CONTENTS VOLUME 1

Chapter 1	Review of Newtonian Fluid Dynamics		
1.1	The Equations of Fluid Dynamics		
1.2	Newtonian Fluid Dynamics		
	Example 1.2-1	Laminar Newtonian Flow between Parallel Plane Surfaces	9
	Example 1.2-2	Viscous Heating in Flow between Plane Parallel Surfaces	10
	Example 1.2-3	Laminar Flow in a Circular Tube	12
	'Example 1.2-4	Creeping Flow around a Sphere	14
	Example 1.2-5	The Cone-and-Plate Viscometer	18
	Example 1.2-6	Squeezing Flow between Two Parallel Disks	19
1.3	Polymer Fluid Dyn	namics	21
Chapter 2	The Structure of	of Polymeric Fluids	53
2.1	Structure and Synt	hesis	54
2.2	Molecular Weight	and Molecular Weight Distributions	57
	Example 2.2–1	Calculation of Average Molecular Weights of a Blend of Two Polydisperse Samples	58
	Example 2.2–2	The Most Probable Distribution of Molecular Weights for a Linear Step-Reaction Polymerization	6Q
2.3	Macromolecular C	Configurations in Fluids at Rest	61
	Example 2.3-1	Mean Square Radius of Gyration	69
	Example 2.3–2	The One-Dimensional Random Flight	71
	Example 2.3–3	Time-Average Tension in a Polymer Chain	72
2.4	Polymer-Solvent a	nd Polymer-Polymer Interactions	75
2.5	The Stress Tensor in Flowing Polymeric Fluids		79
Chapter 3	Flow Phenome	na in Polymeric Fluids	89
3.1	Tube Flow and "S	hear Thinning"	90
		C C	
3.2	Rod-Climbing Example 3.2–1	Interpretation of a Tangential Annular Flow Experiment	92 93

* An asterisk designates material that can be omitted on first reading or for an elementary course.

x	DYNAM	ICS OF POLYME	RIC LIQUIDS	
3.3		Axial Annular Flor	W	95
		Example 3.3–1	Interpretation of an Axial Annular Flow Experiment	96
3.4		Hole Pressure Erro	r	97
		'Example 3.4–1	Significance of Pressure Measurements in Flow along an Axial Slit	99
3.5		Extrudate Swell		101
3.6		Secondary Flows in	n the Disk and Cylinder System	103
3.7		Convex Surface in	a Tilted Trough	104
		Example 3.7–1	Interpretation of Free-Surface Shapes in the Tilted Trough Experiment	105
3.8		Recoil		107
3.9		The Tubeless Siph	n	108
3.10		The Uebler Effect	and the Flow through a Sudden Contraction	109
3.11		Drag Reduction in Turbulent Flow		
3.12		Vortex Inhibition		114
3.13		Effect of Polymer	Additives on Heat Transfer in Turbulent Flow	115
Chap	ter 4	Material Funct	ions for Polymeric Fluids	129
Chap 4.1	ter 4		ions for Polymeric Fluids matics and Classification	129 130
-	ter 4		ematics and Classification	
-	ter 4	Shear Flows: Kine Example 4.1-1	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential	130
4.1	ter 4	Shear Flows: Kine Example 4.1 – 1 Unidirectional She	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow	130 137
4.1 4.2	ter 4	Shear Flows: Kine Example 4.1 – 1 Unidirectional She Steady Shear Flow	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor	130 137 139
4.1 4.2 4.3	ter 4	Shear Flows: Kine Example 4.1 – 1 Unidirectional She Steady Shear Flow Unidirectional Un	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor Material Functions	130 137 139 141
4.1 4.2 4.3 4.4	ter 4	Shear Flows: Kine Example 4.11 Unidirectional She Steady Shear Flow Unidirectional Un Experimental Arra	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor Material Functions steady Shear Flow Material Functions	130 137 139 141 148
4.1 4.2 4.3 4.4	ter 4	Shear Flows: Kine Example 4.1 1 Unidirectional She Steady Shear Flow Unidirectional Un Experimental Arra Example 4.5 - 1	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor Material Functions steady Shear Flow Material Functions ingements for Shear-Flow Measurement Measurement of Viscosity and Normal Stress Coefficients	130 137 139 141 148 170
4.1 4.2 4.3 4.4	ter 4	Shear Flows: Kine Example 4.1 1 Unidirectional She Steady Shear Flow Unidirectional Un Experimental Arra Example 4.5 - 1	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor Material Functions steady Shear Flow Material Functions ingements for Shear-Flow Measurement Measurement of Viscosity and Normal Stress Coefficients in the Cone-and-Plate Instrument Measurement of the Viscometric Functions in the Parallel-Disk Instrument	130 137 139 141 148 170 173
4.1 4.2 4.3 4.4	ter 4	Shear Flows: Kine Example 4.1 1 Unidirectional She Steady Shear Flow Unidirectional Un Experimental Arra Example 4.5 - 1 Example 4.5 -2	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor Material Functions steady Shear Flow Material Functions ingements for Shear-Flow Measurement Measurement of Viscosity and Normal Stress Coefficients in the Cone-and-Plate Instrument Measurement of the Viscometric Functions in the Parallel-Disk Instrument Obtaining the Non-Newtonian Viscosity Function from	130 137 139 141 148 170 173 176
4.1 4.2 4.3 4.4	ter 4	Shear Flows: Kine Example 4.11 Unidirectional Sho Steady Shear Flow Unidirectional Un Experimental Arra Example 4.5-1 Example 4.5-2 Example 4.5-3	ematics and Classification Kinematics of Steady Tube Flow, Steady Tangential Annular Flow, and Steady Helical Flow ear Flows: Form of the Stress Tensor Material Functions steady Shear Flow Material Functions ingements for Shear-Flow Measurement Measurement of Viscosity and Normal Stress Coefficients in the Cone-and-Plate Instrument Measurement of the Viscometric Functions in the Parallel-Disk Instrument Obtaining the Non-Newtonian Viscosity Function from Capillary Viscometer Data Analysis of a Torsional Oscillatory Viscometer for	 130 137 139 141 148 170 173 176 179

CONTENTS	xi
CONTENTS	

Chapter 5	The Generalized Newtonian Fluid		205
5.1	The Generalized Newtonian Fluid: Its Origin, Usefulness, and Limitations		206
5.2	Isothermal Flow Problems		213
	Example 5.2–1	Flow of a Power-Law Fluid in a Straight Circular Tube and in a Slightly Tapered Tube	213
	Example 5.2–2	Thickness of a Film of Polymer Solution Flowing down an Inclined Plate	215
	Example 5.2–3	Plane Couette Flow	217
	Example 5.2-4	Tangential Annular Flow (Bingham Fluid)	218
	Example 5.2–5	Axial Annular Flow (Ellis Fluid) — an Approximate Treatment	221
	Example 5.2–6	Squeezing Flow between Two Circular Disks	223
	Example 5.2–7	Enhancement of Axial Annular Flow by Rotating Inner Annulus (Helical Flow of a Power-Law Fluid)	226
*5.3	Isothermal Flow F	Problems by the Variational Method.	229
	'Example 5.3–1	Axial Annular Flow of a Power-Law Fluid	230
	*Example 5.3-2	Estimation of Velocity Distribution for Axial Eccentric Annular Flow (e.g., in a Wire-Coating Device)	232
5.4	Nonisothermal Flo	ow Problems	233
	Example 5.4–1	Flow in Tubes with Constant Wall Heat Flux (Asymptotic Solution for Large z)	238
	Example 5.4–2	Flow in Tubes with Constant Wall Heat Flux (Asymptotic Solution for Small <i>z</i>)	240
	Example 5.4–3	Flow in Tubes with Constant Wall Temperature (Asymptotic Solution for Large z)	242
	Example 5.4–4	Flow in Tubes with Constant Wall Temperature (Asymptotic Solution for Small z)	245
	Example 5.4–5	Flow in a Circular Die with Viscous Heating	246
	Example 5.4–6	'Viscous Heating in a Cone-and-Plate Viscometer	251
5.5	Justification for th	ne Use of the Generalized Newtonian Fluid	254
	Example 5.5–1	Simplification of the CEF Equation for a Specific Steady Shearing Flow	255
Chapter 6	The General L	inear Viscoelastic Fluid	275
6.1	The General Line	ar Viscoelastic Fluid: Its Origin, Usefulness, and Limitations	276
6.2	Solution of Time-	Dependent Shearing Problems	281
	Example 6.2–1	Small-Amplitude Oscillatory Motion	281
	Example 6.2–2	Stress Relaxation after a Sudden Shearing Displacement	283
	Example 6.2–3	Stress Relaxation after Cessation of Steady Shear Flow	284

xii 'DYNAMICS OF POLYMERIC LIQUIDS

	Example 6.2-4	Stress Growth at Inception of Steady Shear Flow	285
	Example 6.2–5	Constrained Recoil after Cessation of Steady Shear Flow	286
	Example 6.2–6	Creep after Imposition of Constant Shear Stress	287
	Example 6.2–7	Wave Transmission in a Semi-Infinite Viscoelastic Liquid	289
•6.3	Solution of Linear	Viscoelastic Problems by Laplace Transform	290
	'Example 6.3-1	Alternative Formulations of Linear Viscoelastic Models	291
	'Example 6.3-2	Constrained Recoil after Cessation of Steady Shear Flow	292
6.4	Justification for the	Use of the General Linear Viscoelastic Fluid	293
	Example 6.4–1	Illustration that the General Linear Viscoelastic Model Is not "Objective"	294
Chapter 7	Quasilinear Co	rotational Models	305
7.1	Basic Concepts of	Corotational Theories	306
7.2	Objectivity and the	Transformation Laws between Reference Frames	314
	'Example 7.2–1	Objectivity of the Second-Order Fluid	324
7.3	The Corotational J	effreys Model	327
	Example 7.3–1	Steady Shear Flow	328
	Example 7.3–2	Small-Amplitude Oscillations	33 1
	Example 7.3–3	Stress Growth at Inception of Steady-State Shear Flow	333
	Example 7.3–4	Stress Relaxation after Cessation of Steady Shear Flow	333
7.4	The Generalized Z	FD Model	335
7.5	The Goddard-Mille	er Model	338
	Example 7.5–1	Elongational Stress Growth for Goddard-Miller Fluid	343
	Example 7.5–2	Integro-Differential Equation for the Dynamics of a Gas Bubble Suspended in a Viscoelastic Fluid	344
	Example 7.5–3	Estimation of Extrudate Swell for Polymer Melts	347
7.6	Corotational Rheo	logical Equations of State in Curvilinear Coordinates	348
	'Example 7.6–1	Calculation of Kinematic Quantities in a Curvilinear Flow	351
Chapter 8	Nonlinear Coro	tational Models	365
8.1	Nonlinear Differer Model)	tial Corotational Models (the Oldroyd Eight-Constant	366
	Example 8.1-1	Material Functions for the Oldroyd Eight-Constant Model	367
	Example 8.1-2	The Integral Form of the Oldroyd Eight-Constant Model	370.
	Example 8.1–3	The Rayleigh Problem for an Oldroyd Fluid	371
	'Example 8.1–4	Tube Flow of an Oldroyd Fluid with a Pulsatile Pressure Gradient	373

		CONTENTS	xiii
8.2	Nonlinear Integral	Corotational Models	378
8.3	The Corotational Memory Integral Expansion		379
8.4	The Retarded-Mot	ion Expansion	384
	Example 8.4–1	The Journal-Bearing Problem	386
	Example 8.4–2	The Hole Pressure Error	388
	'Example 8.4-3	Flow of a Macromolecular Fluid near a Rotating Sphere	390
8.5	1 1	ns for Steady-State Flows (the Criminale-Ericksen-Filbey e Reiner-Rivlin Equation)	395
	Example 8.5-1	Centripetal Pumping between Parallel Disks	397
	*Example 8.5-2	Normal Stress Stabilizing Force in Wire-Coating Dies	399
Chapter 9	Codeformationa	al Models	417
9.1	Basic Concepts of	the Codeformational Formalism	418
	Example 9.1–1	Integration of the Differential Forms of Oldroyd's Fluids A and B	426
*9.2	Kinematical and D	Dynamical Codeformational Tensors, and Objectivity	427
*9.3	Convected Coordi	nate Formalism	435
9.4	Empirical Rheolog	ciat Equations of State	442
	Example 9.4–1	Model Testing and Parameter Evaluation	443
	Example 9.4–2	Start-Up of Elongational Flow for Lodge's Rubberlike Liquid	449
9.5	Memory Integral I	Expansions	451
*9.6	Rheological Equations of State in Curvilinear Coordinates		457
	**Example 9.6–1	Inflation of a Spherical Viscoelastic Film	458
Appendix A Appendix B	Components	Vector and Tensor Notation of the Equation of Motion, the Rate-of-Strain Ter Tensor, and the Finite Strain Tensors in Three ems	
Notation	for Volume 1		N-1
	for Volume 1 for Volumes 1 a		Al-l SI-l

CONTENTS VOLUNIE 2

Chapter 10	Elastic Dumbbel	l Models for Flexible Polymers	471
10.1	The Elastic Dumbbell Model		
10.2	The "Diffusion Equ	ation" for the Configurational Distribution Function	475
	Example 10.2-1	Equilibrium Configurational Distribution Function in Dilute Solutions of Macromolecules	481
	Example 10.2-2	Time Rate of Change of Average Values	483
	Example 10.2-3	Evaluation of $\langle RF^{(c)} \rangle$ at Equilibrium	484
10.3	Kinetic Theory Exp	ression for the Stress Tensor	484
	Example 10.3-1	Configurational Distribution Function and Stress Tensor for Steady-State, Homogeneous. Potential Flow for Any Elastic Dumbbell	489
10.4	Infinitely Extendabl	e Linear Elastic Dumbbells (Hookean Dumbbells)	490
+	Example 10.4-1	Steady Shear Flow of Hookean Dumbbell Solutions	492
	Example 10.4-2	Unsteady Elongational Flow of Hookean Dumbbell Solutions	493
10.5	Finitely Extendable	Nonlinear Elastic Dumbbells ("FENE" Dumbbells)	455
*	Example 10.5-1	Elongational Viscosity for a Dilute Solution of Macromolecules Modeled as FENE Dumbbells	504
10.6	Hydrodynamic Inte	eraction	507
	Example 10.6-1	The Effect of Hydrodynamic Interaction on the Intrinsic Viscosity of a Suspension of Hookean Dumbbells	509
Chapter 11	Rigid Dumbbell	Model for Rodlike Polymers	521
11.1	The Rigid Dumbbe	ll Model	522
11.2	The "Diffusion Equation" for the Orientational Distribution Function		524
	Example 11.2-1	Equilibrium Diatrtbution Function for Rigid Dumbbells	528
	Example 11.2-2	Time Evolution of (B) and $\langle RR \rangle$	529
11.3	Kinetic Theory Exp	pressions for the Stress Tensor	530
3	Example 11.3-1	Steady-Stat; Homogeneous. Potential Flow of a Dilute Rigid Dumbbell Suspension	531
11.4	Solution of the Kir	netic Theory Equations for Special Flows	532
	Example 11.4-1	Steady Simple Shear Flow	534
	Example 11.4-2	Small-Amplitude Oscillatory Motion	537

xvi DYNAMICS OF POLYMERIC LIQUIDS

	Example 11.4-3	Steady Elongational Flow	541
	Example 11.4-4	Stress Growth at the Inception of Steady Elongational Flow	543
11.5	Solution of the Kine	etic Theory Equations for General Flows	549
11.6	Hydrodynamic Inte	raction	555
	Example 11.6-1	Comparison of Viscometric Functions for Rigid Dumbbells with Equilibrium-Averaged and Complete Hydrodynamic Interaction	558
	*Example 11.6-2.	Steady Shear Flow Properties of Rigid Dumbbell Suspensions at Arbitrary Shear Rates: (Numerical Calculation)	560
Chapter 12	Chainlike Mode	ls for Flexible Polymers	581
12.1	Description of Cont	iguration of Chainlike Models	582
12.2		n" for the Configurational Distribution Function for the nlike Bead-Spring Model	585
	Example 12.2-1	Use of Normal Coordinates to Simplify the Diffusion Equation for the Rouse Model	588
12.3	Kinetic Theory Exp Chainlike Bead-Spri	ressions for the Stress Tensor for the Free-Draining ing Model	590
	Example 12.3-1	Rheological Equation of State for the Rouse Model	590
	Example 12.3-2	Material Functions for the Rouse Model	592
12.4	The Chainlike Beac	l-Spring Model with Hydrodynamic interaction	594
	Example 12.4–1	Stress Relaxation after Cessation of Steady Homogeneous Flows for Chainlike Models with Preaveraged Hydrodynamic Interaction and Nonlinear Springs	601
Chapter 13	General Bead-R	od-Spring Models for Polymers	609
13.1	Description of Con	figuration of Complex Models	609
	Example 13.1 - 1	Calculation of Configurational Quantities for the Rigid Dumbbell Model	616
	Example 13.1-2	Calculation of Configurational Quantities for the Three-Bead-Two-Rod Model	617
13.2	The "Diffusion Equ	ation" for the Configurational Distribution Function	619
	Example 13.2–1	Diffusion Equation for the Orientational Distribution Function for Rigid Dumbbells	621
13 3	Kinetic Theory Exp	pressions for the Stress Tensor	62 1

* An asterisk Jesignates material that can be omitted on first readine or for an elementary course.

CONTENTS	xyi	i
----------	-----	---

	x for Volume 2 x for Volumes 1 and 2	2.A - 1 SI-1
Appendix C Notation	Summary of Continuum Mechanics Notation and Results	C-I 2 N-1
15.4	Modified Network Models for Macromolecular Fluids	714
15.3	An Elementary Network Model for a Macromolecular Fluid	711
15.2	An Elementary Network Model for a Macromolecular Solid Example 15.2-1 Simple Deformations of a Mooney Material	70,3 708
15.1	Description of Network Models	701
Chapter 15	Network Theories for Polymer Melts and Concentrated Solutions	701
*14.7	Approximate Expression for the Stress Tensor in Terms of the Singlet Configuration-Space Distribution Function	692
	*Example 14.6– l Equilibration in Momentum Space	69 1
*14.6	An Approximate Diffusion Equation for the Singlet Configuration-Space Distribution Function	687
•14.5	Time Evolution of the Singlet Configuration-Space Distributron Function	685
*14.4	The Stress Tensor in Terms of Configuration-Space Distribution Functions	678
*14.3	Contracted Distribution Functions	676
	*Example 14.2–1 Interpretation of the Contributions to <i>S</i>	674
•14.2	Ensemble Averages and the Equations of Change	668
'14.1	Classical Dynamics of a Solution Containing Polymer Molecules and Solvent Molecules	664
Chapter 14	Phase-Space Kinetic Theory of Polymer Solutions	663
	Example 13.7-1 Estimation of Intrinsic Viscosity of the Myosin Molecule	653
*13.7	Shielding Coefficients and Rigid Biopolymers	648
	•Example 13.6–1 Calculation o i Relaxation Modulus for Arbitrary Rigid Axisymmetric Bead-Rod Models	642
*13.6	Unsteady Flows of Free-Draining Bend-Rod Models	638
	'Example 13.5-1 Elongational Viscosity of a Chainlike Bead-Rod Model	635
13.5	Steady Flows of Free-Draining Chainlike Bead-Rod Models	632
	Example 13.4-1 Second-Order Fluid Constants for the Rigid Tridumbbell Example 13.4-2 Second-Order Fluid Constants for the Elastic Rhombus	630 631
13.4	Second-Order Fluid Constants for Complex Models	623