Instabilities	117
3.4.1.2	Screw Frequency Instabilities	120
3.4.1.3	Low-Frequency Instabilities	122
3.4.1.4	Very Slow Fluctuations	123
3.4.1.5	Random Fluctuations	123
3.4.2	Functional Instabilities	124
3.4.2.1	Solids-Conveying Instabilities	125
3.4.2.2	Plasticating Instabilities	125
3.4.2.3	Melt-Conveying Instabilities	126
3.4.2.4	Devolatilization Instabilities	126
3.4.2.5	Mixing Related Instabilities	127
3.4.2.6	Distributive Mixing Sections	127
3.4.2.7	Dispersive Mixing Sections	132
3.4.2.8	Solving Mixing Problems	139
3.4.2.9	Melt Temperature Variation	140
3.4.3	Solving Extrusion Instabilities	149
3.5	Air Entrapment	151
3.6	Gel Problems	153
3.6.1	Measuring Gels	153
3.6.2	Gels Created in the Extrusion Process	154
3.6.3	Removing Gels Produced in Polymerization	155
3.7	Die-Flow Problems	156
3.7.1	Melt Fracture	156
3.7.2	Die-Lip Buildup ("Die Drool")	158
3.7.3	V- or W-Patterns	159
3.7.4	Specks and Discoloration	160
3.7.5	Lines in Extruded Product	161
3.7.5.1	Weld Lines	162
3.7.6	Optical and Appearance Properties	163

4 Case Studies	165
4.1 Film Coextrusion – Degradation in the Middle Layer	165
4.1.1 Description of the Problem	165
4.1.2 Analysis of the Problem	166
4.1.3 Solution	167
4.2 Film Coextrusion with Interfacial Problems	169
4.2.1 Description of the Problem	169
4.2.2 Analysis of the Problem	169
4.2.3 Solution	170
4.3 Lines in the Extruded Film	170
4.3.1 Description of the Problem	170
4.3.2 Analysis of the Problem	171
4.3.3 Solution	172
4.4 Color Variation in Polypropylene Carpet Fiber	172
4.4.1 Description of the Problem	172
4.4.2 Analysis of the Problem	173
4.4.3 Solution	174
4.5 Plastic Film with Poor Transparency	175
4.5.1 Description of the Problem	175
4.5.2 Analysis of the Problem	176
4.5.3 Solution	177
4.6 Wear Problem in Film Extrusion	178
4.6.1 Description of the Problem	178
4.6.2 Solution	178
4.7 Multilayer Film – Several Appearance Problems	179
4.7.1 Description of the Problem	179
4.7.2 Analysis of the Problem	179
4.7.3 Solution	180
4.8 Dispersion Problem in a High-Density Polyethylene Bottle	181
4.8.1 Description of the Problem	181
4.8.2 Analysis of the Problem	181
4.8.3 Solution	182
4.9 Polymer Degradation	184
4.9.1 Description of the Problem	184
4.9.2 Analysis of the Problem	184
4.9.3 Solution	185
4.10 Heat-Sealing Problems in a Coextruded Film	187
4.10.1 Description of the Problem	187
4.10.2 Analysis of the Problem	188
4.10.3 Solution	189

4.11 Output Problem in a Blown Film Line	190
4.11.1 Description of the Problem	190
4.11.2 Analysis of the Problem	190
4.11.3 Solution	192
4.12 Masterbatch Selection	193
4.12.1 Description of the Problem	193
4.12.2 Analysis of the Problem	194
4.12.3 Solution	195
4.13 Pipe Extrusion Problem	196
4.13.1 Description of the Problem	196
4.13.2 Analysis of the Problem	196
4.13.3 Solution	197
4.14 Gel Formation in a Coextruded Film	199
4.14.1 Description of the Problem	199
4.14.2 Analysis of the Problem	199
4.14.3 Solution	200
4.15 Agglomerates and Grammage Variation in a PP Sheet	200
4.15.1 Description of the Problem	200
4.15.2 Analysis of the Problem	201
4.15.3 Solution	203
4.16 Insufficient Melting and Mixing in a Plasticating Unit	204
4.16.1 Description of the Problem	204
4.16.2 Analysis of the Problem	205
4.16.3 Solution	207
4.17 High Melt Temperature and Insufficient Output in Coextrusion	208
4.17.1 Description of the Problem	208
4.17.2 Analysis of the Problem	209
4.17.3 Solution	210
4.18 Deficient Solids Conveying and Dispersion	213
4.18.1 Description of the Problem	213
4.18.2 Analysis of the Problem	213
4.18.3 Solution	215
4.19 Instability of Formation at the Die	216
4.19.1 Description of the Problem	216
4.19.2 Analysis of the Problem	217
4.19.3 Solution	219
4.20 Intermittent Pumping in a Vented Extruder	222
4.20.1 Description of the Problem	222
4.20.2 Analysis of the Problem	223
4.20.3 Solution	225

4.21 Melt Fracture or Sharkskin in m-PE	227
4.21.1 Description of the Problem	227
4.21.2 Analysis of the Problem	227
4.21.3 Solution	228
4.22 Scale-up of LLDPE Single Screw Extruder	229
4.22.1 Description of the Problem	229
4.22.2 Analysis of the Problem	229
4.22.3 Solution	230
4.23 Non-homogeneous Melt in Blow Molding	232
4.23.1 Description of the Problem	232
4.23.2 Analysis of the Problem	232
4.23.3 Solution	232
4.24 High Melt Temperature in Sheet Extrusion	234
4.25 Gear Pump Speed Variation in Sheet Extrusion	238
4.26 Melt Temperature Variation in Tubing Extrusion	244
4.27 Black Specks in Tubing Extrusion	247
4.28 Mechanical Degradation in TPE Extrusion	252
4.29 Degradation in a Long Adapter	255
4.30 Shrink Voids in Rod Extrusion	258
4.31 Improper Preheating of Extruders	268
Appendix 1: Systematic Problem Solving	285
Appendix 2: Machine Troubleshooting and Maintenance	287
A2.1 Check the Oil	287
A2.2 Unusual Noises	288
A2.3 Vibration Monitoring	288
A2.4 Drive Motors and Belts	289
A2.5 Spare Parts	290
A2.6 Screw and Barrel	290
A2.7 Extruder Maintenance Checklist	291
Appendix 3: Extruder Barrel Temperatures	295
A3.1 Setting Extruder Barrel Temperatures	295
A3.2 Extruder Barrel Temperature Profile Optimization	296
A3.2.1 Introduction	296
A3.2.2 Facts about Barrel Temperature Profile (BTP)	296

A3.2.3 Typical Process Temperatures for Different Plastics	298
A3.2.4 Guidelines and Considerations for Setting Barrel Temperatures	299
A3.2.5 BTP Optimization by Design of Experiments (DOE)	304
A3.2.6 BTP Optimization by One-at-a-Time Experiments (OTE)	305
A3.2.7 Dynamic BTP Optimization	305
A3.2.8 Other Studies on Optimization of Extruder Barrel Temperature Profiles	307
A3.2.9 Conclusions	321
Appendix 4: Process Signal Analysis Using Fast Fourier Transform	323
References	335
Index	347