

Index

A

Acceleration

- convected, 25
- local, 25
- material/Lagrangian description, 24
- spatial/Eulerian description, 25
- wave, 103

Augmented Lagrangian, viii, ix

- functional, 229, 231, 232, 235
- method, 20, 47, 206, 225, 226, 235, 248, 249, 267, 268

B

Banach space, 162

Bi-viscosity model, 56, 267

Bingham

- fluid, vii, viii, 1, 3, 7, 10, 14, 16, 18, 20, 30, 32, 48, 51, 53, 56, 60, 63, 65, 66, 68, 72, 81–83, 85, 87, 91, 99, 100, 103, 106, 107, 110, 114, 116, 117, 124, 128, 132, 136, 142, 149, 150, 156, 158, 162, 163, 165–167, 170, 174, 175, 181–183, 186, 200, 201, 205, 207, 210–213, 216–218, 221, 223, 225, 226, 230–232, 234–236, 238, 262, 267, 268
- weakly compressible, 252, 260
- number, vii, 8–10, 71, 75, 85, 90, 114, 117, 118, 125, 132, 136, 193, 194, 196, 198, 199, 201, 202, 206, 208, 209, 215, 217, 221, 223, 237, 238, 241, 243, 244, 248, 268

Bingham fluid

- drag, 201
- entrapment
- sphere, 202
- spherical bubble, 202

extinction time, 16

rising bubble, 201

Bingham, E. C., 18

Boundary condition

- enclosed flow, 257
- open or partially open, 257

Boussinesq approximation, 237

Bubble

- critical Bingham number, 196, 198, 199, 201
- static, 193

Buckingham equation, vii, 9, 71, 118, 217, 221

C

Casson fluid, 48, 83, 109, 124, 128, 142, 150, 163, 165, 231

Cauchy

- first law of motion, 38, 134
- second law of motion, 40
- stress principle, 38, 69, 72, 78

Cauchy-Schwarz inequality, 142, 150, 151, 154, 175, 177, 192, 200, 206, 220

Cavity flow

- lid driven, 236, 262, 264
- thermally driven, viii, 235, 240

Compressible fluid

- exponential model, 260
- linear model, 260
- weak, 261

Conservation of mass, 26, 36, 42, 174, 251, 254

correction, 254

Constitutive equation, vii, 3, 5, 20, 48, 50, 54–56

Bingham fluid, 53, 60, 63

- Casson fluid, 61, 64
- compressible viscoplastic fluid, 58, 177
- Herschel-Bulkley fluid, 60, 63
- weakly compressible viscoplastic fluid, 255
- Continuity equation, 36, 252, 253, 255
- Continuum mechanics, 24, 26, 27, 35–38, 43, 48, 49, 51, 140
- Control surface, 43
- Control volume, 43
- Convected derivative problem, 241, 259, 261
- Convex analysis, viii, 139, 158
- Convex set, 163
- Critical
 - pressure drop per unit length, 1, 3, 68, 73, 88
 - Reynolds number, 136, 137
 - shear rate, 56
 - value for plug break, 121
 - value of shear stress, 157
 - yield stress number, 17
- Cubic equation, 9, 80, 115
- Curl of a vector
 - physical components, 32
 - Cartesian coordinates, 33
 - cylindrical coordinates, 33
 - spherical coordinates, 33
- D**
- Deformation gradient, 26
- Direct method, 159–161
- Dirichlet
 - boundary condition, 56, 139, 161, 164, 171, 175, 176, 230, 267
 - principle, 159
- Dirichlet, P. G. L., 159
- Discriminant, 10, 71, 81, 222
- Divergence of a vector
 - physical components, 32
 - Cartesian coordinates, 32
 - cylindrical coordinates, 33
 - spherical coordinates, 33
- E**
- Energy balance equation, 42
- Equation of state, 252
- Equations of motion
 - Cartesian coordinates, 45
 - cylindrical coordinates, 45
 - spherical coordinates, 46
- Equivalence
 - variational inequality and equations of motion, 168
 - variational inequality and variational principle, 166, 230, 231
 - variational inequality and viscoplasticity constraint tensor, 176
- Euler
 - turbomachine equation, 44
- Extinction time
 - channel flow, 211
 - Couette flow, 215
 - pipe flow, 212
 - simple shear, 212
 - wall slip, 216
- F**
- Fictitious domain method, 206, 235
- Finite element method, 86, 161, 168, 202, 240, 261
- Finite extinction time, 213, 268
- First Rivlin-Ericksen tensor, 29
- Flow
 - approach to steady state, 209
 - Couette, 32
 - helical/spiral, 32
 - in a channel, 31, 268
 - in a wavy channel, 116
 - in an annulus, 31
 - inclined plane, 66
 - Poiseuille, 31
 - simple shear, 30
 - steady
 - in a pipe, 149
- Flow in a cavity
 - lid driven, 260
- Flow rate, 115, 118, 192, 268
- Fluidity function
 - Bingham fluid, 124
 - Casson fluid, 124
 - Herschel-Bulkley fluid, 124
 - Papanastasiou model, 125
- Fourth order equation, 71
- Free surface problem, 66, 91, 171, 174
- Function space, 158, 161, 163
- Functional
 - bilinear, 153
 - convex, 164
 - kinematically admissible, 143, 145, 148, 150, 158
 - presence of wall slip, 157
 - minimiser, 166
 - proper, 164

- statically admissible, 144, 146, 148
 - presence of wall slip, 157
 - strictly convex, 164
 - trilinear, 153, 173
- Fundamental inequality
 - compressible fluid, 59, 178
 - incompressible fluid, 139, 150, 152, 157, 172, 176, 195, 204
- G**
- Galerkin, B. G., 161
- Gateaux derivative, 166, 232
- Gateaux differential, 166
- General energy balance equation, 139, 155
- Green, H., 18
- H**
- Hadarnard
 - Lemma, 104, 105, 109
 - propagating singular surfaces, viii, 97, 100
- Hadarnard-Rybczynski formula, 199, 202
- Halting number, 211, 215, 216
- Heat transfer, 83
 - across a cavity, 242
 - circular tube, 85
 - parallel walls, 65, 85
- Hele-Shaw flow, 81, 114, 122, 126, 128, 131, 132
 - average velocity field
 - asymmetric case, 130
 - Bingham fluid, 128
 - power law fluid, 127
 - symmetric case, 126
 - viscous fluid, 127
- Herschel-Bulkley fluid, 48, 53, 83, 109, 124, 128, 142–144, 150, 165, 194, 231
- Hilbert space, 162
- I**
- Incompressibility, 44, 47, 50, 51, 54, 87, 103
- J**
- Jerk wave, 103, 106–109
- K**
- Karush-Kuhn-Tucker condition, 229
- Kinematic invariant, 42, 63
- Kolodner
 - functional equation, 91, 95
 - method, 90, 99
- L**
- L.s.c., 160, 161
 - convex functional, 166
 - functional, 167
 - proper and convex, 164
- Lagrange multiplier, 50, 229, 231
 - method, 226
- Lagrange, J.-L., 226
- Lagrangian mechanics, 37, 48, 51
- Lamé coefficients, 253
- Lambert W function, 125
- Laplace transform, 98
- Laplace's equation, 128, 159
- Laplacian, 230, 237
- Lebesgue, H., 160
- Lid driven flow, viii, 171, 226, 240, 266
- Low Mach number
 - flow, 250, 252
- Lower semi-continuity, 160
- Lubrication approximation, 114, 116
- Lubrication paradox, 114, 116, 119
- M**
- Mach number, 252
- Material derivative, 25
- Maximum principle
 - parabolic equations, 98
- Mixed boundary condition, 161
- N**
- Navier, C - L., 16
- Navier-Stokes equation
 - compressible fluid, 252, 254
 - incompressible fluid, 113, 168, 235, 251
- Navier-Stokes equations
 - compressible fluid, 253
- Neumann
 - boundary condition, 161
- Newton
 - heat transfer coefficient, 84
 - second law, 35
- Newtonian fluid, 136, 174
 - compressible, 250, 255
 - drag, 201
 - rising bubble, 199
- No slip boundary condition, 134
- Non-isothermal flow, 235, 236, 239, 240, 253

- Non-Newtonian
 - fluid, 18, 19, 56, 81, 85, 174, 201
 - fluid mechanics, 168
 - viscosity, 56, 84
- Numerical experiments, 166, 176, 226
- Nusselt number, 65, 83–85
 - averaged, 238, 248
 - local, 238, 245
- O**
- Obstacle problem, 12, 14
- Operator-splitting, viii, ix, 249
 - method, 20, 56, 139, 225, 235, 236, 239, 242, 261, 267
 - methods, 176
 - scheme, 47
- Operator-splitting method
 - compressible fluid, 258
- Orr, W. M., 217
- Orr-Sommerfeld energy equation, 132, 181
- Orthogonal projection method, 249
- P**
- Papanastasiou model, 56, 109, 124, 128, 199, 202, 267, 268
 - parameter, 58, 268
- Perturbation
 - first order, 118, 120
 - isentropic case, 251
 - kinetic energy, 217
 - long wavelength, 114, 121
 - modal, 136
 - non-modal, 136
 - one dimensional, 135
 - periodic, 134
 - regular, 10, 71
 - span wise, 136
 - stream wise, 136
 - three dimensional, 136
 - two dimensional, 135
 - velocity field, 218, 221, 222
- Plug
 - annular, 73
 - central, 69
 - flow, 67
 - pseudo, 118–120
 - rigid, 68
 - semi-width, 5
 - solid, 3
 - true, 120
 - velocity, 4
- Polar decomposition theorem, 28
- Prandtl number, 238, 245
- Pressure
 - definition, 51
 - field, 1, 51, 66, 79, 82, 128, 168, 198, 234, 236
 - scaling, 132
- Pressure drop per unit length, 80, 88, 132, 135, 149, 171
 - critical, 181, 182, 184
 - circular pipe, 186
 - equilateral triangular pipe, 187
 - igloo shape, 188
 - in an annulus, 186
 - L-shaped cross-section, 188
 - rectangular pipe, 187
 - square pipe, 186
- Projection operator, 230, 239, 259
- R**
- Rate of deformation/stretching tensor, 29
- Rayleigh number, 238, 242
- Regularised models, viii, 20, 47, 56, 226, 267, 268
- Reynolds
 - number, 8, 117, 223
 - critical, 114, 132, 223
 - transport theorem, 24, 36
- Reynolds'
 - transport theorem, 35–37
- Reynolds, O., 217
- Reynolds-Orr energy equation, 217, 218
- Riemann, B., 159
- Rigid body motion
 - mobility problem, 201
 - resistance problem, 201
- Rigid motion, 27
- Ritz, W., 161
- Rivlin-Ericksen tensor, 23, 29, 30, 33, 42, 47, 52, 54, 182, 251
 - physical components, 33
- Rivlin-Ericksen tensors, 30
- S**
- Saddle point, 228, 229, 232
 - method, 225, 227
 - problem, 235
- Second invariant, 63
 - kinematic, 42, 152, 165
 - stress, 52
- Shear rate, 4, 6, 8, 19, 43, 53, 56, 58, 60, 63, 81, 83, 99, 100, 122–124, 142, 165, 209, 267

- Shear stress, 1–3, 5, 8, 19, 55, 58, 60, 63, 65, 73, 83, 87, 102, 123
 - bi-viscosity model, 56
 - Casson fluid, 53
 - channel flow, viii, 66
 - Couette flow, 77
 - flow in an annulus, 72
 - helical/spiral flow, 80
 - Herschel-Bulkley fluid, 53
 - inclined plane, 67
 - non-Newtonian, 165
 - Papanastasiou model, 58, 124
 - parallel plate flow, 83
 - Poiseuille flow, 69
 - scaling, 117
 - simple shear, 66
 - unsteady channel flow, 88
 - unsteady flow in a half-space, 100, 101
 - vector, 122, 126
 - Size of core
 - pipe flow, 192
 - Sobolev space, 161
 - Spectral element method, 161
 - Sphere
 - critical Bingham number, 206
 - Spin tensor, 29
 - physical components, 34
 - Stability
 - conditional bound
 - channel flow, 223
 - global bound
 - channel flow, 221
 - Poiseuille flow, 221
 - linearised
 - channel flow, 132, 136, 251
 - helical flow, 136
 - nonlinear, 181, 217, 221
 - Stagnant zone, 183
 - existence, 190
 - Stefan problem, vii, 11, 12
 - Stick-slip model, 18, 157
 - Stokes problem, 240, 258, 261
 - Stokes' law
 - drag, 201, 202
 - Stokes' relation, 250
 - Stream function, 128, 135, 198
 - Stress field
 - in shear, 68, 100
 - scaling, 132
 - statically admissible, 140
 - with slip, 157
 - Stress potential, 62
 - Bingham fluid, 60, 63
 - Casson fluid, 61, 64
 - Herschel-Bulkley fluid, 61, 64
 - Stress power difference
 - non-zero, 173
 - zero, 170
 - Stress tensor
 - extra, 45, 47–49
 - total, 47–50
 - Stress vector, 37
 - Surface of constraint, 50
 - Surface tension, 194, 195
- T**
- Thermodynamic pressure, 250
 - Trace of a function, 162
- U**
- Unsteady flow
 - Bingham fluid
 - channel flow, 87
 - Couette flow, 99
 - in a half-space, 100
 - Poiseuille flow, 99
 - Rayleigh problem, 107, 109
 - Uzawa algorithm, 230, 239, 262
 - Uzawa, H., 225
- V**
- Variational inequality, vii, 12, 14, 15, 18, 113, 150, 158, 165–170, 172, 176, 193, 204, 209, 230, 234
 - falling sphere, 202
 - static bubble, 195
 - steady flow in a pipe, 230
 - unsteady flow in a pipe, 172, 207
 - Variational principle, viii, ix, 16, 18, 20, 59, 139, 140, 149, 154, 158, 181, 199
 - steady flow in a pipe, 150, 231
 - Velocity
 - Eulerian description, 23, 25
 - gradient, 25
 - Lagrangian description, 23
 - material/Lagrangian description, 24
 - maximum in a core, 193
 - steady, 23
 - Velocity field
 - kinematically admissible, 140
 - steady, 25
 - unsteady, 25
 - Velocity potential, 62
 - Bingham fluid, 60, 63

Casson fluid, 61, 64
 Herschel-Bulkley fluid, 61, 63
 Virtual power
 principle, viii, 140, 145, 147, 148
 Viscometric fluidity function, 81, 114, 123, 124
 Viscoplastic fluid
 compressible, 255
 Viscoplasticity constraint tensor, vii, 47, 55, 59, 139, 225, 230, 236, 259
 Viscoplasticity constraint tensor problem, 241, 259, 262
 Viscosity
 Bingham fluid, 53
 Casson fluid, 53
 Herschel-Bulkley fluid, 53
 power law, 53, 124, 128
 shear rate dependent, 52
 Viscous
 dissipation rate integral, 152, 163, 178
 Vortex sheet, 103
 Vorticity vector, 30

W

Wall shear stress, 6, 17, 18, 68, 132, 156
 critical, 17
 Wall slip, 18, 139, 156, 157
 Weierstrass, K., 159

Y

Yield stress, 1, 3, 7, 17, 52–54, 56, 58, 65, 68, 73, 84, 86, 100, 102, 105, 106, 127, 142
 dissipation, 136, 137, 151
 dissipation rate integral, 153, 163, 178
 shear rate dependent, 149
 Yield stress fluid, 119, 122
 Yield surface, viii, 5, 6, 14, 16, 55, 77, 78, 82, 87, 90, 91, 93, 95, 97, 99–103, 105–110, 114, 118, 120, 134, 136, 231
 perturbed, 134
 pseudo, 118, 119