

Subject Index

A

- Accelerating motion, 95, 187, 188, 199, 271, 499, 527
- Acivos equation, 481
- Adsorption of polymers, 188, 318, 341, 370, 382
- Aggregation of particles, 33, 99, 196
- Agricultural waste slurry, 4, 10
- Alignment of particles, 6, 316
- Allen-Uhlherr viscosity equation, 64
- Anisotropy, 161, 325, 434
- Anomalous effects in porous media, 381
- Apparent viscosity, 18, 20, 22
 - rheopexy, 28, 30, 32
 - thixotropy, 29–34, 128, 151
- Archimedes number, 56, 57, 93, 94, 121, 414
- Arrays of cylinders, 286, 314
 - parallel flow, 319
 - transverse flow, 320
- Arrays of spheres, 264, 302
- Aspect ratio of
 - bubbles, 237–239, 249
 - bylinders, 314
 - spheroids, 110, 121
- Average shear rate for a sphere, 89, 564, 569, 575, 582
- Axial dispersion in packed beds, 330, 381, 422
- Azimuthal velocity, 71
- two-phase fluidized beds, 409, 410, 412, 421–423

B

- Basset term, 58, 95
- Bead-spring models, 41
- Bed expansion behavior of
 - three-phase fluidized beds, 424, 426–429, 434
- Benchmark problem, 168, 171, 172
- Best number, 56
- Bingham model, 16, 22–25
- Bingham number, 134, 137, 140, 141, 142, 146, 152, 153, 154, 157
- Bingham plastic fluids
 - bubbles in, 257
 - cylinders in, 152–156
 - in porous media, 352–355, 374
 - spheres in, 132–151
- Bingham yield stress, 24
- Blake model, 293, 294, 348
- Blake-Kozeny model, 293, 294, 343, 348, 352
- Blood viscosity, 4, 10, 23, 568
- Boger fluids, 14, 182–184, 186, 187, 194, 273, 328, 338, 375, 376, 380, 422, 545
- Bond number, 224, 276
- Boundary conditions, 247
 - at cell surface 301
 - on stress 60
- Boundary elements method, 60
- Boundary layer flow, 449
 - over a cylinder, 465–473
 - laminar, 449–489
 - over a plate, 450–463
 - of power-law fluids, 450–489
 - over a sphere, 473
 - thermal, 450–489
 - thickness of, 465
 - thin, 473, 477, 485, 503
 - visco-elastic, 489–495
 - visco-plastic, 443, 446, 465
- Boundary wall effects, 521
- Boussinesq-Basset expression, 57
- Breakage of drops, 272
- Break-up of jets and sheets, 217

- Brinkman equation, 307
 Bubble chains, 213, 232
 Bubble columns, 9, 203, 264, 267, 276, 437
 Bubble ensembles, 264
 Bubble swarms, 264
 Bubbles
 in boiling polymer solutions, 218
 coalescence of, 267
 collapse of, 218
 in confined flows, 273
 creeping motion of, 246
 critical radius of, 242–243
 deformation of, 273
 dilatational characteristics of, 267
 final volume of, 206
 formation of, 205
 free motion of, 246
 terminal velocity-volume behaviour of, 239
 growth of, 218
 mass transfer to, 495
 hydrodynamics of, 203
 in low gravity fields, 275, 203
 in microgravity, 275
 non-spherical, 221, 224
 rupturing of, 267
 shapes of
 in Newtonian fluids, 221
 in non-Newtonian fluids, 224
 swarms of, 264
 Bulk porosity of beds, 283, 313
 Bulk rheological characteristics of polymer solutions, 381
 Burgers viscoelastic fluid model, 40, 41
 Burke-Plummer equation, 292
- C**
- Capillary bundle model, 293
 Capillary models, 293
 deficiencies of 297
 of fluidized beds 398, 412
 of laminar flow, 293
 of porous media, 293
 of pressure loss, 293
 Capillary number, 245, 259, 260, 273, 275, 276
 Capillary viscometry, 17, 45
 Carman-Kozeny equation, 292
 Carreau model fluids
 bubbles in, 253, 263
 drops in, 253, 265
 fluidization with, 412
 mass transfer in, 503
 packed bed flows of, 352
 porous media flow of, 352
 Carreau number, 74–76, 82, 122
 Carreau viscosity equation, 21
 Casson model, 25, 46, 128, 148
 Casson yield stress, 25
 Caswell method, 561
 Caswell-Schwarz method, 561
 Cavitation, 203, 218
 Cell models
 cylindrical, 320
 free surface, 300–303
 zero vorticity, 300–303
 Chains of bubbles, 232, 213
 Chains of spheres, 109, 110, 116, 196
 Channelling in beds, 292, 308, 309, 316, 336
 Characteristic time of fluids, 42–44, 81, 185, 263, 370, 394, 471, 573
 Clay suspensions, 28, 30, 79, 125–129, 136, 158
 Coalescence of bubbles, 267
 Coil-stretch transition, 372
 Colburn factor, 462
 Coleman-Noll model, 41
 Collapse of bubbles, 218
 Composite shape factor, 117
 Concrete rheology, 3, 4, 45
 Conductance of porous media, 284
 Conduit models, 293
 Confined flows, 273, 521
 Confining walls, 273, 521
 Conglomerates of spheres, 109, 110
 Consolidated porous medium, 281, 282, 293, 307, 314, 326, 340
 Constant flow conditions, 209–212, 214, 337, 347, 382
 Constant pressure conditions, 211, 337, 347, 382
 Constant relaxation time, 162, 179
 Constant shear viscosity, 182, 192
 Constant viscosity, 13–15, 19
 Continuity equation, 59, 219
 Continuous phase, 203, 204, 212, 215, 216, 221, 222, 224, 225, 244, 251, 258
 Convection
 forced, 450, 465, 473, 489
 free, 456, 469, 480, 493

- mixed, 463, 471, 486
 - natural, 456, 469, 480, 493
 - Converging-diverging flow, 297, 298
 - Cooking oil, 11
 - Copper spheres, 481
 - Corn syrup, 11, 12
 - Cosmetics, 1, 4, 9
 - Countercurrent gas-liquid flow, 388
 - Creeping flow
 - approximation of, 54
 - cessation of, 76, 93, 101, 141
 - Creeping flow region
 - drag coefficients, 54, 59, 111, 112, 128, 136, 152, 168, 252
 - experimental results, 76, 116
 - mass transfer in, 473, 474, 475, 501, 502, 504
 - viscoelastic fluids in, 152, 168
 - Creeping motion
 - of bubbles, 246
 - of drops, 246
 - of spheres, 54, 59, 111, 112
 - Cross viscosity model, 20
 - Cross viscosity equation, 20
 - Cusped bubbles, 231
 - Cygan method, 566
 - Cylindrical boundaries wall effects, 521
- D**
- Dairy waste systems, 10
 - Darcian flow, 284
 - Darcy flow regime, 284
 - Darcy's equation, 284
 - Davidson-Schuler model of bubble formation, 203
 - Deborah number
 - critical, 365
 - definition, 6, 43, 44, 362
 - porous media and, 362
 - Deformation
 - of bubbles, 273
 - of drops, 273
 - elastic, 32, 125, 132
 - plastic, 132
 - rate of, 5, 53, 59, 121, 122
 - Deformation rate tensor, 59, 121, 122
 - Degradation, mechanical, 386
 - Deviatoric normal stresses, 13
 - Die swell, 33
 - Diffusion, 151
 - Diffusive heat transfer, 447, 485, 492, 495, 498, 499, 500
 - Dilatant fluids; see also Shear-thickening fluids, 15, 16, 26–28, 100, 101, 110, 218, 326, 329, 333, 336, 352, 354, 375, 382, 479, 473, 507
 - Dilute/semi-dilute drag reducing polymers, 3, 19, 28, 188–190, 218, 221, 368, 369, 372, 391, 446, 491, 494, 559
 - Dimensional analysis, 42, 57, 65, 72, 82, 105, 147, 491, 495, 574
 - Disintegration of jets and sheets, 217
 - Dispersion
 - axial, 330, 381, 422
 - drops in, 1, 3, 5, 272, 273
 - gas-liquid, 9, 32
 - in packed beds, 286, 303, 330, 337, 381, 422
 - Dissipation, 100, 252, 290, 372, 438, 450, 474, 494, 521
 - Diverging-converging flow, 297, 298
 - Drag coefficients of; also see Drag correction factor for
 - ellipsoids, 110, 158
 - form; see Pressure drag, 52, 53, 85
 - friction, 52, 53, 85
 - isometric particles, 104, 107
 - lower bound on, 66, 72–75, 77, 83, 84, 126, 138, 152, 153, 252–254
 - in porous media, 299–302, 356
 - oblates, 105, 108, 110, 111, 119
 - pressure, 52, 53, 85
 - prolates, 105, 108, 110, 111, 119
 - rods, 320
 - rising light spheres, 101
 - Schiller-Naumann drag equation, 92
 - Stokes, 52
 - upper bound on, 66, 72–75, 77, 83, 84, 126, 138, 152, 153, 252–254
 - visco-elastic fluids, 162, 168, 177, 190
 - Drag coefficient
 - bubbles, 123, 246, 257
 - cylinder, 65, 89, 90, 106, 108, 10, 112, 114, 116, 118, 119, 152, 190
 - for creeping motions of spheres, 55, 59, 110
 - disk, 104
 - drops, 248–256
 - friction, 52, 53, 85
 - free falling spheres, 59–61
 - multiparticle assemblages, 299–302, 356

- Drag coefficient (*Continued*)
 in Newtonian fluids, 52, 53
 non-spherical particles, 104
 numerical predictions of, 70
 numerical values of, 70
 of particle assemblages, 299–302, 356
 sphere, 52, 53–55, 129
 in viscoelastic fluids, 161
- Drag correction factor for
 bubbles, 248–256
 a cylinder, 65, 89, 90, 106, 108, 152, 190
 non-spherical particles, 104, 107
 a sphere, 52, 53–55, 129
- Drag force in
 shear-thinning fluids, 100
 visco-elastic fluids, 162, 168, 177, 190
 viscoplastic fluids, 123, 136, 152,
 157, 158
- Drag reducing fluids, 188, 368
- Drag reduction in external flows, 188
- Drops
 breakage of, 272
 coalescence of, 267, 271, 272
 in confined flows, 273
 creeping motion of, 246
 deformation of, 273
 ensembles of, 264
 formation of, 212
 free falling, 221, 239
 free motion of, 221, 239
 heat transfer in, 499
 hydrodynamics of, 203
 in power law fluids, 251
 shapes of
 in Newtonian fluids, 221
 in non-Newtonian fluids, 224
 size of
 in viscoelastic fluids, 212
 volume of, 212
 terminal velocity-volume behavior
 of, 239
- Dupuit equation, 293
- Dynamic parameter, 143, 144, 146, 147

E

- Eccentricity of bubbles, 224, 225, 237, 238
- Einstein's expression, 267
- Elastic deformation, 32, 125, 132
- Elastic forces, 43
- Elastic turbulence, 44

- Elasticity number, 44, 47
- Elastic stress, 370
- Electro-rheological fluids, 23
- Ellipsoidal bubbles, 222, 224, 225,
 249, 251
- Ellis model
 bubbles and, 226, 243, 253, 258
 packed beds and, 227, 229, 336, 346
 porous media and, 227, 229, 336, 346
 spheres settling in, 72
- Ellis number, 72–74, 83, 84
- Ellis viscosity model, 22
- Elongational flow, 37, 174, 192, 245, 272,
 273, 388

- Elongational viscosity, 37–40, 218
- Eorvos number, 222, 224, 276
- Equal volume sphere diameter, 106, 116,
 121, 237, 239, 310, 312
- Equilibrium
 in viscoplastic media, 123, 257
 bubbles, 123, 257
 rigid particle, 123, 129, 257
- Ergun equation, 292
- Excess pressure drop, 304, 332, 362, 364,
 375, 380
- Excess pressure loss, 304, 332, 362, 364,
 375, 382
- Extensional viscosity, 37–40, 218
- Extrapolation methods, 559
- Extremum principles, 60
- Eyring model, 19

F

- Falling ball method, 557
- Falling ball viscometry, 557
 Newtonian fluids, 557
 shear dependent viscosity and, 559, 568
 viscoelastic fluids and, 573
 yield stress, 570
 zero shear viscosity and, 560
- Falling cylinder viscometer, 578
- Falling needle viscometer, 578
- Fibrous beds, 314
- Fibrous media, 314
- Fixed beds, 279, 298
- Flow
 boundary layer, 449
 confined, 194, 273, 521
 diverging- converging, 297, 298
 in periodically constricted tubes, 360

in fibrous beds, 314
 in porous media, 286
 over a cylinder, 104, 152, 190
 over a disk, 105, 109, 115
 over a sphere, 54, 59, 100, 101, 129, 162
 over spheroidal particles, 112, 275
 rotational, 263
 Flow curves, 15, 16
 Flow induced degradation of
 polymers, 386
 Flow regimes in porous media, 286, 341
 Flow visualization, 286
 Fluid-like zones, 6, 132, 136–139, 141,
 155, 156
 Fluidization
 bed expansion behavior and, 406, 426
 liquid-solid, 397
 gas-liquid-solid, 423
 incipient, 397
 models of, 397
 with Newtonian fluids, 394, 406
 with power law fluids, 400, 406
 with visco-elastic fluids, 421
 Fluidization velocity, 398, 400, 424
 Fluidized beds
 expansion behavior of, 406, 426
 heat transfer in, 510, 511
 incipiently, 397
 mass transfer in, 510, 511
 three-phase, 423
 Forced convection, 450, 465, 473, 489
 Forchheimer equation, 306, 307
 Formation
 of bubbles, 205
 of drops, 212
 Form drag; see Pressure Drag, 85
 Free convection, 456, 469, 480
 Free falling drops, 239, 264
 Free falling spheres, 59, 136, 168, 177
 Free fall terminal velocity, 56
 Free settling velocity, 56
 Free surface cell model, 301
 Friction (see also Drag)
 in packed beds, 342
 pressure loss-throughput
 relationship, 342
 Frictional pressure drop, 288, 342,
 386, 397
 Frictional pressure gradient, 288, 342, 386,
 397
 Froude number, 43, 47, 276, 516

G

Galileo number, 56
 Gas Hold-up, 427
 Gas-liquid flow, 423, 388
 Gas-liquid-solid fluidization, 423
 Gel formation, 328, 337, 370
 Generalized Newtonian fluids(GNF),
 bubbles in, 221
 spheres in, 49, 129
 non spherical particles in, 104, 158
 Giesekus method, 561
 Giesekus fluid model, 167, 376
 GNF; see Generalized Newtonian fluids,
 14, 94, 342
 Grashof number, 457, 458, 463, 470, 484,
 488, 516
 Gravity-yield parameter, 129
 Growth of bubbles, 218

H

Hadamard-Rybczynski solution, 248
 Hagen-Poiseuille equation, 294
 Happel's cell model, 301
 Heat transfer
 in bubbles, 495
 convective, 437
 free convection, 456, 469, 480
 in drops, 409
 in fluidized beds, 510, 511
 mixed convection, 463, 471, 486
 in packed beds, 504
 in porous media, 504
 in power law fluids, 504
 in three phase fluidized beds, 511
 Hedstrom number, 141, 159
 Herschel-Bulkley model, 25
 porous media and, 327
 Hexagonal array, 320–322
 Hindered settling; see Sedimentation, 427
 Hold-up in two-phase flow, 427
 Hydraulic diameter, 293
 Hydraulic radius, 293

I

Incipient fluidization, 397
 Incipiently fluidized beds, 397
 Inertial flow regime, 193, 287, 288,
 306, 307

- Inflation of fluid cavity, 218
- Inhomogenities in
 hindered settling, 423
 fluidization, 423
- In situ* rheological characteristics, 337, 338, 382
- Integral rheological models, 41
- Interlocking of particles, 397
- Interstitial space in a porous medium, 283
- Interstitial velocity, 293
- Inviscid flow, 208, 209, 210, 290
- Isotropic porous media, 290, 300, 307, 314, 343, 348, 367, 381
- Isotropic pressure, 13
- K**
- K-BKZ fluid model, 165–167
- Kaolin slurries, 335, 353
- Kelvin model, 40, 41
- Kelvin-Voigt mode, 40, 41
- Kozeny-Carman equation, 293
- Kozeny constant, 288, 315, 316, 318, 324, 348, 392
- Kumar-Kuloor model
 of bubble formation, 207
 of drop formation, 212
- L**
- Laminar boundary layers, 449
- Laminar flow
 capillary model of, 293, 342
 porous media and, 286, 320, 341, 342
- Linear flow curves, 15, 16
- Lockhart-Martinelli parameter, 390
- Low molecular weight liquids, 11
- Lubrication flow approximation, 323, 327, 361
- M**
- Mach number, 201
- Magneto-rheology, 23, 130
- Magneto-sphere viscometer, 558
- Marangoni number, 499
- Mass transfer
 in bubbles, 493, 495
 convective, 450, 465, 473
- in drops, 499
- enhancement in, 496
- in fluidized beds, 510, 511
- gas-liquid, 511
- in packed beds, 504
- particle-liquid, 504
- in porous media, 504
- in power law fluids, 449
- rates of, 449
- from solid surfaces, 501
- from sphere ensembles, 501, 504
- from spheres
 forced convection, 473
 free convection, 480
- in three-phase fluidized beds, 510, 511
- in tube bundles, 513
- in viscoelastic fluids, 489
- viscoelasticity and, 489
- Mathematical models of
 pseudoplastic behavior, 15
 visco-elastic behavior, 32
 visco-plastic behavior, 22
- Maxwellian relaxation time, 179, 244
- Maxwell model
 porous media and, 355, 367
- Meat extract rheology, 9, 23
- Memory effects, 33, 275, 304
- Meter model, 336, 352
- Migration of particles, 163, 164, 166, 179, 194–196, 273, 274
- Minimum fluidization velocity
 two-phase systems, 397
 three-phase systems, 424
- Mixed convection, 463, 471, 486
- Mixing in packed beds, 381
- Molecular network theories, 21
- Momentum equations, 51–53, 253
- Morton number, 222, 224, 237, 277
- Multi-phase mixtures, 2, 3, 9, 45
- Multi-particle interactions, 276, 298–300, 356, 431
- Visco-elastic fluids, 196
- Visco-plastic fluids, 129
- N**
- Natural convection, 456, 469, 480
- Navier-Stokes equations, 13, 53
- Negative thixotropy, 28, 30

Negative wake, 166, 167, 176, 179, 180, 187, 192, 196, 199, 228, 232, 233, 237, 244, 263, 269

Newtonian fluids
 bubbles in, 248
 definition of, 10
 drops falling in, 248
 falling ball viscometry of, 557
 generalized, 14, 62, 65, 94, 95, 120
 in porous media, 285
 sedimentation in, 429
 settling in, 429

Newtonian viscosity, 10

Newton's law of viscosity, 10

Nonlinear flow curves, 15, 16

Non-Newtonian fluids, 14
 characterization of, 45
 definition, 14
 types of, 14

Non-shearthinning visco-elastic fluids, 182

Non-spherical particle shapes, 104, 110, 116, 158, 190, 197, 546

Normal stress
 continuity of, 247
 deviatoric, 13
 primary, 34
 secondary, 34
 in steady shearing flows, 33
 unequal, 34

No-shear condition, 239, 242, 244, 245

No-slip boundary condition, 239, 242, 244, 245, 301, 319

Nusselt number, 191, 389, 452, 453, 458, 467, 469–471, 480–483, 486

O

Oldroyd model
 falling ball viscometry and, 561
 heat transfer and, 494, 498, 499, 549
 mass transfer and, 494, 498, 499, 549

Oscillatory behavior of settling spheres, 180, 187, 188, 197, 237, 325

Oscillatory measurements, 182

Oscillatory wake, 237

Oseen drag expression, 55, 103

Overshoot in velocity, 186

P

Packed beds 279
 Blake-Kozeny model of, 293
 dilute/semidilute drag reducing polymers in, 368
 dispersion in, 381
 fibrous systems, 374
 friction in, 293
 heat transfer in, 504
 mass transfer in, 504
 miscellaneous effects, 381
 mixing in, 381
 particle shape effects, 373
 rheological parameters from flow in, 371–372
 slip effects, 384
 visco-elastic fluids in, 362
 visco-plastic fluids in, 352, 354
 wall effects, 372

Passage time distribution of particles, 100

Peclet number, 438, 446, 474, 476, 492, 495, 496, 498–501, 504, 513

Penetrometer for yield-stress measurement, 583

Periodically constricted tubes (PCT), flow in, 304

Permeability
 of packed beds, 284, 300
 of fibrous beds, 314
 increase in, 375
 of porous media, 284, 300
 reduction in, 335

Phan-Thien-Tanner fluid model, 164, 165, 180, 191, 192

PIV measurements, 75, 176, 232, 233, 244, 246, 263, 269

Plastic deformation, 132

Plastic viscosity, 22–24, 149

Polymers
 adsorption of molecules of, 381
 dilute, 368
 dilute/semidilute drag reducing, 188, 368
 extensional viscosity of, 37, 39, 192, 193, 218, 221, 272, 371
 in porous media, 352, 354, 362
 retention of, 381
 solvent interactions with viscoelastic, 186, 386, 387

Pore friction factor, 296

Pore Reynolds number, 296

- Pores**
 blind (dead end), 282
 blockage of, 331, 370, 384
 geometry of, 282, 304
 nonuniformities in, 304
 plugging of, 331, 370, 384
 size distribution of, 304, 373
 volume of, 283
- Porosity**
 bed, 283
 bulk, 283
 fluidization and, 406
 local, 372
 mean, 372
 radial, 372
- Porous media, 279**
 anomalous effects in, 381
 capillary model of, 293
 classification of, 282
 conductance of, 284
 compressible, 280, 313
 consolidated, 282–283
 Darcy flow regime, 286
 description of, 282
 dispersion in, 381
 drag in, 298
 field equations for flow through, 304
 heat transfer in, 504
 homogeneous, 282
 increase in permeability in, 375
 inertial flow regime, 287
 loss of porosity in, 331, 370, 384
 mass transfer in, 504
 Newtonian fluids in, 285
 Non-Newtonian fluids in, 326
 Visco-elastic fluids in, 362
- Powell-Eyring model, 20, 62**
- Power law fluids**
 boundary layer flow of, 449
 bubbles in, 251
 convection in, 437
 creeping sphere motion in, 59
 Darcy's law for, 361
 deficiencies of, 18
 drops in, 251
 falling ball viscometry of, 559
 in fixed beds, 342–350
 fluidization with, 400
 heat transfer in, 437
 inadequacy of, 18
 in porous media, 342
 liquid jets in, 217
 mass transfer in, 504–511
 non-spherical particles in, 109
 sedimentation in, 429
 spherical particles in, 59–85
 Prandtl number, 191, 452, 458, 459, 464, 466, 467, 469, 472, 481, 488, 514
 Pressure distribution on the surface, 95
 Pressure drag, 85
 Pressure drag coefficient, 143
 Pressure drop
 due to a settling particle, 103
 excess, 362
 fluidization and, 397
 frictional, 342
 particle shape and, 373
 two-phase, 388
 wall effects on, 372
 Pressure loss
 capillary model of, 342
 excess, 362
 for generalized Newtonian fluids, 342
 particle shape and, 373
 Pressure loss-throughput relationship
 capillary models of, 342
 conduit models of, 342
 drag theories and, 356
 empirical correlations for, 361
 field equations for, 360
 submerged object models of, 356
 Primary normal stress difference, 34
Pseudoplastic fluids
 drops in, 251
 falling ball viscometry and, 559
 heat transfer in, 437
 mass transfer in, 504–511
 mathematical models of, 15
 wall effects in, 535
Purely viscous fluids, 14
 with yield stress, 22
 flow field and, 130
 static equilibrium and, 129
 wall effects and, 535
 yield stress values and, 147
 without yield stress, 49
 wall effects and, 535
- R**
 Rabinowitsch-Mooney equation, 329, 334, 344, 347

Radial porosity distribution in a bed, 309, 311
 Rayleigh-Taylor instability, 212
 Reiner-Rivlin model, 62, 65, 112
 Relaxation times
 characteristic, 42, 43, 162, 187
 Maxwellian, 41, 42, 43
 Reynolds number for Ellis model fluids, 72, 91
 Reynolds number for power law fluids, 65
 Rheograms, 11
 Rheological behavior of
 agro-slurries, 4
 cosmetics, 4
 dairy waste slurries, 4
 egg albumen, 4
 muds, 4, 28, 31
 salvia, 4
 semen, 4
 toileteries, 4
 Rheological equations of state, 15, 28, 40
 Rheological models, 15, 28, 40
 Rheometry 45
 Rheopectic behaviour, 30
 Rheopexy, 30
 Richardson number, 463, 471, 472, 473, 486, 487
 Rising spheres, 101
 Rod bundles, flow and heat transfer, 314, 374, 513
 Rod climbing effect, 33
 Rolling ball viscometry for
 Newtonian fluids, 574
 non-Newtonian fluids, 574–576
 Rotating sphere viscometer, 576

S

Schiller-Naumann drag formula, 92
 Schmidt number, 449, 452, 458, 459, 464, 466, 467, 469, 472, 481, 488, 514
 Secondary normal stress difference, 34
 Second order fluid, 163, 164, 166, 167, 169, 176, 191, 196, 197, 201
 Sedimentation in
 Newtonian fluids, 53, 105
 non-Newtonian fluids, 59, 100, 109
 power law fluids, 59, 109
 slurries, 429
 Segregation in
 Fluidization, 423
 Sedimentation, 423
 Settling under
 dynamic conditions, 128
 static conditions, 53, 59, 100, 105, 109
 Settling velocity
 time-dependent, 149, 185
 Shapes
 of bubbles
 in Newtonian fluids, 221
 in non-Newtonian fluids, 224, 233, 234
 of drops
 in Newtonian fluids, 221
 in non-Newtonian fluids, 224, 236
 Shear rate
 average, 89, 564, 569, 575, 582
 characteristic, 89, 564, 569, 575, 582
 effective, 89
 falling ball viscometry and, 535, 564, 569, 582
 surface average, 569
 at wall, 343
 Shear rate dependent viscosity, 15–28
 Shear stress
 average, 564, 569, 575, 582
 at cell surface, 301
 Shear-thickening fluids, 15, 26–28, 49, 100, 101, 110, 332, 338
 Shear-thinning fluids, 59, 251, 264, 342, 374, 398–427, 449–486, 504–513, 535, 548, 552, 559
 Shear wave velocity, 170, 191, 244
 Sherwood number, 191, 389, 452, 453, 458, 467, 469–471, 480–483, 486
 Sisko model, 62
 Slip effects in beds, 384
 Slip line theory, 131, 133, 134, 152, 153
 “Soup-bowl” effect, 33
 Specific surface area, 285
 Spheres
 bulk porosity for, 283, 307
 cessation of motion of, 129
 creeping motion of, 59, 100, 129, 162
 free fall velocity for, 93, 162
 free settling of, 93, 162
 in generalized Newtonian fluids, 59, 100, 101, 136, 162
 interactions between, 194, 427
 mass transfer in, 473
 regular arrays of, 302
 settling of, 53, 59, 100, 105, 109
 shear rate around, 89

Spheres (Continued)

- steady motion of, 59
- terminal velocity of, 93, 162
 - in viscoplastic fluids, 129
 - in dilatant fluids, 100
 - in visco-elastic fluids, 162
 - transient motion of, 185
 - drag reducing fluids and, 188
- Sphere-to-tube diameter ratio, 521
- Sphericity, 106, 108, 117
- Spriggs model, 178, 336
- Stagnation point, 175
- Standard drag curve, 53, 56
- Static equilibrium, 129
- Strain-hardening, 39, 40
- Stress relaxation, 148, 182
- Submerged object models, 298, 356
- Surface average particle diameter, 290
- Surface roughness, 293
- Surface tension, 209, 210, 217, 220, 225, 230, 238, 243, 244, 274, 426, 427
- Sutterby fluid model, 19, 20, 63, 75, 77
- Sutterby number, 76
- Synovial fluid, 4, 10, 33

T

- Tangential stress, 247
- Tangential velocity, 247
- Terminal velocity
 - effect of orientation, 104, 152, 194
 - effect of shape, 104, 152, 194
 - of cylinders, 152, 190
 - of non-spherical particles, 104, 152, 194
 - of spheres, 93, 129, 162
- Terminal velocity-volume behavior of bubbles, 239
- Thixotropy, 28–32, 151
- Three-phase fluidized bed (TPFB)
 - systems, 423, 511
- Time-dependent systems, 28
- Time-independent systems, 15
- Tortuosity factor, 284, 285, 289, 293, 294, 296, 297, 318, 345
- Transient flow, 57, 95
- Transitional flow, 289, 353, 354
- Transverse flow
 - cylinder, 109, 152, 190
 - plate, 157
- Trouton ratio, 33, 38–40, 42
- Tube bundles, 314, 374, 513
- Tubeless siphon, 33

- Turbulence, elastic, 44
- Turbulent flow, 287–290, 293, 295, 297, 341, 353, 354, 441, 442, 449, 456, 462, 463, 494, 523, 526, 532
- Two-phase flow in packed beds, 388

U

- Unconsolidated porous media, 281, 284, 290, 292, 342, 348, 381
- Unsteady motion, 57, 95

V

- Vane method for yield stress, 46
- Variational principles, 60, 62–64, 72, 100, 126, 133, 138
- Velocity
 - fluidization, 397, 424
 - free fall, 56, 94
 - free rise, 239
 - free settling, 56
 - minimum fluidization, 397, 424
 - over-shoot in, 186
 - sedimentation, 427
 - shear wave, 170, 191, 244
 - superficial, 293, 294, 301, 364, 379, 393, 420–422, 424
 - terminal, 93
 - time dependent, 57, 149, 185, 186
- Velocity profile, 71
- Velocity-volume behavior of bubbles, 239
- Visco-elastic fluids
 - bubbles in, 258
 - characteristic time for, 42, 43, 162, 187, 573
 - convection and, 489
 - drag coefficient and, 168, 190, 194
 - drag reduction in, 188
 - drops in, 258
 - fluidization with, 421
 - mass transfer in, 489
 - in porous media, 362
 - sedimentation in, 421
 - wall effects in, 544
- Viscometry
 - capillary, 45
 - falling ball, 557
 - falling cylinder, 578
 - falling needle, 578
 - rolling ball, 574

rotational sphere, 576

Viscoplastic fluids

- bubbles in, 257
- cylinders in, 152
- drag force in, 136, 152
- drops falling in, 257
- interaction between two spheres, 194, 196, 201
- porous media flow, 352
- spheres in, 136
- thixotropic behavior of, 151
- wall effects in, 542

Viscosity

- at elevated pressure, 91
- at elevated temperature, 19
- Carreau equation for, 21, 64, 65, 74, 76
- Ellis equation for, 22
- elongational, 37, 38
- falling ball method for, 557
- falling cylinder method for, 578
- falling needle method for, 578
- Newtonian, 13
- Newton's law of, 10
- plastic, 22, 24, 149
- rolling ball method, 574
- temperature dependent, 19
- zero shear; see zero shear viscosity, 15

Viscosity values for common substances, 12

Viscous dissipation, 438, 450, 474, 494

Voidage (see Porosity), 283

Void volume, 283

Voigt model, 40

Volume averaging of equations, 306

Vortex shedding, 113, 118

W

Wake characteristics, 55, 95, 102, 113, 175

Wall correction factor, 522

Wall effects, 521

- anomalous, 381
- in confined flows, 273
- in falling ball viscometry, 523, 525
- in porous media, 307, 372
- in visco-elastic fluids, 544
- in visco-plastic fluids, 542

Wall factor, 522

Walters fluid model, 163, 164

Weber number, 224, 238, 249, 251

Weissenberg number, 6, 44, 84, 181, 194, 199, 259, 362, 376, 380

Williamson model, 63, 65, 85

Worm-like micellar solutions, 180, 198, 199, 231

Y

Yield-gravity parameter, 129, 130, 141, 160

Yield stress

- Bingham, 24
- Casson, 25
- falling ball viscometry, 557, 568, 576, 583
- measurement of, 576

Young's modulus, 32

Z

Zero shear viscosity

- determination of, 560
- extrapolation methods for evaluation of, 560
- falling ball viscometry, 557

Zero vorticity cell model, 300–301