Handbook of Troubleshooting Plastics Processes
A Practical Guide

Edited by
John R. Wagner, Jr.
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>xvii</td>
</tr>
<tr>
<td>List of Contributors</td>
<td>xix</td>
</tr>
<tr>
<td><strong>Part 1: Troubleshooting Basics</strong></td>
<td>1</td>
</tr>
<tr>
<td>1 The Economics of Troubleshooting Polymer Processing Systems</td>
<td>3</td>
</tr>
<tr>
<td>Mark D. Wetzel</td>
<td></td>
</tr>
<tr>
<td>1.1 Introduction</td>
<td>3</td>
</tr>
<tr>
<td>1.2 Economic Incentives and Necessities</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Troubleshooting Resources and Their Cost</td>
<td>6</td>
</tr>
<tr>
<td>1.4 Managing Resources and Costs</td>
<td>11</td>
</tr>
<tr>
<td>1.5 Troubleshooting Techniques and Their Relative Costs</td>
<td>12</td>
</tr>
<tr>
<td>1.6 Case Histories</td>
<td>14</td>
</tr>
<tr>
<td>1.6.1 Single Screw Extrusion Instability</td>
<td>14</td>
</tr>
<tr>
<td>1.6.2 Compounding Extruder Catastrophic Failure</td>
<td>14</td>
</tr>
<tr>
<td>1.6.3 Polymer Degradation During Melt Processing</td>
<td>16</td>
</tr>
<tr>
<td>1.7 Conclusions</td>
<td>20</td>
</tr>
<tr>
<td>References</td>
<td>20</td>
</tr>
<tr>
<td>2 Troubleshooting Philosophy</td>
<td>21</td>
</tr>
<tr>
<td>John R. Wagner, Jr.</td>
<td></td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>21</td>
</tr>
<tr>
<td>2.2 Troubleshooting Methodology</td>
<td>23</td>
</tr>
<tr>
<td>Bibliography</td>
<td>25</td>
</tr>
<tr>
<td>3 Statistical Tools for Trouble Shooting a Process</td>
<td>27</td>
</tr>
<tr>
<td>Vincent Vezza</td>
<td></td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>27</td>
</tr>
<tr>
<td>3.2 Basic Statistical Concepts</td>
<td>28</td>
</tr>
<tr>
<td>3.2.1 Histogram</td>
<td>28</td>
</tr>
<tr>
<td>3.2.2 Scatter Diagram</td>
<td>28</td>
</tr>
<tr>
<td>3.3 Sample Mean and Standard Deviation</td>
<td>29</td>
</tr>
<tr>
<td>3.4 Design of Experiments (DOE)</td>
<td>31</td>
</tr>
<tr>
<td>3.4.1 Factorial Design</td>
<td>31</td>
</tr>
<tr>
<td>3.4.2 Fractional Factorial Design</td>
<td>34</td>
</tr>
<tr>
<td>3.5 Process Capability</td>
<td>37</td>
</tr>
<tr>
<td>3.6 Control Charts</td>
<td>38</td>
</tr>
<tr>
<td>3.7.1 Central Limit Theorem</td>
<td>39</td>
</tr>
<tr>
<td>3.7.2 Variable Data Control Charts</td>
<td>41</td>
</tr>
<tr>
<td>3.7.3 Control Charts for Attribute Data</td>
<td>43</td>
</tr>
</tbody>
</table>
6.5 Part Weight as Dimensional Aimpoint Control 79
  6.5.1 Unconstrained Process 80
  6.5.2 Partially Constrained Process 81
  6.5.3 Constrained Process 82
  6.5.4 Warpage 82
  6.5.5 Relationship of Shot Weight and Hydraulic Pressure 84
6.6 Determining the Gate Freeze-Off Time 85
  6.6.1 Procedure to Determine the Freeze-Off Point 86
  6.6.2 Time Analysis 86
  6.6.3 Pressure Procedure 86
References 88

7 Blown Film 89
Karen Xiao and Steve Gammell
7.1 Introduction 89
7.2 Process Description 92
  7.2.1 Extruders 94
  7.2.2 Dies 94
  7.2.3 Process Cooling 97
  7.2.4 The Bubble Collapsing Process and Systems 98
  7.2.5 Haul-Off/Primary Nip 99
  7.2.6 Film Winding 101
    7.2.6.1 Center-drive Winder 102
    7.2.6.2 Surface Winders 102
7.3 Special Tools for Troubleshooting 105
  7.3.1 Winding Systems 108
7.4 Case Studies 109
  7.4.1 Case Study 1: Carbon Buildup 109
  7.4.2 Case Study 2: Poor Gauge Uniformity 110
References 111

8 Cast Film Troubleshooting 113
Andrew W. Christie and Beth M. Foederer
8.1 Coextrusion Film Systems 113
8.2 Troubleshooting Method 114
  8.2.1 The Problem Statement 115
  8.2.2 The Hypothesis 115
  8.2.3 Testing the Hypothesis 116
  8.2.4 Evaluating the Results 117
8.3 Common Problems, Hypotheses and Tests 117
  8.3.1 Gels in Film 117
  8.3.2 Film Clarity 120
  8.3.3 Wrinkling 120
  8.3.4 Inability to Reach Output 121
  8.3.5 Poor Melt Mixing 122
  8.3.6 Melt Temperature Too Low 123
  8.3.7 Melt Temperature Too High 123
  8.3.8 Extruder Power Insufficient 124
8.3.9 Film Streaks or Lines 124
8.3.10 Melt Appearance Defects 125
8.3.11 Thickness Variation – Cross Direction 125
8.3.12 Thickness Variation – Machine Direction 126
8.3.13 Poor Wound Roll Appearance 126
8.3.14 Edge Tear (Unstable Edges) 127
8.3.15 Pin Holes 127
8.3.16 Extruder Surging 128
8.3.17 Draw Resonance 128
8.3.18 Film Discoloration 129
8.3.19 Poor Heat Seal Strength 129
8.3.20 Odor – Flavor Scalping 129
8.3.21 Poor Strength 129
8.3.22 Film Blocking 130
8.3.23 Poor Printability 130
8.3.24 Camber or Curl 131
8.3.25 Scratches 131

References 131

9 Oriented Films-Troubleshooting and Characterization 133

Eldridge M. Mount, III

9.1 Introduction 133
9.2 Process Overview: Biaxial Orientation 134
9.3 Oriented Film Markets 141
9.3.1 Oriented Polypropylene OPP or BOPP 141
9.3.2 Oriented Polyester OPET 143
9.3.3 Oriented Polystyrene OPS 144
9.3.4 Oriented Polyamide (Nylon) OPA 145
9.4 Troubleshooting the Film Orientation Process as Applied to OPP Films 146
9.4.1 Control Variables 146
9.4.1.1 Resin Drying 146
9.4.1.2 Extrusion 147
9.4.1.3 Casting and Pinning 149
9.4.1.4 Machine Direction Orientation 153
9.4.1.5 Transverse Direction Orientation 153
9.4.1.6 Web Handling and Surface Treatment 156
9.4.1.7 Winding 156
9.4.2 Noise Variables 157
9.4.3 Dependent Variables 157
9.5 Special Tools for Troubleshooting 158
9.6 Case Studies 159
9.6.1 Casting Capacity Limitation in PET Film Production 159
9.6.2 Floating Gauge – Extrusion Instability and MDO Heat Transfer Limitations 160
9.6.3 Output Limitation from Coextrusion Instability 162

References 164

Bibliography 164
12 PET Stretch Blow Molding

Dan Weissmann

12.1 Introduction
12.2 The PET Universe
12.3 Technology History
12.4 PET Chemistry
12.5 PET Morphology
12.6 Bottle Universe
12.7 Bottle Manufacturing
12.8 Commercial Manufacturing Processes
12.9 Process Elements
  12.9.1 Injection Molding
    12.9.1.1 IV Drop
    12.9.1.2 Acetaldehyde
    12.9.1.3 Molding Stresses
  12.9.2 Hot Runner System
    12.9.2.1 Gate Crystallinity and Separation
    12.9.2.2 Gate Pin Holes
  12.9.3 Mold Cooling
    12.9.3.1 Preform Problem Analysis
  12.9.4 Blow Molding
    12.9.4.1 General Principles – Reheating and Preform Temperature
  12.9.5 Preform Temperature Profiling
  12.9.6 Blowing
    12.9.6.1 Quality Attributes and Performance Issues
    12.9.6.2 Blow Molding Process Monitoring
    12.9.6.3 On Line Inspection
    12.9.6.4 Testing and Test Procedures
    12.9.6.5 Special Processes
12.10 Case Sample: Thermal Stability Failure of CSD Bottles

References

13 Blow Molding – Problems and Solutions

Norman C. Lee

13.1 Introduction
13.2 Troubleshooting
13.3 Variables Affecting the Blow Molding Process
  13.3.1 PART I: Defects in Article
    13.3.1.1 PART I – Defect in Finished Article
  13.3.2 PART II: Parison Defects
    13.3.2.1 PART II – Defects of the Parison

References
14 Extrusion Coating Troubleshooting
Beth M. Foederer and Andrew W. Christie

14.1 Coextrusion Extrusion Coating/Laminating Systems

14.2 Troubleshooting Method

14.3 Common Problems, Hypotheses and Tests
14.3.1 Gels in Film
14.3.2 Poor Adhesion
14.3.3 Wrinkling
14.3.4 Low Output
14.3.5 Poor Melt Mixing
14.3.6 Melt Temperature Too Low
14.3.7 Melt Temperature Too High
14.3.8 Extruder Power Insufficient
14.3.9 Die Lines
14.3.10 Melt Appearance Defects
14.3.11 Thickness Variation – Cross Direction
14.3.12 Thickness Variation – Machine Direction
14.3.13 Poor Wound Roll Appearance
14.3.14 Edge Tear (Unstable Edges)
14.3.15 Pin Holes
14.3.16 Extruder Surging
14.3.17 Draw Resonance
14.3.18 Poor Heatseal
14.3.19 Odor – Flavor Scalping
14.3.20 Poor Printability
14.3.21 Camber or Curl
14.3.22 Scratches

References

Part 3: Non-extrusion Processes

15 Adhesive and Thermal Lamination
Tom Dunn

15.1 Introduction
15.1.1 Process Overview
15.1.2 Markets Served
15.1.3 Historical and Future Growth Projections – Technology Challenges and Threats
15.2 Process Description
  15.2.1 Major Process Components
  15.2.2 Equipment Production Ranges
  15.2.3 Manufacturers

15.3 Control Variables

15.4 Random Cause Variables

15.5 Dependent Variables

15.6 Special Tools for Troubleshooting
  15.6.1 Product

15.7 Case Studies
  15.7.1 Easy-peel or Rip-off
  15.7.2 Spotty Results

Bibliography

16 Troubleshooting for Rotomolding

Paul Nugent

16.1 The Basic Process

16.2 Key Quality Control Steps in Rotomolding
  16.2.1 Materials In-bound and Powder Preparation
  16.2.2 Colorants and Additives
  16.2.3 Material Mixing
  16.2.4 Molds and Fixtures
  16.2.5 Machinery
  16.2.6 Calibration
  16.2.7 Production Process and Records

16.3 Typical Rotomolding Problems

16.4 Typical Solutions
  16.4.1 Adhesion – Difficulty in Painting or Applying Labels
  16.4.2 Blowholes – Around Inserts
  16.4.3 Blowholes – Other Areas
  16.4.4 Blowholes – Parting Line
  16.4.5 Bubbles on Part Surface or in the Cross-section
  16.4.6 Coining (Pockmarks)
  16.4.7 Color – Part Burned/Discolored
  16.4.8 Color – Static Swirl
  16.4.9 Color – Unevenness
  16.4.10 Flash at the Parting Line
  16.4.11 Foaming – Coarse or Uneven Foam
  16.4.12 Foaming – Gaps in Wall Cross-section
  16.4.13 Foaming – Part Deformation
  16.4.14 Incomplete Material Fusion
  16.4.15 Incomplete Mold Fill (Bridging)
  16.4.16 Low Impact Strength
  16.4.17 Low Part Stiffness
  16.4.18 Long Oven Cycle
  16.4.19 Long-term Part Failure
  16.4.20 Mold Distortion, Explosion
17 Plastics Calendering

Chellappa Chandrasekaran

17.1 Introduction

17.2 Blending and Fluxing

17.3 Mills and Strainers

17.4 Calender

17.5 General Description of a Calendering Machine

17.5.1 Rolls

17.5.2 Sheet Finishes

17.5.3 Roll Contours

17.5.4 Frame

17.5.5 Roll Adjustment

17.5.6 Bed Plate

17.5.7 Lubrication

17.5.8 Temperature Control

17.5.9 Safety and Safety Regulations

17.6 The Calendering Process

17.6.1 Heating and Delivery to the Calender

17.6.2 Roll Banks

17.6.3 Sheet Takeoff and Post-processing

17.6.4 Embossing and Laminating

17.7 Input Materials and Products

17.7.1 The Formulas

17.8 Why Calendering is Preferred to Extrusion

17.9 Calendering Process Variables

17.9.1 Barring and Noise Due to Roll Vibration

17.9.2 Machine Dependent Variable

17.9.3 Product Variation

17.9.4 Overcoming and Correcting Process Variation

17.10 Conclusion

References

Bibliography

18 Compression Molding

Muralisrinivasan Natamai Subramanian

18.1 Introduction

18.2 Materials

18.2.1 Thermoplastics and Compression Molding

18.2.2 Thermosets and Compression Molding

18.2.3 Premix or Prepreg Preparation

18.2.4 Fiber Alignment
18.2.5 Pre-form 386
18.2.6 Prepreg 386

18.3 Sheet Molding Compound – Production 386
18.3.1 Mold 388

18.4 Technology – Compression Molding 388
18.4.1 Important Variables during Processing 389

18.5 Troubleshooting 390

18.6 Problems and Solution(s) 392

18.7 Summary 393
18.7.1 Fundamentals 393
18.7.2 Advantages 393
18.7.3 Disadvantages 394
18.7.4 Future Trends 394

References 395

19 Transfer Molding 397
Muralisrinivasan Natamai Subramanian

19.1 Introduction 397
19.2 Curing 398
19.3 Processing 399
19.4 Mold 400
19.5 Process Optimization 400
19.6 Method 401
19.7 Pot Type Transfer Molding 401
19.7.1 Plunger/Transfer Molding 402
19.7.2 Screw Type Transfer Molding 402
19.7.3 Screw Injection Type 402
19.8 Troubleshooting 403
19.9 Summary 404
19.9.1 Advantages 404
19.9.2 Disadvantages 404
19.9.3 Future Trends 405
19.9.4 Fundamentals 405

References 405

20 Pultrusion Process Troubleshooting 407
Joseph E. Sumerak

20.1 Introduction 407
20.1.1 Pultruded Products are Governed by a Performance Specification 409
20.2 Materials Review 410
20.2.1 Resin 410
20.2.2 Resin Reactivity 411
20.2.3 Resin Reactivity Measurement 412
20.2.4 Resin Viscosity 414
20.2.5 Reinforcements 415
20.3 Process Parameters 416
20.3.1 Composition and Process Specification 417
20.4 Manufacturing Defects 417
20.4.1 Defects 417
20.5 Material Related Defects 419
20.5.1 Resin 419
20.5.2 Reinforcements 420
20.6 Process Parameter Related Defects 422
20.7 Methods Related Defects 426
20.8 The Troubleshooting Process 429
20.8.1 Subjective versus Objective 429
20.8.2 Visual Tools 430
20.8.3 On-Line Quantitative Analysis Tools 434
20.8.4 Off-Line Quality Assessment Tools 435
20.9 Troubleshooting Examples 438
20.10 Summary 438
Acknowledgement 439
References 439

21 Troubleshooting Static Problems in Plastics Processes 441
Kelly Robinson 441
21.1 Introduction 441
21.1.1 Nature and Character of Static 441
21.1.2 Cost of Static Problems 442
21.2 Root Causes of Static 443
21.2.1 Tribocharging/Contact Charging 443
21.2.1.1 Triboelectric Series 444
21.2.2 Application of the Triboelectric Series 445
21.2.3 Charge Induction 446
21.2.4 Ionizer Imbalance (Active Charging) 446
21.3 Static Measurement Tools 447
21.3.1 Electrostatic Fieldmeters (FMs) and Non-Contacting Electrostatic Voltmeters (ESVMs) 447
21.3.1.1 Electrostatic Fieldmeters – Fieldmeters Respond to Net Charge 447
21.3.1.2 Non-contacting Electrostatic Voltmeter – Voltmeters Respond to Surface Charge 448
21.3.1.3 Spatial Resolution and Response Time 450
21.3.1.4 Typical Applications – Monitor Static Performance with Fieldmeters and Voltmeters 451
21.3.2 Charge Meter – Coulomb Meters are a Direct Measure of Charge 455
21.3.2.1 Principles of Operation 455
21.3.2.2 Typical Applications 456
21.3.3 Resistivity Meters 457
21.3.3.1 Volumetric Resistivity Meters 457
21.3.3.2 Surface Resistivity Meters 460
21.3.4 Charge Dissipation Time Measurements 463
21.3.4.1 Importance of Charge Dissipation Time 463
21.3.4.2 Principles of Operation – Static Dissipation Time 463
21.3.4.3 Typical Application – Static Dissipation Time 464
21.4 Static Problem Diagnosis
  21.4.1 Understand the Problem 464
  21.4.2 Baseline Data and Control Charts 465
  21.4.3 Hot Rolls 467
  21.4.4 Static Specifications 469

21.5 Solving Static Problems 470
  21.5.1 Locate the Source of Charge Separation 471
    21.5.1.1 Unwinding Roll 471
    21.5.1.2 Drive Roller 472
    21.5.1.3 Coater Backing Roller 472
    21.5.1.4 Dryer Conveyance Rollers 474
    21.5.1.5 Dryer Exit Nip Roller 474
    21.5.1.6 Winder Lay-on Roller 474
  21.5.2 Static Control System Maintenance 475
    21.5.2.1 Clean Static Bars 476
    21.5.2.2 Replace Ionizing String 476
    21.5.2.3 Verify Gaps 476
    21.5.2.4 Verify Performance 476
    21.5.2.5 Clean Rollers, Belts and Guides 476
    21.5.2.6 Restore Surfaces of Tacky (Cleaning) Rollers 476
    21.5.2.7 Check the Electrical Resistivity of Static Dissipative Rollers 476
    21.5.2.8 Test the Bearing Drag on Low Wrap Rollers 477
    21.5.2.9 Align Roller 477
    21.5.2.10 Nip Pressure 477
    21.5.2.11 Lay-on Rollers 477
    21.5.2.12 Web Tension 477
    21.5.2.13 Winding Tension Profile 477
    21.5.2.14 Humidifier Maintenance 477
  21.5.3 Conductive Layers in Products 477

References 478
Recommended Reading for Further Study 479