Contents

	Preface	9
Chapter 1	**Flow Properties—An Introduction**	1
	1.1 Introduction	1
	1.2 Rheological Equations of State	2
	1.2.1 The Ideal (Elastic) Solid (Hookean Solid)	3
	1.2.2 The Pascallian Fluid	5
	1.2.3 The Ideal Fluid—Newtonian Fluid	5
	1.3 Non-Newtonian Fluids	7
	1.3.1 Time-Independent Fluids	8
	1.3.2 Time-Dependent Fluids	14
	1.3.3 Elasticoviscous Fluids	16
	References	20
Chapter 2	**Flow Through Channels of Simple Cross Section**	21
	2.1 Introduction	21
	2.2 Flow through a Pipe (capillary flow)	21
	2.2.1 Shear Stress at the Wall of a Pipe	22
	2.2.2 Shear Rate at Wall	24
	2.2.3 Simplification of the Rabinowitsch Equation	26
	2.2.4 The Special Case of a Power Law Fluid	28
	2.2.5 The Special Case of Newtonian Fluids	29
	2.2.6 Another Look at Apparent Viscosity	29
	2.3 Flow Between Parallel Plates	30
	2.4 Flow through an Annulus	31
	2.5 Summary	31
	Appendix	32
	References	34

Chapter 3 **Measurement of Flow Properties** 35
3.1 Introduction 35
3.2 Types of Capillary Viscometers 35
3.3 Review of Assumptions 36
3.3.1 No-Slip 36
3.3.2 Time-Independence 37
3.3.3 Constant Flow Pattern 38
3.3.4 Isothermal Flow 39
3.3.5 Incompressibility 39
3.4 Corrections to Data obtained from Capillary Rheometers 39
3.4.1 Entrance-effect Corrections 40
3.4.2 Elastic Absorbence of Energy 41
3.4.3 Head Effects 42
3.4.4 Kinetic Energy Effects 45
3.5 Summary 45
References 46

Chapter 4 **Factors Affecting Viscous Flow** 47
4.1 Introduction 47
4.2 Effect of Temperature 47
4.3 Effect of Pressure 50
4.3.1 Volume Viscosity 54
4.3.2 Shear-Induced Crystallisation 54
4.4 Effect of Shear History 55
4.5 Viscosity Changes during Extrusion 57
4.6 Effect of Molecular Structure on Viscous Flow 59
References 62

Chapter 5 **Elastic Effects in Polymer Melt Flow** 63
5.1 Introduction 63
5.2 Die Swell 63
5.3 Elastic Turbulence or Melt Fracture 69
5.3.1 Mechanism of Elastic Turbulence 74
5.3.2 Smooth Flow at Very High Shear Rates 77
5.4 Sharkskin 78
5.4.1 Mechanism of Sharkskin 80
5.5 Frozen-In Orientation 81
5.6 Draw-down 84
5.7 Measurement of Elastic Effects 87
References 88

Chapter 6 **The Application of Rheological Studies to Polymer Processing** 89
6.1 Introduction 89
6.2 Extrusion 90
6.3 Injection Moulding 94
6.3.1 Elastic Effects in Injection Moulding 95
6.3.2 Compressibility and Shrinkage Effects 99
6.4 Bottle Blowing and Related Blow Moulding Operations 104
6.5 Compression and Transfer Moulding of Thermosetting Materials 109
6.6 Transfer Moulding of Thermosetting Materials 113
6.7 Calendering 115
6.8 Vacuum Forming and Related Shaping Applications 116
6.9 Flow Properties of Individual Thermoplastics 116
6.9.1 Polyethylene 116
6.9.2 Polypropylene 119
6.9.3 Poly-4-methyl Pentene-1 120
6.9.4 Polystyrene 120
6.9.5 Polymethyl methacrylate 121
6.9.6 Polyvinyl chloride 121
6.9.7 The Nylons 122
6.9.8 Polyacetals 123
6.9.9 Polytetrafluoroethylene (PTFE) 123
6.9.10 Tetrafluoroethylene–Hexafluoropropylene Copolymers 123
6.9.11 Polycarbonates 124
6.9.12 Polysulphones 124
References 124

Chapter 7 **More Complex Rheological Problems** 126
7.1 Introduction 126
7.2 Components of Stress 128
7.3 Time Derivatives 134
7.4 The Equation of Continuity 136
7.5 The Equations of Momentum 138
7.6 Examples of Applications of Continuum Mechanics in Rheology 142
7.6.1 Shear Stress in Capillary Flow 142
7.6.2 Flow in the Melt Zone of a Single Screw Extruder 143

7.6.3 Other Flow Problems Solved by Use of Continuum Mechanics 150
7.6.4 Normal Stresses in Simple Shearing Flow 150
7.7 Measurement of Elastic Effects in Polymer Flow 153
References 158

Chapter 8 **Tensile Deformation in Molten Polymers** 159
8.1 Introduction 159
8.2 Measurement of Tensile Deformation 160
8.3 Traction Viscosity of Polymer Melts 162
8.4 Significance of Traction Viscosity in Polymer Processes 164
8.5 Elastic Strains in Tension 165
8.6 Melt Strength 166
References 166

Appendix
A.1 Shear Stress at the Wall during Flow between Parallel Plates 167
A.2 Shear Rate at Wall of Plate 168
A.3 The Special Case of Power Law Fluids in Parallel Plate Flow 171
A.4 The Special Case of Newtonian Fluids in Parallel Plate Flow 173
A.5 Flow through an Annulus 173
A.6 Shear Stress in Slit Flow 175
A.7 Velocity Distribution in a Pipe 176
A.8 Velocity Distribution between Parallel Plates 178
A.9 Analysis of Slippage in Capillary Flow 180
Suggestions for Further Reading 181

Index 185