

Contents

1	Introduction to Scientific Processing	1
1.1	The Evolution and Progress of Injection Molding	1
1.2	The Molding Process	1
1.3	The Three Types of Consistencies Required in Injection Molding	2
1.4	Scientific Processing	4
1.5	The Five Critical Factors of Molding	5
1.5.1	Part Design	5
1.5.2	Material Selection	6
1.5.3	Mold Design and Construction	6
1.5.4	Machine Selection	6
1.5.5	Molding Process	6
1.6	Concurrent Engineering	7
2	Introduction to Polymers and Plastics	9
2.1	Polymers	9
2.2	Molecular Weight and Molecular Weight Distribution	10
2.3	Polymer Morphology (Crystalline and Amorphous Polymers)	12
2.4	Role of Morphology in Injection Molding	16
2.4.1	Differences in Shrinkage Between Amorphous and Crystalline Materials	16
2.4.2	Melt Processing Range	16
2.4.3	Mold Filling Speed	17
2.4.4	Mold Temperatures	17
2.4.5	Barrel Heat Profile	18
2.4.6	Screw Recovery Speeds	19
2.4.7	Nozzle Temperature Control	19
2.4.8	Cooling Times	19
2.4.9	Mechanical Properties	19
2.4.10	Optical Clarity	20
2.5	Thermal Transitions in Polymers	20
2.6	Shrinkage in Polymers	23

3	Polymer Rheology	27
3.1	Viscosity	27
3.2	Newtonian and Non-Newtonian Materials	29
3.3	Viscosity in Polymer Melts	30
3.4	Effect of Temperature on Viscosity	32
3.5	Velocity and Shear Rate Profiles	33
3.6	Application to Injection Molding	35
3.6.1	Flow Imbalance in an 8-Cavity Mold	35
3.6.2	Racetrack Effect in a Part with Constant Thickness	37
3.6.3	Stress Build-Up in Molded Parts	37
3.6.4	Warpage Difference Between Cavities	38
3.7	Solving Flow Imbalances Using Melt Rotation Techniques	38
3.8	Characterization of Polymer Viscosity	40
4	Plastic Drying	43
4.1	Problems in Melt Processing Related to the Presence of Moisture	44
4.1.1	Degradation of Plastic	45
4.1.2	Presence of Surface Defects	45
4.2	Hygroscopic Polymers	48
4.3	Drying of Plastics	50
4.3.1	Drying Temperatures and Times	50
4.3.2	Relative Humidity and Dewpoint	52
4.3.3	Air Flow Rate	52
4.4	Equipment for Drying Plastics	53
4.4.1	Oven Dryers	53
4.4.2	Hot Air Dryers	53
4.4.3	Desiccant Dryers	53
4.4.4	Classifications Based on the Location of the Dryer	54
4.5	Determination of the Amount of Moisture	54
4.5.1	The Glass Slide Technique (TVI Test)	54
4.5.2	The Karl-Fischer Titration Method	55
4.5.3	Electronic Moisture Analyzer	55
4.5.4	Measurement of the Dew Point	56
4.6	'Overdrying' or Overexposure to Drying Temperatures	56
4.7	Cautions	62
4.8	Prevention of Overexposure to Longer Drying Times	63
4.9	Overdrying Controller	63

5	Common Plastic Materials and Additives	67
5.1	Classification of Polymers	67
5.2	Commercially Important Plastics	68
5.2.1	Polyolefins	68
5.2.2	Polymers from Acrylonitrile, Butadiene, Styrene, and Acrylate	69
5.2.3	Polyamides (PA)	70
5.2.4	Polystyrenes (PS)	71
5.2.5	Acrylics	72
5.2.6	Polycarbonates (PC)	72
5.2.7	Polyesters	72
5.2.8	Polyvinyl Chloride (PVC)	72
5.2.9	Polyoxymethylene (POM or Acetal)	73
5.2.10	Fluoropolymers	73
5.3	Additives	74
5.3.1	Fillers	74
5.3.2	Plasticizers	74
5.3.3	Flame Retardants	74
5.3.4	Anti-Aging Additives, UV Stabilizers	75
5.3.5	Nucleating Agents	75
5.3.6	Lubricants	75
5.3.7	Processing Aids	76
5.3.8	Colorants	76
5.3.9	Blowing Agents	76
5.3.10	Other Polymers	76
5.4	Closing Remarks	77
6	Injection Molding	79
6.1	The History of Injection Molding	79
6.2	Injection Molding Machines and Their Classifications	79
6.3	Machine Specifications	82
6.3.1	Clamp Force (Tonnage)	82
6.3.2	Shot Size	82
6.3.3	Screw Diameter and L/D Ratio	83
6.3.4	Plasticating Capacity	83
6.3.5	Maximum Plastic Pressure	83
6.4	The Injection Molding Screw	83
6.5	Screw Designs	86

6.6	The Check Ring Assembly	87
6.7	Intensification Ratio (IR)	87
6.8	Selecting the Right Machine for the Mold	88
6.8.1	Physical Size of the Mold	88
6.8.2	Tonnage of the Machine	90
6.8.3	Percentage Shot Size Used	91
6.8.4	Residence Time of the Material in the Barrel	92
7	Scientific Processing and Scientific Molding	95
7.1	Introduction	95
7.1.1	Process Robustness	96
7.1.2	Process Consistency	96
7.2	Storage and Drying of Resin	99
7.2.1	Plastic Drying	99
7.3	Setting of the Melt Temperatures	102
7.4	Setting Mold Temperatures	103
7.5	The Injection Molding Cycle	104
7.5.1	Speed and Pressure	104
7.5.2	Pressure Limited Process	105
7.5.3	Injection, Pack, and Hold	105
7.5.4	Decoupled Molding SM	106
7.5.5	Intensification Ratio (IR)	108
7.5.6	Screw Speed	108
7.5.7	Back Pressure	109
7.6	Process Optimization – The 6-Step Study	110
7.6.1	Step 1: Optimization of the Injection Phase –Rheology Study ...	110
7.6.2	Step 2: Determining the Cavity Balance – Cavity Balance Study .	118
7.6.3	Step 3: Determining the Pressure Drop – Pressure Drop Studies	124
7.6.4	Step 4: Determining the Process Window – Process Window Study	128
7.6.5	Step 5: Determining the Gate Seal Time – Gate Seal Study	132
7.6.6	Step 6: Determining the Cooling Time – Cooling Time Study ..	135
7.6.7	Optimization of Screw Speed and Back Pressure	137
7.6.8	Post-Mold Shrinkage Studies	138
7.7	Recommended Mold Function Qualification Procedure	141
7.8	Recommended Adjustments to Maintain Process Consistency and Robustness	142
7.9	Process Documentation	143

8	Design of Experiments for Injection Molding	145
8.1	Parameters in Injection Molding	145
8.2	Terminology	149
8.2.1	Factor	149
8.2.2	Response	149
8.2.3	Level	150
8.2.4	Designed Experiment	150
8.3	Relationships Between the Number of Factors, Levels, and Experiments	151
8.4	Balanced Arrays	152
8.5	Interactions	154
8.6	Confounding or Aliasing	156
8.7	Randomization	158
8.8	Factorial Experiments	159
8.9	Data Analysis	159
8.9.1	Tornado Charts	161
8.9.2	Contour Plots	162
8.9.3	Prediction Equation	162
8.9.4	Process Sensitivity Charts	164
8.10	Using the Results from DOE	165
8.10.1	Process Selection	165
8.10.2	Cavity Steel Adjustment	165
8.10.3	Process Adjustment Tool	166
8.10.4	Setting Process Change Tolerances	166
8.10.5	Setting Alarm Limits	166
8.10.6	Reducing Inspection	167
9	The Aesthetic, the Dimensional, and the Control Process Window	169
9.1	The Aesthetic Process Window (APW)	169
9.2	The Dimensional Process Window (DPW)	171
9.3	The Control Process Window (CPW)	171
9.4	Multiple Dimensions	173
9.5	Multiple Cavities	175
9.6	Closing Remarks	175
10	Mold Qualification Flowchart, Production Release, and Troubleshooting	177
10.1	Mold Qualification Flowchart	177
10.1.1	Mold Function Qualification Procedure	177
10.1.2	Mold and Part Quality Qualification Procedure	177

10.2	Mold Qualification Checklist	179
10.3	Process Documentation	180
10.3.1	Process Sheet	180
10.3.2	Waterline Diagrams	181
10.3.3	Mold Temperature Maps	182
10.3.4	Setup Instructions	182
10.3.5	Operator Instructions	183
10.4	Documentation Books	183
10.5	Qualification Production Runs	183
10.6	Mold Specific Troubleshooting Guide	185
10.7	Molding Startup and Shutdown	185
10.7.1	Purging	185
10.7.2	Startup of a Molding Machine	186
10.7.3	Shutdown of a Molding Machine	187
10.8	Troubleshooting	187
10.9	Important Equipment and Tools for Qualifications and Troubleshooting ..	190
10.10	Common Defects, Their Cause, and Prevention	193
11	Miscellaneous Topics Affecting the Process – Mold Cooling, Venting, and Regrind Management	195
11.1	Mold Cooling	195
11.1.1	Number of Cooling Channels	195
11.1.2	Reynolds Number of the Coolant Flow	196
11.1.3	Type of Coolant	197
11.1.4	Series and Parallel Cooling	197
11.2	Venting	198
11.2.1	Dimensions of the Vent	200
11.2.2	Primary Vent Depths	201
11.2.3	Location of Vents	203
11.2.4	Forced Venting or Vacuum Venting	204
11.3	Regrind	205
11.3.1	Effect of the Molding Process on the Part Properties	205
11.3.2	Using Regrind	207
11.3.3	Batch and Continuous Processes of Incorporating Regrind	207
11.3.4	Estimating the Amount of Regrind from different Generations ..	208
11.3.5	Effect of Regrind on Processing	210
11.3.6	Closing Remarks	211

12 Related Technologies and Topics	213
12.1 Cavity Pressure Sensing Technology	213
12.1.1 Sensors and Output graphs	213
12.1.2 Types and Classification of Pressure Sensors	215
12.1.3 Use of Information from the Pressure Graphs	217
12.1.4 Controlling the Process with Cavity Pressure Sensors	219
12.1.5 Sensor Locations	221
12.2 Building a Knowledge Base	221
12.3 Concurrent Engineering in Injection Molding	223
12.3.1 The Product Designer	225
12.3.2 The Tooling Engineer	226
12.3.3 The Mold Designer and Mold Maker	226
12.3.4 The Material Supplier	226
12.3.5 The Process Engineer	227
12.3.6 The Quality Engineer	227
12.3.7 The Sales Team at the Molder	228
12.3.8 Mandatory for All Departments	228
12.3.9 Implementing Concurrent Engineering	229
Appendix A Materials Data Sheet	231
Appendix B Conversion Tables for Commonly Used Process Parameters	239
Appendix C Water Flow Tables	240
Appendix D Part Design Checklist	243
Appendix E Mold Design Checklist	245
Appendix F Mold Qualification Checklist:	247
Appendix G Regrind Tables – Percentage of regrind in total shot.	249
Subject Index	251