

Contents

Dedication V

Preface VII

1 Introduction to Rheology 1

1.1 The Field of Rheology	5
1.2 Viscous Liquids or the Newtonian Fluid.....	7
1.3 Linear Elasticity or the Hookean Spring.....	10
1.4 Viscoelasticity and the Maxwell Model.....	13
1.5 Time Scale and the Deborah Number.....	16
1.6 Deformation, Rate of Deformation, and the Deviatoric Stress Tensors...	18
1.7 Guide to the Book.....	20
Problems	21
References.....	21

2 Structure and Properties of Deforming Polymers 25

2.1 Molecular Structure of Polymers.....	25
2.2 Stress Relaxation Behavior	32
2.3 Shear Thinning Behavior.....	37
2.4 Normal Stresses in Shear Flow	40
2.5 Stress Overshoot during Start-up Flow	44
2.6 Melt Strength or Melt Fracture	45
2.7 Dynamic Response.....	47
Problems	56
References.....	57

3 Generalized Newtonian Fluid (GNF) Models. 59

3.1 Temperature Dependence of Viscosity.....	61
3.2 Viscous Flow Models.....	65
3.2.1 The Power Law Model	66
3.2.2 The Bird-Carreau-Yasuda Model.....	68

3.2.3	The Cross-WLF Model.....	70
3.2.4	The Bingham Model.....	71
3.2.5	The Herschel-Bulkley Model.....	72
3.2.6	Accounting for Pressure Dependence in Viscous Flow Models .	73
3.2.6.1	Power Law.....	73
3.2.6.2	Carreau-WLF	73
3.2.6.3	Cross-WLF	74
3.2.6.4	Universal Temperature and Pressure Invariant Viscosity Function	75
3.3	Elongational Viscosity	80
3.4	Suspension Rheology	82
3.5	Chemo-Rheology.....	87
	Problems.....	95
	References	97
4	Transport Phenomena.....	101
4.1	Dimensionless Groups	102
4.2	Balance Equations	106
4.2.1	The Mass Balance or Continuity Equation	106
4.2.2	The Material or Substantial Derivative	107
4.2.3	The Momentum Balance or Equation of Motion	109
4.2.4	The Energy Balance or Equation of Energy	114
4.3	Model Simplification.....	117
4.3.1	Reduction in Dimensionality.....	119
4.3.2	Lubrication Approximation.....	123
4.4	Viscometric Flows	125
4.4.1	Pressure Driven Flow of a Newtonian Fluid through a Slit ...	125
4.4.2	Flow of a Power Law Fluid in a Straight Circular Tube (Hagen-Poiseuille Equation)	126
4.4.3	Volumetric Flow Rate of a Power Law Fluid in Axial Annular Flow	129
4.4.4	Circular Annular Couette Flow of a Power Law Fluid	131
4.4.5	Squeezing Flow of a Newtonian Fluid between Two Parallel Circular Discs	134
4.4.6	Flow of a Power Law Fluid between Two Parallel Circular Discs.....	137
	Problems.....	140
	References	141

5 Viscoelasticity	143
5.1 Linear Viscoelasticity	144
5.1.1 Relaxation Modulus	144
5.1.2 The Boltzmann Superposition Principle	145
5.1.3 The Maxwell Model – Relaxation	147
5.1.4 Kelvin Model	148
5.1.5 Jeffrey's Model	150
5.1.6 Standard Linear Solid Model	152
5.1.7 The Generalized Maxwell Model	154
5.1.8 Dynamic Tests	160
5.2 Non-Linear Viscoelasticity	164
5.2.1 Objectivity	164
5.2.2 Differential Viscoelastic Models	166
5.2.3 Integral Viscoelastic Models	179
References	184
6 Rheometry	187
6.1 The Sliding Plate Rheometer	189
6.2 The Cone-Plate Rheometer	191
6.3 The Parallel-Plate Rheometer	194
6.4 The Capillary Rheometer	196
6.4.1 Computing Viscosity Using the Bagley and Weissenberg-Rabinowitsch Equations	198
6.4.2 Viscosity Approximation Using the Representative Viscosity Method	201
6.5 The Melt Flow Indexer	202
6.6 Extensional Rheometry	203
6.7 High Pressure Rheometers	209
6.8 Integrated Mold Sensors for Quality Control	214
Problems	217
References	218
Subject Index	221