

CONTENTS

PREFACE	v
1. INTRODUCTION	
1.1 What is rheology?	1
1.2 Historical perspective	1
1.3 The importance of non-linearity	4
1.4 Solids and liquids	4
1.5 Rheology is a difficult subject	6
1.6 Components of rheological research	9
1.6.1 Rheometry	9
1.6.2 Constitutive equations	10
1.6.3 Complex flows of elastic liquids	10
2. VISCOSITY	
2.1 Introduction	11
2.2 Practical ranges of variables which affect viscosity	12
2.2.1 Variation with shear rate	12
2.2.2 Variation with temperature	12
2.2.3 Variation with pressure	14
2.3 The shear-dependent viscosity of non-Newtonian liquids	15
2.3.1 Definition of Newtonian behaviour	15
2.3.2 The shear-thinning non-Newtonian liquid	16
2.3.3 The shear-thickening non-Newtonian liquid	23
2.3.4 Time effects in non-Newtonian liquids	24
2.3.5 Temperature effects in two-phase non-Newtonian liquids	25
2.4 Viscometers for measuring shear viscosity	25
2.4.1 General considerations	25
2.4.2 Industrial shop-floor instruments	26
2.4.3 Rotational instruments; general comments	26
2.4.4 The narrow-gap concentric-cylinder viscometer	27
2.4.5 The wide-gap concentric-cylinder viscometer	28
2.4.6 Cylinder rotating in a large volume of liquid	29
2.4.7 The cone-and-plate viscometer	30
2.4.8 The parallel-plate viscometer	31
2.4.9 Capillary viscometer	32
2.4.10 Slit viscometer	34
2.4.11 On-line measurements	35
3. LINEAR VISCOELASTICITY	
3.1 Introduction	37
3.2 The meaning and consequences of linearity	38

3.3	The Kelvin and Maxwell models	39
3.4	The relaxation spectrum	43
3.5	Oscillatory shear	46
3.6	Relationships between functions of linear viscoelasticity	50
3.7	Methods of measurement	51
3.7.1	Static methods	51
3.7.2	Dynamic methods: Oscillatory strain	52
3.7.3	Dynamic methods: Wave propagation	53
3.7.4	Dynamic methods: Steady flow	54
4. NORMAL STRESSES		
4.1	The nature and origin of normal stresses	55
4.2	Typical behaviour of N_1 and N_2	57
4.3	Observable consequences of N_1 and N_2	60
4.4	Methods of measuring N_1 and N_2	64
4.4.1	Cone-and-plate flow	65
4.4.2	Torsional flow	68
4.4.3	Flow through capillaries and slits	70
4.4.4	Other flows	71
4.5	Relationship between viscometric functions and linear viscoelastic functions	71
5. EXTENSIONAL VISCOSITY		
5.1	Introduction	75
5.2	Importance of extensional flow	77
5.3	Theoretical considerations	80
5.4	Experimental methods	82
5.4.1	General considerations	82
5.4.2	Homogeneous stretching method	83
5.4.3	Constant stress devices	84
5.4.4	Spinning	84
5.4.5	Lubricated flows	86
5.4.6	Contraction flows	87
5.4.7	Open-syphon method	88
5.4.8	Other techniques	89
5.5	Experimental results	89
5.6	Some demonstrations of high extensional viscosity behaviour	95
6. RHEOLOGY OF POLYMERIC LIQUIDS		
6.1	Introduction	97
6.2	General behaviour	97
6.3	Effect of temperature on polymer rheology	101
6.4	Effect of molecular weight on polymer rheology	102
6.5	Effect of concentration on the rheology of polymer solutions	103
6.6	Polymer gels	104
6.7	Liquid crystal polymers	105
6.8	Molecular theories	106
6.8.1	Basic concepts	106
6.8.2	Bead-spring models: The Rouse-Zimm linear models	106
6.8.3	The Giesekus-Bird non-linear models	107
6.8.4	Network models	108
6.8.5	Reptation models	108
6.9	The method of reduced variables	109
6.10	Empirical relations between rheological functions	111

6.11 Practical applications	111
6.11.1 Polymer processing	111
6.11.2 Polymers in engine lubricants	113
6.11.3 Enhanced oil recovery	113
6.11.4 Polymers as thickeners of water-based products	114
7. RHEOLOGY OF SUSPENSIONS	
7.1 Introduction	115
7.1.1 The general form of the viscosity curve for suspensions	115
7.1.2 Summary of the forces acting on particles suspended in a liquid	116
7.1.3 Rest structures	117
7.1.4 Flow-induced structures	119
7.2 The viscosity of suspensions of solid particles in Newtonian liquids	119
7.2.1 Dilute dispersed suspensions	119
7.2.2 Maximum packing fraction	120
7.2.3 Concentrated Newtonian suspensions	121
7.2.4 Concentrated shear-thinning suspensions	125
7.2.5 Practical consequences of the effect of phase volume	127
7.2.6 Shear-thickening of concentrated suspensions	128
7.3 The colloidal contribution to viscosity	131
7.3.1 Overall repulsion between particles	131
7.3.2 Overall attraction between particles	133
7.4 Viscoelastic properties of suspensions	134
7.5 Suspensions of deformable particles	135
7.6 The interaction of suspended particles with polymer molecules also present in the continuous phase	136
7.7 Computer simulation studies of suspension rheology	137
8. THEORETICAL RHEOLOGY	
8.1 Introduction	141
8.2 Basic principles of continuum mechanics	142
8.3 Successful applications of the formulation principles	145
8.4 Some general constitutive equations	149
8.5 Constitutive equations for restricted classes of flows	150
8.6 Simple constitutive equations of the Oldroyd/Maxwell type	152
8.7 Solution of flow problems	156
GLOSSARY OF RHEOLOGICAL TERMS	159
REFERENCES	171
AUTHOR INDEX	181
SUBJECT INDEX	185