

Contents

Nomenclature	13
Preface	17
1. Mathematical description of different rheologically complex fluids	25
1.1. Notations, symbols and tensor operations	25
1.2. General outline and motivation	29
1.3. Kinematic relations.....	33
1.4. Pseudoplastic fluids	37
1.5. Viscoplastic fluids	44
1.6. Viscoelastic fluids	45
1.7. Constitutive equations for generalized second grade fluids.....	51
1.8. Dynamic relations for isotropic fluids	53
1.9. Conducting and magnetic micropolar fluids.....	55
1.10. Nonconducting magnetic fluids (ferrofluids)	58
1.11. Simple ferrofluid based on a Shliomis model.....	59
1.12. Couple stress fluid	62
1.13. Nonconducting electro- and magnetorheological fluids	63
1.14. Remarks on the action of electromagnetic fields.....	65
2. Equations of motion in a curvilinear coordinate system	67
2.1. Introduction and motivations.....	67
2.2. Flow configurations.....	69
2.3. Curvilinear coordinate system on a surface of revolution	70
2.4. Equations of motion for isotropic fluids expressed in a curvilinear coordinate system.....	73
2.5. Equations of motion for conducting and magnetic micropolar fluids expressed in a curvilinear coordinate system	75
2.6. Equations of motion for couple stress fluids expressed in a curvilinear coordinate system.....	76
2.7. Reduced systems of equations	77
2.8. Action of an electromagnetic field on the fluid flow in a thin layer	82
2.9. Appendix	85
2.9.1. Newtonian flows.....	85
2.9.2. Nonconducting and nonmagnetic micropolar fluids.....	90

2.9.3. Equations of motion for couple-stress fluids	93
2.9.4. Equations of electrodynamics in a curved coordinate system.....	94
3. Flows of non-Newtonian fluids in rectilinear channels.....	99
3.1. Introduction.....	99
3.2. Flows of micropolar fluids.....	99
3.2.1. Poiseuille pressurized flow in a plane channel	101
3.2.2. Couette flow (Poiseuille dragged flow) in a plane channel	105
3.2.3. Poiseuille flow through a circular pipe	108
3.2.4. Rotating Couette flow between two coaxial cylinders.....	112
3.3. Flows of couple-stress fluids	115
3.3.1. Poiseuille flow in a plane channel	115
3.3.2. Couette flow without pressure gradient	119
3.3.3. Poiseuille flow through a circular pipe	121
3.3.4. Rotating Couette flow between two concentric cylinders.....	124
3.4. Flows of pseudoplastic fluids based on a DeHaven model.....	126
3.4.1. Poiseuille flow in a plane channel	128
3.4.2. Poiseuille flow through a circular pipe	129
3.4.3. Rotating Couette flow between two coaxial cylinders.....	131
3.5. Flows of generalized second grade fluids based on a Sisko model.....	133
3.5.1. Poiseuille flow in a plane channel	134
3.5.2. Poiseuille flow through a circular pipe	137
3.5.3. Rotating Couette flow between two coaxial cylinders.....	141
3.6. Flows of generalized second grade fluids based on a Shulman model	144
3.6.1. Poiseuille flow in a plane channel	145
3.6.2. Poiseuille flow through a circular pipe	151
3.6.3. Rotating Couette flow	157
3.6.4. Longitudinal Couette flow (dragged flow) in an annular channel	159
3.6.5. Torsional flow between a rotating and fixed disk.....	163
3.6.6. Torsional flow between a rotating cone and fixed disk	165
4. Rheodynamics of flows in porous media	167
4.1. Introduction.....	167
4.2. Nature of porous media.....	168
4.3. Newtonian fluid flow in porous media	171

4.4. Flow of a micropolar fluid in porous media	176
4.4.1. Flow through a matrix composed of capillary fissures	176
4.4.2. Flow through a matrix composed of capillary tubes.....	177
4.5. Flow of couple-stress fluid in porous media.....	179
4.5.1. Flow through a matrix composed of capillary fissures	179
4.5.2. Flow through a matrix composed of capillary tubes.....	181
4.6. Flow of pseudoplastic fluids of a DeHaven type in porous media	182
4.6.1. Flow through a matrix composed of capillary fissures	182
4.6.2. Flow through a matrix composed of capillary tubes.....	183
4.7. Flow of pseudoplastic fluids of a Sisko type in porous media.....	184
4.7.1. Flow through a matrix composed of capillary fissures	184
4.7.2. Flow through a matrix composed of capillary tubes.....	185
4.8. Flows of viscoplastic fluids of a Shulman type	185
4.8.1. Flow through a matrix composed of capillary fissures	186
4.8.2. Flow through a matrix composed of capillary tubes.....	187
4.9. Fractal velocity models for flows in porous media.....	189
4.9.1. Fractal velocity model for a DeHaven fluid flow through a porous matrix.....	190
4.9.2. Fractal velocity model for a Sisko fluid flow through a porous matrix.....	192
4.9.3. Fractal velocity model for a polar fluid flow in a porous matrix.....	192
4.9.4. Fractal velocity model for a Shulman fluid flow in a porous matrix.....	194
4.10. Modelling of flow and diffusion transport through the stratum corneum (SC)	195
4.10.1. Skin as a porous biomembrane	195
4.10.2. Diffusion through brick-and-mortar structure	197
4.10.3. Rheodynamics of flow in the SC as a porous matrix	201
4.10.4. Diffusion transport through the SC.....	203
4.10.5. Steady-state diffusion through the SC	204
4.10.6. Non steady-state diffusion through the SC	205
4.10.7. Mass transport in non steady-state diffusion	206
5. Methods of solutions to reduced equations of flow between surfaces of revolution ..	209
5.1. Introduction	209
5.2. Method of averaged inertia.....	210
5.2.1. Description of the method	210
5.2.2. Flows in annular clearances between conical and spherical surfaces	214

5.3. Method of moments	217
5.3.1. Outline of the method	217
5.3.2. Flows in annular clearances between conical and spherical surfaces	219
5.4. Method of small parameter	221
5.4.1. Reduced equations of motion	221
5.4.2. Solution to the reduced equations	222
5.5. Method of asymptotic solutions	234
5.5.1. Bases of the method	234
5.5.2. Asymptotic solution to the reduced equations	237
5.5.3. Analysis of solutions	240
5.5.4. Convergence of solutions	242
5.5.5. Flows between rotating disks and rotating spherical surfaces	245
5.6. Modified method of averaged inertia	256
5.6.1. Description of the method	256
5.6.2. Flows in an annular clearance between two disks and spherical surfaces	258
5.7. Conclusions	266
6. Flows of non-Newtonian fluids between non-rotating surfaces of revolution	269
6.1. Introduction	269
6.2. Flow of a micropolar fluid between fixed surfaces of revolution	269
6.2.1. Basic equations	269
6.2.2. Reynolds approximation	270
6.2.3. Integral approaches	272
6.2.4. Examples of flows	277
6.2.5. Modified method of averaged inertia	278
6.3. Flow of a couple-stress fluid in a curved squeeze film	284
6.3.1. Basic equations	284
6.3.2. Reynolds approximation	285
6.3.3. Integral approaches	287
6.3.4. Examples of squeeze flows	288
6.3.5. Modified method of averaged inertia	293
6.4. Flow of a viscoelastic fluid of Rivlin-Ericksen between fixed surfaces of revolution	301
6.4.1. Analysis of a fluid flow in the curved clearance	301
6.4.2. Some results and conclusions	304

6.5. Flow of viscoplastic and electrorheological fluids in a curved clearance.....	306
6.5.1. Basic equations.....	306
6.5.2. Solution to the reduced equations.....	308
6.5.3. Particular cases of solution.....	311
6.5.4. Examples of flows.....	323
7. Flows of non-Newtonian fluids between rotating surfaces of revolution.....	343
7.1. Introduction.....	343
7.2. Flow of a viscoelastic fluid between rotating surfaces of revolution.....	343
7.2.1. Basic equations.....	344
7.2.2. Solution to the equations of motion.....	345
7.2.3. Nondimensional form of the solution.....	347
7.2.4. Examples of flows.....	348
7.3. Flow of a generalized second grade fluid between rotating surfaces of revolution.....	352
7.3.1. Basic equations.....	352
7.3.2. Solution to the equations of motion.....	353
7.3.3. Nondimensional form of the solution for the clearance of constant thickness.....	355
7.3.4. Flows of purely power-law fluid.....	357
7.3.5. Flows of purely viscoplastic fluids.....	364
7.4. Flow of a couple-stress fluid between surfaces of revolution: the fixed one and the rotating one.....	380
7.4.1. Basic equations.....	380
7.4.2. Solution of the equations of motion.....	381
7.4.3. Some results and conclusion.....	382
7.5. Flow of a micropolar fluid between surfaces of revolution: the fixed one and the rotating one.....	383
7.5.1. Basic equations.....	383
7.5.2. Solution of the equations of motion.....	384
7.5.3. Examples of flows.....	385
7.5.4. Conclusions.....	392
7.6. Inertia effects in the flow of a micropolar fluid in a slot between rotating surfaces of revolution.....	393
7.6.1. Basic equations.....	393
7.6.2. Solution of the equations of motion.....	394
7.6.3. The zero-order approximation (ZOA).....	400
7.6.4. The first-order approximation (FOA).....	406
7.7. Appendix to Subsection 7.5.....	414

8. Characteristics of throughflow in curvilinear bearings.....	417
8.1. Introduction.....	417
8.2. Roughness and porosity of working surfaces in bearing lubrication	418
8.2.1. Surface layer (SL) of a bearing working surface	418
8.2.2. Roughness in lubricant operations	421
8.2.3. Porosity in lubricant operations	425
8.3. Performance of a curvilinear thrust bearing lubricated with a ferrofluid.....	428
8.3.1. Basic equations	428
8.3.2. Solution of the basic equations	430
8.3.3. Special cases of the flow and special forms of the Reynolds equation.....	431
8.3.4. Bearing mechanical parameters	434
8.3.5. Examples of bearings.....	436
8.3.6. Some conclusions	444
8.4. Flows of conducting and magnetic viscoelastic fluids.....	444
8.4.1. Basic equations	444
8.4.2. Solution of the basic equations	445
8.4.3. Examples of bearings.....	449
8.5. Flows of generalized second grade fluids of power-law type	451
8.5.1. Basic equations	451
8.5.2. Solution of the basic equations	452
8.5.3. Examples of bearings.....	455
8.6. Flow of couple-stress fluids in a bearing with porous walls	457
8.6.1. Basic equations	457
8.6.2. Derivation of the Reynolds equation	459
8.6.3. Solutions to the Reynolds equation.....	463
8.6.4. Examples of bearings.....	465
8.7. Multilobe conical bearings lubricated with a couple-stress fluid.....	470
8.7.1. Bearing description.....	470
8.7.2. Modified Reynolds equation.....	471
8.7.3. Solution to the modified Reynolds equation.....	473
8.7.4. Bearing mechanical parameters	476
8.7.5. Example of application	478

8.8. Inertia effects in a porous rough squeeze film biobearing with a synovial lubricant modelled by a power-law fluid.....	483
8.8.1. Biobearing cartilage and synovial lubrication	483
8.8.2. Analysis of a lubricant flow in a bearing clearance.....	485
8.8.3. Modified Reynolds equation for a bearing with a porous pad.....	487
8.8.4. Solution to the Reynolds equation.....	489
8.8.5. Squeeze film in a radial thrust biobearing.....	490
8.9. Squeeze film bearing lubricated with a DeHaven fluid	495
8.9.1. Equations of motion of the unified DeHaven fluid model; Reynolds equation.....	496
8.9.2. Modified Reynolds equation for a bearing with a porous pad.....	498
8.9.3. Solution to the modified Reynolds equation	500
8.9.4. Radial thrust bearing with a squeeze film.....	503
8.9.5. Spherical squeeze film bearing.....	509
8.10. Squeeze film bearing lubricated with a Sisko fluid	514
8.10.1. Equations of motion of the unified Sisko fluid model; Reynolds equation	514
8.10.2. Modified Reynolds equation for a bearing with a porous pad.....	516
8.10.3. Solution to the modified Reynolds equation.....	517
8.10.4. Radial thrust bearing with a squeeze film.....	519
8.10.5. Spherical squeeze film bearing.....	522
8.11. Squeeze film bearing with a porous wall and rough surfaces lubricated with a Shulman fluid.....	524
8.11.1. Analysis of Shulman fluid flows in the clearance between rough surfaces of revolution ..	525
8.11.2. Modified Reynolds equation.....	529
8.11.3. Solution to the modified Reynolds equation.....	532
8.11.4. Examples of flow	534
8.12. Appendix	547
8.12.1. Appendix to Section 8.7	547
8.12.2. Appendix to Section 8.9	551
References	561
Subject index.....	587