

Index

- active impurities. *See* impurities, active nucleation sites; nucleation sites, active
- activity coefficient, 69
- adiabatic pipe flow 136–143. *See also* countercurrent flow limitation
 - for air–water, 140, 142
 - bubbly flow and, 136
 - CCFL in, 228, 285–305
 - churn flow and, 137
 - co-current horizontal flow and, 139–143, 221–225
 - horizontal, flow regimes, 139–143
 - horizontal, flow regime maps, 143–144
 - for bubbly flow, 136
 - slug flow and, 137
 - vertical upward, 136
- air–water flow regimes
 - adiabatic pipe flow and, 140, 142
 - in minichannels, 316–319
 - in rectangular channels, 310, 311
 - in triangular channels, 309
- annular-dispersed flow regimes
 - CCFL and, 300
 - conservation equations in, 493
 - in dryout, 493–495
 - ideal, 176
 - in horizontal flow, 139
 - in inclined tubes, 233
 - internal flow condensation and, 603, 604–607
 - two-phase mixtures, 137
- annular flow, wall friction, 616–617
- annular-slug flow, 512
- Antoine’s equation, 58
- Archimedean spiral coil, 155
- Armand’s flow parameter, 213
- averaging. *See* flow area averaging; time averaging, in two-phase mixtures
 - axisymmetric disturbances, 78–80
- azeotrope, 17
- azeotropic mixtures, 17
- Bénard cellular flow, 46–50
- binary mixtures
 - azeotropic, 17
 - pool boiling, 389–400
 - nucleate boiling correlations, and, 392–396
 - critical heat flux, and, 396–400
- Fick’s law for, 14
- near-azeotropic, 17
- phase diagrams for, 15–17, 391
- zeotropic, 15–17
- binary systems
 - phase diagrams for, 15–17, 391, 583
- Biot number, 46
- Blasius’s correlation, 28
- boiling. *See* boiling water reactors; film boiling; flow boiling; flow boiling, size/; flow boiling, subcooled; liquid-deficient film boiling; minimum film boiling; nucleate boiling; onset of nucleation boiling point; pool boiling; pool boiling, hydrodynamic theory of; stable film boiling regimes; transition boiling regimes
- boiling water reactors (BWRs), 210
 - choking and, 668
 - flow boiling and, 444
 - flow regimes, and, 145
 - nuclear reactor design and, 486
- Bond number, 46
- Bowring’s pumping parameter, 426
- bubble(s), 83. *See also* bubble ebullition; bubble nucleation; bubble point lines; bubble train
 - flow regimes; capillary bubbly flow; confined bubbly flow; heterogeneous bubble nucleation; isolated bubbly flow; plug-elongated bubbles flow regimes
- coalescence and, 112–113
- growth of, in superheated liquids, 87–89
- Laplace–Kelvin relations and, 90
- nucleation of, 87
- oscillation modes of, 84–87
- Rayleigh equation for, 88–89
- Rayleigh equation, extended, for, 88, 89
- shape regimes for, 83
- in turbulent eddies, 109
- bubble ebullition, 362, 366–369
 - bubble departure in, 367–368
 - cavity nucleus and, 364, 416
 - configurations in OSV, 422
 - growth period for, 367

760 Index

- bubble ebullition (*cont.*)
 - in micro/minichannels, 667–672
 - waiting periods in, 368–369
- bubble nucleation, 27, 668
 - heterogeneous, 361–366
- bubble point lines, 16
- bubble train flow regimes, 335–346
- bubbly flow
 - adiabatic pipe flow and, 136
 - capillary, 309
 - confined, 512
 - isolated, 512
 - minichannels, 307, 308
- buoyancy forces, 49
- BWRs. *See* boiling water reactors
- capillary bubbly flow, 309
- capillary waves, 74
 - in Rayleigh–Taylor instability, 77
- cavity nucleus
 - angle definitions for, 364
 - bubble ebullition and, 364, 416
- CCFL. *See* countercurrent flow limitation CFD codes; computational fluid dynamic codes
- channels, conventional. *See also* fluoropolymer channels; microchannels; minichannels; polyethylene channels; polyurethane channels; Pyrex channels
 - critical flow in, 667–672
 - microchannels *v.*, differences between, 116–117
- channels, rectangular, 319–324
 - air–water flow regimes in, 308, 322, 323
 - DFM and, 321
 - horizontal, 320–324
 - inclined/vertical, 320–322
 - two-phase flow in, 322, 323
- channels, triangular, 309
- Chapman–Enskog model, 23–25
- chemical species mass conservation, 10
- CHF. *See* critical heat flux regimes
- choking. *See also* RETRAN codes
 - bubble nucleation and, 668
 - BWRs and, 668
 - critical flow models for, 649–656, 658–667
 - delayed flashing and, 668
 - homogeneous equilibrium isentropic model for, 649–651, 668
 - interphase slips in, 648–649
 - in micro/minichannels, 667–672
 - non-equilibrium mechanistic modeling for, 672–674
 - omega parameter method, 658–667
 - physics of, 643–644
 - PWRs and, 668
 - RETRAN codes in, 656–658
 - sound velocity and, in single-phase fluids, 644–645
 - in two-phase flow mixtures, 647–674
- chugging, 447
- churn flow, 137, 307
- CISE correlation, 213, 314
- CISE-4 correlation, 481
- Clapeyron’s relations, 5
 - in bubbles, 88
- closure relations, 7–10
 - constitutive relations and, 8
 - transfer relations and, 8
- coalescence, 112–113
 - aerosol population models and, 113
 - bubbles and, 113
 - CHF and, 473
 - interfacial area transport equations and, 238
- co-current horizontal flow
 - adiabatic pipe flow and, 139–143
- Colebrook–White correlation, 250, 328
- computational fluid dynamic (CFD) codes, 162
- condensation, 560–586. *See also* direct contact condensation; internal flow condensation; laminar film condensation
 - binary fluids, 583–586, 634–638
 - direct contact, 562–563, 609–614
 - dropwise, 562
 - film, 562
 - fog formation and, 582–583
 - heat transfer correlations for
 - pure saturated vapor, internal flow, 596–608
 - with noncondensables, 608–609
 - helical flow passages, in, 631–634
 - heterogeneous, 561
 - homogenous, 560–561
 - on horizontal pipes, 574–577
 - as interfacial mass transfer, 53–57
 - interfacial shear and, 569–571
 - internal flow, 590–638
 - laminar film, 565–571
 - in noncondensable presence, 566, 578–581, 608–609
 - of pure vapors, 564
 - small channels, in, 627–631
 - flow regimes, 623–625
 - pressure drop, 625–627
 - heat transfer, 627–631
 - subcooling effects of, 578
 - thermal resistances in, 563–565
 - turbulent film, 571–573
 - two-phase flow regimes, 591–596
 - wavy-laminar, 571–573
- confined bubble flow, 512
- conservation equations. *See also* mass conservation equations; ordinary differential equations
 - in Annular-Dispersed Flow regime, 494–495
 - as ODEs, 188–195
 - one-dimensional, numerical solutions of, 195
- constants, physical, 700
- constitutive relations, 8
- contact angles, 41–43
 - dynamic, 42–43
 - hysteresis in, 42–43

Index

761

- surface wettability and, 42
- variations of, 43
- Young–Dupré equations and, 42
- control volume
 - energy terms homogeneous flow, for, 172
 - in homogenous mixture models, 170, 171
 - liquid/vapor, 180
 - for mass conservation equations, 170, 175
- conventional channels. *See* channels, conventional
- correlation of Akers, 599
- correlation of Bowring, 480–481
- correlation of Bromley, modified, 384
- correlation of Caira, 481–482
- correlation of Chen, 433–434
 - suppression factors in, 434
- correlation of Chen, flow condensation, 598
- correlation of Cooper, 373
- correlation of Dobson and Chato, 599–600
- correlation of Forster and Zuber, 376
- correlation of Gorenflo, 373–374
- correlation of Groeneveld, 503
- correlation of Gungor and Winterton, 434–435
- correlation of Kandlikar, 434
- correlation of Liu and Winterton, 435
- correlation of Marsh and Mudawar, 417
- correlation of Rohsenow, 370–372
- correlation of Shah, CHF, 482–483
- correlation of Shah, flow condensation, 599, 600–602
- correlation of Soliman *et al.*, condensation, 597
- correlation of Steiner and Taborek, 435–436
- correlation of Unal, 419
- correlation of Wallis, 290
- correlations of Stephan and Abdelsalam, 372–373
- Couette flow film models, 32, 33–34
 - in interfacial mass transfers, 62, 63
 - interfacial shear and, 573–574
 - noncondensable presences and, 578–581
- countercurrent flow limitation (CCFL), 228, 285–305
 - in adiabatic pipe flow, 228, 285–305
 - annular, 300
 - correlation of Wallis in, 290, 297, 299
 - deflooding point in, 290
 - envelope method analysis in, 299, 300–302
 - flooding curve in, 287, 290. *See* flooding line
 - flooding line in, 287
 - flow reversal point in, 289
 - hanging film phenomenon and, 303
 - in horizontal/inclined channels, 299–300
 - LB-LOCA and, 296
 - patterns in, 289
 - in perforated plates, 293–296
 - phase change effects on, 300
 - in porous media, 296
 - PWRs and, 298
 - in rectangular/vertical channels, 296
 - reflux phenomenon in, 285
 - separated-flow momentum equations and, 300–302
 - Tien–Kutateladze flooding correlation in, 291
 - vertical flow passages in, correlations for, 290–293
 - zero liquid penetration point in, 289
- critical discharge rates, 645–646
- critical flow, 643. *See also* choking; critical flow model (Henry/Fauske); critical flow model (Moody); critical flow model, isenthalpic
 - models for, 649–656, 658–667
 - pressure profiles in, 669
- critical flow model (Henry/Fauske), 653–655
 - extended, 656
 - RETRAN codes and, 656–658
 - temperature profiles in, 654
- critical flow model, omega parameter, 658–667
- critical flow model (Moody), 651–653
- critical flow model, isenthalpic, 656
- critical heat flux (CHF) regimes, 358, 372. *See also*
 - critical heat flux regimes, post
 - binary liquid mixtures, in, 396–400, 504–505
 - CISE-4 correlation in, 481
 - coalescence and, 474
 - correlation of Bowring and, 480–481
 - correlation of Caira and, 481–482
 - correlation of Shah and, 482–483
 - diameter effects in, 478, 545–546
 - DNB and, 472
 - DNBR and, 488
 - dryout and, 405, 475
 - exit quality effects on, 477, 478
 - flow boiling and, maps for, 473
 - flow oscillations in, 548
 - global conditions correlations in, 479–480
 - hydrodynamic theory of boiling and, 71
 - in inclined/horizontal systems, 495–497
 - inlet conditions correlations in, 479
 - KfK correlation and, 487
 - liquid superheat and, 473
 - local conditions correlations in, 479
 - mass flux effects on, 477
 - mechanisms for, 472–475
 - MFB and, 502
 - in minichannels, 545–556
 - models for, 549–556
 - in nonuniformly heated channels, 486–487, 498–500
 - in nuclear reactor design, 485–488
 - oscillation modes and, 522–525
 - parametric effects on, 377–379
 - parametric trends for, 475–479
 - post-CHF regimes and, 500–501
 - PWRs and, 485
 - rising jets schematics in, 377
 - rod bundles and, 487–488
 - saturated flow boiling and, 431–444
 - shape/size corrections for, 377–379
 - in slug/plug flow, 475
 - in small channels, 515, 545–556
 - subcooled liquid correlations in, 488–493
 - surface size effects on, 377–379

762 Index

- critical heat flux (CHF) regimes (*cont.*)
 - table look-up method for, 503–504
 - in uniformly heated channels, 476
 - upward flow correlations in, 479–488
 - vapor formation and, 473
- critical heat flux (CHF) regimes, post, 500–501
 - ECCS and, 500
 - LB-LOCA and, 500
 - liquid-deficient film boiling as, 503
 - stable film boiling as, 502
 - transition boiling as, 502
- curved flow Passages, 149–157
 - two-phase flow, 149–157
 - bends, and 150–153
 - flow reversal, and, 152
 - helicoidally coiled passages, and, 154–157
- Dalton's law, 12
- DC condensation. *See* direct contact condensation
- deflooding, 290
- Deissler eddy diffusivity model, 30
- density-wave oscillations
 - dynamic instabilities and, 447
 - velocity of, 448
- departure from nucleate boiling (DNB)
 - CHF regimes and, 472
 - flow boiling and, 473, 474
 - Helmholtz stability theory and, 491
 - mechanistic models for, 490–493
 - model of Celata, 492–493
 - model of Katto, 490–492
 - OSV correlations in, 492
 - vapor blankets and, 473
- departure from nucleate boiling ratio (DNBR), 488
- dew point lines, 16
- DFM. *See* drift flux model
- diffusion models, for two-phase mixtures, 167. *See also* drift flux model
- DFM, 167, 199–213, 219
- diffusivity. *See also* mass diffusivity
 - binary surface, 45
- direct contact (DC) condensation, 562–563, 609–614
 - OC-OTEC and, 614, 641
 - on subcooled liquid droplets, 610–611
 - on subcooled liquid jets, 611–614
- disjoining pressure, 50–52
 - in Lennard-Jones model, 50
- dispersed-droplet flow regimes, 138
- dispersion equations, 76
- dissipation range, 107
- DNB. *See* departure from nucleate boiling
- DNB model of Celata, 492–493
- DNB model of Katto, 490–492
- DNBR. *See* departure from nucleate boiling ratio
- drift flux model (DFM), two-phase mixtures, 167, 199–213
 - BWRs and, 210
 - co-current slug flow in, 203
 - concentration parameters in, 200
 - concept of, 199–202
 - countercurrent slug flow in, 203
 - distribution parameter, 200
 - gas, 200
 - gas drift velocity in, 200
 - minichannels and, 212–213, 341
 - pipe flow parameters in, 203–210
 - PWRs and, 210
 - rod bundle parameters in, 210–212, 219
 - SB-LOCA and, 210
 - slip ratio in, 201
 - slip velocity in, 201
 - subcooled flow boiling and, 424–425
 - 2FM v., 202–203
 - two-phase distribution coefficient in, 200
 - two-phase flow model equations and, 202–203
 - in two-phase flow regimes, 225–227
- dropwise condensation, 562
- dryout
 - annular-dispersed flow regimes in, 493–495
 - CHF and, 405, 475
 - in flow boiling, 405
 - mechanistic models for, 493–495
 - in saturated flow boiling, 442
- dynamic contact angles, 42–43
- dynamic instabilities, 447
 - density-wave oscillations and, 447
- ECCS, 500. *See* emergency core cooling system
 - eddies; turbulence, in eddies emergency core cooling system (ECCS)
- energy conservation equations
 - in HEM models, 172–173
 - mixture, separated flow, 180–183
- envelope method analysis, 299, 300–302
- Eötvös numbers, 84
- equilibrium states
 - Clapeyron's relations in, 5
 - P - v - T surfaces and, 4
 - phases in, 3–5
 - of single phase flow, 3
 - triple point as, 3
 - for vapors, 51–52
- Euler's equations
 - in linear stability analysis models, integration of, 71
 - ODEs and, 195
- evaporation, 53–57
- falling films, 123–126
 - on flat surfaces, 123
 - heat transfers for, 127–128
 - Kapitza number and, 122, 125
 - linear stability analysis, 125
 - mass transfer processes in, 124, 130
 - mechanistic modeling, 129–131
 - modeling of, mechanistic, 129–131
 - Reynolds number in, 122, 124
 - roll waves in, 125

Index

763

- small-amplitude waves in, 125
 - thermally developed flow for, 130
 - turbulence for, 127–128
 - turbulent eddies and, 130
 - liquid diffusion and, 25
 - film boiling, 379–386
 - on horizontal surfaces, 379–381
 - on horizontal tubes, 385
 - modified Bromley correlation and, 384
 - thermal radiation effects in, 385–386
 - on vertical surfaces, 382–384
 - film condensation, 562
 - finely dispersed bubbly flow regime, 138, 139, 223–224
 - flooding. *See* countercurrent flow limitation
 - flow area averaging, 100–101
 - flow boiling, 404–471, 509–559. *See also* flow
 - boiling, saturated; flow boiling, subcooled; two-phase flow instability
 - buoyancy effects on, 409–410
 - BWRs and, 444
 - CHF and, maps for, 473
 - curves in, 411
 - DNB and, 407, 408
 - dryout in, 405
 - forced, regimes, 404–410
 - heat transfers in, 412–413, 449–453, 456–459, 531–544
 - in horizontal channels, 440–444
 - in microchannels, 509–511, 559
 - in minichannels, 509–511, 559
 - NVG and, 413
 - ONB and, 404, 405, 408, 413–418
 - OSV and, 413, 419–423
 - partial, 429–430
 - saturated, 431–444
 - in small channels, 509–559
 - stratified regimes for, definitions of, 442
 - subcooled, hydrodynamics of, 424–429
 - two-phase flow instability and, 444–449
 - two-phase patterns for, 512–525
 - flow boiling curves, 411
 - flow boiling, saturated, 431–444
 - correlation of Chen and, 433–434
 - correlation of Gungor and Winterton and, 434–435
 - correlation of Kandlikar and, 434
 - correlation of Liu and Winterton and, 435
 - correlation of Steiner and Taborek and, 435–436
 - dryout in, 442
 - heat transfers and, 432–440
 - in horizontal channels, flow regime dependent, 440–444
 - flow boiling, subcooled
 - Bowring's pumping parameter and, 426
 - curves in, 411
 - DFM and, 424, 425
 - fluid-surface parameters and, 431
 - heat transfer, 430–431
 - hydrodynamics of, 424–429
 - NVG and, 413
 - OSV and, 413
 - pressure drops in, 429
 - pumping effect and, 426
 - 2FM and, 424–425
 - void generation and, 426–427
 - flow regimes. *See* bubbly flow; capillary bubbly flow; churn flow; frothy slug-annular; laminar flow; pseudo-slug flow; slug flow; wavy-annular flow
 - flow reversal point, 289
 - fog, 560, 582–583
 - form pressure drops, 246
 - Fourier's law
 - in gas–liquid interfacial phenomena, 62
 - heat transfers and, 31
 - in transport equations, 8
 - fugacity, 67, 68
 - fugacity coefficient, 68
 - fractions. *See* phase volume fractions; void fractions
 - frothy slug-annular flow, 308
 - fundamental void–quality relation, 103
 - gas drift velocity, 200
 - gaskinetic theory (GKT), 21–25
 - Chapman–Enskog model for, 24–25
 - Lennard–Jones model for, 24
 - Maxwell–Boltzmann distribution in, 22
 - molecular effusion in, 23
 - gases. *See also* gas kinetic theory
 - equilibrium states for, 3
 - ideal, 690
 - selected, binary diffusion coefficients of, 695
 - sparingly soluble, in interfacial mass transfers, 59–61
 - gas–liquid interfacial phenomena, 38–90. *See also*
 - contact angles; Kelvin–Helmholtz instability; mass transfers; mass transfers, interfacial; Rayleigh–Taylor instability; surface tension, in gas–liquid interfacial phenomena; thermocapillary; vapor–liquid systems
 - contact angles in, 41–43
 - disjoining pressure, 50–52
 - Fourier's law in, 62
 - Kelvin–Helmholtz instability, 75–80
 - linear stability analysis models for, 125
 - mass transfers, 53–61
 - Rayleigh–Taylor instability, 77, 81–83
 - surface-active impurities' effect on, 45
 - surface tension in, 38–41
 - thermocapillary effects in, 46
 - vapor–liquid interphase, 51–52, 53–61
- general dynamic equation. *See* population balance equation
- geysering, 447
- Gibbs free energy, 39
 - in vapor–liquid systems, 51
- Gibbs rule, 15

764 Index

- GKT. *See* gaskinetic theory
 gravity waves, 74
- Hadamard–Rybczyński creep flow solution, 49
 hanging film phenomenon, 303
 heat transfers, 31–36. *See also* heat transfers, flow boiling
 condensation correlations for, 596–608
 Couette flow film model and, 32, 33–34
 in flow boiling, 408, 409–410, 429–431, 432–440
 Fick's law and, 31, 34
 Fourier's law and, 31, 34
 in internal flow condensation, 596–608, 614–631
 for laminar films, 127–128
 liquid-deficient regimes for, 503
 mass transfer analogy and, 34–35
 molar flux-based formulation and, 33–34
 naphthalene and, 35
 in nucleate boiling, 370–375, 437
 Ranz–Marshall correlation and, 35
 saturated flow boiling and, 432–440
 in single phase flow, 115
 subcooled flow boiling and, 413, 430–431
 heat transfers, flow boiling, 410, 411, 429–431, 432–444
 binary liquid mixtures, in, 449–453
 in helically coiled tubes, 456–459
 in minichannels, 531–544
 mechanisms for, in small flow passages, 532–536
 helically coiled flow passages, 453–459
 helical coil number, 271
 Helmholtz free energy, 39, 67
 Helmholtz instability, 376
 Helmholtz stability theory, 491
 HEM. *See* homogenous-equilibrium mixture model
 Henry number, 59
 Henry's constant, 59, 696
 Henry's law, 59
 heterogeneous bubble nucleation, 361–366
 active nucleation sites and, 361–366
 heterogeneous condensation, 560–561
 HM. *See* homogeneous mixture models, for two-phase mixtures
 Homogeneous-equilibrium isentropic model, 649–651, 668
 homogeneous condensation, 560–561
 homogeneous mixture (HM) models, for two-phase mixtures, 167
 control volume forces in, 171
 HEM, 104, 167, 169
 pressure drops in, 247–250, 264
 homogeneous-equilibrium mixture (HEM) model, 104, 167, 169
 energy conservation equations in, 172–173
 mass conservation in, 170
 momentum conservation in, 170–172
 pressure drops in, 247–250
 thermal/mechanical energy equations in, 173
- horizontal flow
 in adiabatic pipes, 139–143
 CCFL and, 299–300
 in CHF, 495–497
 condensation in, 574–577
 drainage during, 139
 flow boiling and, 410
 internal flow condensation correlations for, 599–608, 627–631
 laminar film condensation and, 574–577
 MFB and, 386–388
 in rectangular channels, 310, 311
 saturated flow boiling and, 432–440
 horizontal surface, film boiling, 379–381
 hydrodynamic stability theory, 71
 hydrodynamic theory of boiling, 71, 306–354, 360. *See also* pool boiling, hydrodynamic theory of
 hysteresis, 42–43
- impurities, active
 gas-liquid interfacial phenomena and, effect on, 44–46
 surface tension and, 44–46
 inertial size range, 107
 instantaneous conservation equations, 7–15
 interfacial area transport equations, 235–236
 coalescence and, 238
 one-group, 237
 simplification of, 236–238
 two-group, 238–242
 interfacial mass transfers. *See* mass transfers, interfacial
 interfacial shear, 573–574
 condensation and, 569–571
 Couette flow film models and, 573–574
 in internal flow condensation, 616
 internal flow condensation, 590–638
 annular flow models for, 603, 614–619
 annular flow regimes and, 594, 596, 597, 603, 614–619, 624
 correlation of Akers for, 599
 correlation of Dobson and Chato for, 599–600
 correlation of Shah for, 599, 600–602
 horizontal flow correlations for, 599–608
 horizontal flow regimes for, 592–596
 interfacial shear stress in, 616
 method of Cavallini for, 604–606
 method of Kosky and Staub for, 603–604
 method of Moser for, 606–607
 in micro/minichannels, 619–631
 noncondensable effects on, 565, 578–581
 pressure drops in, 619–631
 semi-analytical models for, 603–608
 in two-phase flow regimes, 591–596
 vertical flow correlations for, 597–599
 wall friction and, 616–617
 interphase balance equations, 163–166
 jump conditions in, 165
 inverted-annular flow regimes, 138

Index

765

- isolated bubbly flow, 512
- isotropic turbulence, 106
 - three-dimensional spectrum in, 107
- Kapitza number, 122
- Kelvin–Helmholtz instability, 75–80
 - dispersion equations in, 76
 - neutral conditions in, 77
 - in two-phase flow regimes, 229
- KfK correlation, 487
- Knudsen numbers 114
- Knudsen rates, 54
- Kolmogorov’s theory, 106, 107, 108
- Kutateladze number, 291
- laminar film condensation, 565–571
 - on horizontal tubes, 574–577
 - Nusselt’s integral analysis on, 566–569
- laminar flow
 - in microchannels/minichannels, 325, 334–335
- Laplace length scales, 77
 - Laplace–Kelvin relations, 52
- large-break loss of coolant accident (LB-LOCA), 500
 - countercurrent flow limitation and, 296
- LB-LOCA. *See* large-break loss of coolant accident
- Ledinegg instability, 445
- Lennard-Jones potential model, 24, 50
 - collision diameter, for diffusion in liquids 26
 - collision integrals for, 699
 - model constants for, 698
- linear stability analysis models, 125
 - Euler’s equation integration in, 71
 - hydrodynamic stability theory, 71
 - for laminar films, 125
 - two-dimensional surface waves in, 45, 71–72
- liquid diffusion, 25
 - Fick’s law and, 25
 - Stokes–Einstein expression and, 26
- liquid films. *See* laminar films
- liquid slugs
 - adiabatic pipe flow for, 137
- liquid-deficient film boiling regimes, 500
- liquid-deficient heat transfer regimes, 503
- LOCA. *See* loss of coolant accident
- local instantaneous equations, 163–166
- Lockhart–Martinelli method, 250–251
 - Martinelli parameter in, 250, 251
- loop seal effect, 151
- loss of coolant accident (LOCA), 388
- Marangoni effect, 44
 - thermocapillary effects and, 46
- Marangoni number, 46
- Martinelli parameter, 250, 251
- Martinelli–Nelson method, 255
- mass conservation equations, 9
 - control volumes for, 170, 175
 - in HEM model, 170
 - in separated flow models, for two-phase mixtures, 175–177
- mass diffusivity, for species, 9
 - mass flux in, 9
 - molar flux in, 9, 14–15
 - transfers for, 9
 - transport properties and, 21
- mass flux
 - CHF and, effects on, 477
 - for critical flow model (Moody), 653
 - Fick’s law for, 14
 - in mass species diffusivity, 9
 - in momentum conservation equations, 9
 - phasic, 101
 - two-phase mixtures, 101
- mass fractions, 11
 - profiles, 60
- mass transfer, 9, 31–36. *See also* mass transfers, interfacial
 - analogy, heat and, 34–35
 - heat transfers and, 31–36
 - interfacial, 53–61
 - naphthalene and, 35
 - Ranz–Marshall correlation and, 35, 36
- mass transfers, interfacial, 53–61
 - condensation as, 53–57
 - in Couette flow film models, 62, 63
 - evaporation as, 53–57
 - Henry number in, 59
 - Henry’s law for, 59
 - Knudsen rates in, 54
 - oscillation modes and, 86
- Maxwell–Boltzmann distribution, 22
- metastable states, 5–7
 - spinodal lines in, 6
 - spontaneous phase change within, 6–7
 - statistical thermodynamic predictions within, 5
- method of Cavallini, 604–606
- method of Chisholm, 625
- method of Kosky and Staub, 603–604
- MFB. *See* minimum film boiling
- microchannels, 114
 - bubble ebullition in, 509
 - choking in, 667–672
 - conventional channels v., differences between, 116–117
 - flow boiling in, 509–511, 559
 - internal flow condensation in, 619–631
 - laminar flow in, 325
 - single-phase flow regimes in, 115–117, 325
 - surface wettability in, 311, 317
 - thin annuli, 323–324
 - two-phase flow regimes in, 316–319
- minichannels, 114
 - air–water flow regimes in, 316–319
 - bubble ebullition in, 509
 - bubble train regimes in, 335–346
 - bubbly flow in, 307
 - Chisholm method for, 328
 - choking in, 667–672

766 Index

- minichannels (*cont.*)
 - churn flow, 307
 - DFM and, 314
 - flow boiling heat transfers in, 509–544
 - flow boiling in, 509–511, 559
 - frothy slug-annular flow in, 308
 - geometry of, as factor for, 325
 - with hard inlet conditions, flow regimes for, 526–528
 - homogeneous flow models in, 327–328
 - ideal annular flow in, 334–335
 - internal flow condensation in, 619–631
 - isolated bubble flow in, 512
 - laminar flow in, 325, 335
 - parallel channel instability in, 524–525
 - pressure drop oscillations in, 522–524
 - pressure drops in, 324–331, 342–343
 - pseudo-slug flow in, 307
 - schematics for, 510, 511, 523
 - slug flow in, 307, 335
 - Taylor flow regimes in, 335–346
 - two-phase flow regimes in, 307–314
 - vapor backflow in, 549
 - void fractions in, 314–316
 - wavy-annular flow in, 308
- minimum film boiling (MFB), 359, 386–388, 502
 - on horizontal surfaces, 386–388
 - TMFB correlations and, 386–388
- mixture energy conservation equations,
 - homogeneous two-component, 175
- mixture mass conservation equations,
 - homogeneous two-component, 175
- mixture momentum conservation equations,
 - homogeneous two-component, 175
- mixtures. *See* azeotropic mixtures; binary mixtures; near-azeotropic mixtures; single-phase multi-component mixtures; vapor-noncondensable gas mixtures; zeotropic mixtures
- modified Bromley correlation. *See* correlation of Bromley, modified
- molar concentrations, 11
- molar flux, 14–15
 - heat transfers and, 33–34
- mole fractions, 11
- molecular effusion, 23
- momentum conservation equations, 9
 - in HEM models, 170–172
 - mass flux in, 9
 - in separated flow models, for two-phase mixtures, 175–184
 - in transport equations, 10
- momentum density, 264
- Morton numbers, 84
- multi-fluid models, for two-phase mixtures, 167.
 - See also* two-fluid model
 - flow field in, 167
 - 2FM, 167
- multiphase flow conservation equations,
 - simplified, 166
- naphthalene
 - heat/mass transfers and, 35
- Navier–Stokes equations
 - for two-phase mixtures, 162
- near-azeotropic mixtures, 17
- net vapor generation (NVG), 413
- noncondensable presences, 565, 578–581
 - Couette flow film models and, 53–57
 - internal flow condensation and, effects on, 608–609, 619
- nonlinear chaos dynamics, 369
- nucleate boiling, 361–366, 370–375. *See also* bubble ebullition; departure from nucleate boiling; onset of nucleation boiling point
 - inary liquid mixtures, and, 392–396
 - bubble ebullition and, 366–369
 - correlation of Cooper and, 373
 - correlation of Forster and Zuber and, 372
 - correlation of Gorenflo and, 373–374
 - correlation of Rohsenow and, 370–372
 - correlations of Stephan and Abdelsalam and, 372–373
 - gravity and, 360
 - heat transfer mechanisms in, 369–375
 - nonlinear chaos dynamics and, 369
 - ONB and, 357, 413–418
 - surface roughness and, 359
- nucleation sites, active, 366
 - heterogeneous bubble nucleation and, 366
- Nukiyama's experiment, 357
- Numerical Recipes*, 195
- Nusselt's integral analysis, 566–569
 - improvements to, 569–571
 - on laminar condensation, 574–577
- NVG. *See* net vapor generation
- OC-OTEC. *See* open-cycle ocean thermal energy conversion
- ODEs. *See* ordinary differential equations
- OFI. *See* onset of flow instability
- ONB. *See* onset of nucleation boiling point
- onset of flow instability (OFI), 446
 - OSV and, 528
- onset of nucleate boiling point (ONB), 404, 408
 - correlation of Marsh and Mudawar and, 417
 - flow boiling and, 404, 408, 526–531
 - hard inlet conditions and, 526–528
 - models for, 413–418
 - in parallel channels, 528–531
 - pool boiling and, 357
 - flow boiling and, 413–418
 - tangency in, 414
- onset of significant void (OSV), 413
 - empirical correlations for, 419–423
 - flow boiling and, 526–531
 - hard inlet conditions and, 526–528
 - models for, 419–422
 - OFI and, 528
 - Small passages, and 526–531

Index

767

- subcooled flow boiling and, 424
- two-phase flow instability and, 447
- onset of significant void (OSV), models for, 419–422
 - model of Levy, 420–421
 - model of Rogers, 421–422
- Open-cycle ocean thermal energy conversion (OC-OTEC), 641
- ordinary differential equations (ODEs), 189–195
 - Euler equations and, 195
 - numerical solutions of, 189–195
 - Runge–Kutta method and, 195
 - state variables for, 189
 - stiffness in, 195
- ordinary diffusion, 9
- oscillation modes
 - of bubbles, 84–87
 - CHF and, 548
 - density-wave, 447
 - interfacial transfer processes and, 84
 - pressure drop-flow rate, 447
 - schematics for, 85
- OSV. *See* onset of significant void
- P - v - T surfaces, 4
- P - T phase diagrams, 5
- partial density, for species, 12
- PBE. *See* population balance equation
- perforated plates, 293–296
- phase diagrams, 3–5. *See also* vapor-liquid systems
 - azeotropic mixtures in, 17
 - for binary mixtures, 15–17
 - for binary systems, 15–17
 - Gibbs rule in, 15
 - for P - v - T surfaces, 4
 - for pure substances, 3–5
 - for T - v , 5
 - for zeotropic mixtures, 15–17
- phase volume fractions, 97–99
 - void fractions and, 98
- physical constants. *See* constants, physical
- plug flow
 - CHF in, 475
- Plug-elongated bubbles flow regimes, 139
- polyethylene channels, 311
- polyurethane channels, 311
- pool boiling, 357–403. *See also* film boiling;
 - minimum film boiling; nucleate boiling; onset of nucleation boiling point; pool boiling, hydrodynamic theory of
- binary liquid mixtures, and, 389–400
- CHF and, 376–379
- curve for, 357–361, 390
- film boiling and, 379–386
- in fully developed boiling region, 358
- heterogeneous bubble nucleation and, 361–366
- hydrodynamic theory of, 376–379
- liquid subcooling and, 306–354, 360
- MFB and, 359, 386–388
- nucleate boiling and, 359–361, 369–375
- Nukiyama's experiment and, 357
- ONB and, 357, 413–418
- surface wettability and, 359
- table look-up method for, 503–504
- transition regimes and, 359, 388–389, 423–424
- vapor structures in, 370
- pool boiling, hydrodynamic theory of, 376–379
 - CHF and, 376–379
 - Helmholtz instability and, 376
 - Taylor instability, MFB and, 387
- population balance equation (PBE), 111–112
 - simplified forms of, 111
- Prandtl number, 28
- pressure drop-flow rate oscillations, 447
 - in helically coiled flow passages, 270–277
 - in minichannels, 522–525
- pressure drops, in intermittent-flow regimes, 331–334
- pressure drops, in single-phase flow regimes, 258
 - from flow disturbances, 258–263
 - loss coefficients in, 263
 - reversible, 259
 - sudden contractions and, 261–263, 265–266
 - sudden expansions and, 260–261, 263–265
- pressure drops, in two-phase flow, 246–258, 262–269, 274–284
 - acceleration in, 246
 - bend configurations in, 264
 - empirical methods for, 250–256
 - form, 246
 - in HEM models, 247–250
 - in HM models, 247–250, 281
 - in internal flow condensation, 625–627
 - local, 257, 262–269
 - Lockhart–Martinelli method for, 250–251
 - Martinelli–Nelson method for, 255
 - in minichannels, 324–331, 342–343, 347–348
 - momentum density in, 264
 - one-dimensional system schematics for, 247
 - in orifices, 266
 - in spacer grids in rod bundles, 266
 - sudden contraction and, 265–266, 347–348
 - sudden expansion and, 263–265, 347–348
 - two-phase multipliers and, 247–250, 262, 326
- pressurized water reactors (PWRs), 210
 - CCFL and, 293
 - CHF and, 485
 - core schematic for, 298
 - flow regimes, and, 145
- pseudo-slug flow, 307
- PWRs. *See* pressurized water reactors
- quality profile fit, 425, 492
- Ranz–Marshall correlation
 - heat/mass transfers and, 35, 36
- Rayleigh equations, 88–89

768 Index

- Rayleigh–Taylor instability, 77
 axisymmetric disturbances in, 78–80
 capillary waves in, 74
 dispersion equations in, 76
 Laplace length scales in, 77
 neutral conditions in, 77
 in two-phase mixtures, 119
 unstable wavelengths and, 80
 for viscous liquids, 80
 rectangular channels. *See* channels, rectangular
 reflux phenomenon, 285
 RELAP5–3D code, 147–149
 relative humidity, 12, 561
 definitions for, 12
 relaxation instability, 447
 RETRAN codes, 656–658
 critical flow model (Henry/Fauski) and, 657–658
 critical flow model (Moody) and, 656
 isenthalpic flow models and, 656
 RETRAN-03, 656
 RETRAN-3D, 656
 Reynolds numbers, 28, 84
 in falling film hydrodynamics, 124, 131
 ripples, 77. *See* capillary waves
 rod bundles
 CHF and, 487–488
 in DFM, 210–212
 spacer grids in, 266
 vertical, 145–148
 roll waves, 125
 Runge–Kutta method, 195

 saturated flow boiling. *See* flow boiling, saturated
 saturated steam. *See* steam, saturated
 saturated water. *See* water, saturated
 SB-LOCA. *See* small break loss of coolant
 accident
 separated flow models, for two-phase mixtures,
 175–184
 CCFL and, 300–302
 energy conservation equations in, 180–183
 energy transfers at interphase, in, 182–183
 mass conservation equations in, 175–177
 momentum conservation equations, in, 177–180
 virtual mass force terms in, 177, 180
 simplified multiphase flow conservation equations.
 See multiphase flow conservation
 equations, simplified
 single phase flow, 7–15. *See also* equilibrium states;
 heat transfers; metastable states; pressure
 drops, in single-phase flow regimes;
 single-phase multicomponent mixtures;
 turbulent boundary layer velocity
 closure relations with, 7–10
 continuum regime in, 115
 critical discharge rates in, 647–656, 674
 equilibrium states of, 3
 heat transfers in, 31–36
 metastable states for, 5–7
 microchannels in, 115–117
 phase diagrams for, 3–5
 single-phase multicomponent mixtures in, 10–15
 size classification for, 114
 sound velocity in, 647–674
 temperature profiles in, 28–29
 transport equations with, 7–15
 transport properties for, 21–26
 turbulent boundary layer velocity and, 27–30
 single-phase multicomponent mixtures, 10
 Dalton’s law in, 12
 partial density in, for species, 11
 relative humidity definitions in, 12
 slip ratios, 103, 201
 slip velocity, 101, 201
 slug flow,. *See also* slug flow regimes
 adiabatic pipe flow and, 137
 CHF in, 475
 frothy-annular, 308
 unit cells in, 332
 slug flow regimes, 139
 small break loss of coolant accident (SB-LOCA),
 210
 small flow passages. *See* microchannels;
 minichannels
 small-amplitude waves, 125
 Soret effect, 9
 species
 chemical mass conservation for, 10
 mass diffusivity for, 9, 21
 mass fraction of, 11
 molar concentration of, 11
 mole fraction of, 11
 noncondensable, 174
 partial density of, 11
 partial pressure of, 12
 spinodal lines, 6
 spontaneous phase change, 6–7
 stable film boiling regimes, 502
 steam, saturated. *See also* flow boiling, saturated
 thermodynamic properties of, 678
 transport properties of, 680
 Stokes–Einstein expression, 25
 stratified-smooth flow regimes, 139
 stratified-wavy flow regimes, 139
 subcooled flow boiling. *See* flow boiling, subcooled
 subcooled liquid jets, 611–614
 surface tension, in gas–liquid interfacial
 phenomena, 38–41. *See also* thermocapillary
 active impurities and, 44–46
 Bénard cellular flow in, 46–50
 Gibbs free energy and, 39
 Helmholtz free energy and, 38, 39
 interfacial pressure in, 41
 Marangoni effect in, 44
 nonuniformity, 43–44
 for pure liquids, 38–40
 thermocapillary effects and, 46–50
 thermodynamic definition of, 38–39
 velocity of interphase, 45
 Young–Laplace equation in, 40

Index

769

- surface wettability
 - contact angles and, 42
 - in microchannels, 311, 317
 - pool boiling and, 359
- T - v phase diagrams, 5
- Taylor flow regimes, 335–346
 - rise velocity, and, 345
 - unit cell definitions in, 340
- temperature glides, 16, 17
- “temperature law of the wall”, 28–29
- thermal radiation
 - in film boiling, 385–386
- thermal/mechanical energy equations, 173
- thermocapillary effects, 46–50
 - buoyancy forces and, 49
 - Hadamard–Rybczynski creep flow solution and, 49
 - linear stability analysis within, 125
 - Marangoni effect and, 46
- thermodynamics
 - statistical predictions for, 5
- tie lines, 17
- Tien–Kutateladze flooding correlation, 291
- time averaging, in two phase mixtures, 97–99
 - double, 98
 - properties in, 99–100
- TMBF correlations, 386–388
- transfer(s). *See also* heat transfers; mass transfers;
 - mass transfers, interfacial; transfer relations
 - in Fick’s law, 31
 - in Fourier’s law, 31
 - in GKT, 54, 55
 - interfacial mass, 61–66
 - mass, 31–36
 - molar flux and, 33–34
 - naphthalene and, 35
 - in separated flow models, for two-phase mixtures, 182–183
 - in single phase flow, 31–36, 115
- transfer relations, 8
- transition boiling regimes, 359, 388–389, 502
 - LOCA and, 500
 - as post CHF regime, 500–501
- transport equations, 7–15. *See also* mass diffusivity,
 - for species
 - chemical species mass conservation in, 10
 - Fick’s law in, 8
 - Fourier’s law in, 8
 - mass conservation in, 9
 - momentum conservation, 10
 - ordinary diffusion in, 9
 - Soret effect in, 9
 - species mass diffusivity in, 9
 - thermal energy in, 10
- transport properties, for single phase flow, 21–26.
 - See also* gaskinetic theory; liquid diffusion
 - gaskinetic theory GKT and, 21–25
 - liquid diffusion and, 25
 - mixture rules within, 21
 - species mass diffusivity for, 21
- triangular channel, 309
- triple point, 3
- turbulence, in eddies, 106–110
 - breakup and, 113–114
 - bubbles in, 109
 - coalescence and, 112–113
 - energy spectrums in, 107
 - falling films and, 129–131
 - in equilibrium, 106
 - homogenous, 106
 - inertial, 108
 - as isotropic, 106
 - in Kolmogorov’s theory, 106
 - particle-eddy collision frequency in, 112
 - PBE in, 111–112
 - stationary, 106
 - in universal equilibrium range, 107
- turbulent boundary layer velocity, 27–30
 - Blasius’s correlation in, 28
 - bubble nucleation, 27
 - Deissler correlation in, 30
 - Karman’s constant in, 30
 - Prandtl number in, 28
 - Reynolds number in, 28
 - “temperature law of the wall” and, 28–29
 - Van Driest model, 30
- turbulent film condensation, 571–573
- two-dimensional surface waves, 72–74
 - capillary, 74
 - gravity, 74
- two-fluid model (2FM), 167
 - conservation equations in, 234
 - DFM v., 202–203
 - generalized drag forces in, 187–188
 - interfacial transport terms in, 186
 - material derivatives for, 188
 - multi-dimensional, 185–188
 - subcooled flow boiling and, 424–425
 - virtual mass terms in, 187–188
- two-phase flow instability
 - chugging and, 447
 - dynamic, 447–449
 - flow boiling and, 444–449
 - flow excursions, 445
 - geysering in, 447
 - Ledinegg instability and, 445
 - mal-distribution, 447
 - OFI and, 446
 - OSV and, 447
 - relaxation instability and, 447
 - static, 445–447
- two-phase mixtures, 96, 135, 159. *See also* laminar
 - films; turbulence, in eddies; two-phase mixtures, flow regimes for; two-phase mixtures, modeling for
 - CFD codes for, 162
 - conservation equations for, 162
 - definitions in, 101–104
 - density in, 102

770 Index

- two-phase mixtures (*cont.*)
 - field schematic for, 97, 98
 - flow area-averaging in, 100–101
 - flow quality in, 103
 - fundamental void–quality relations in, 103
 - HEM in, 104
 - Knudsen numbers in, 114
 - laminar film hydrodynamics in, 123–126
 - mass flux in, 103
 - modeling for, 162–198
 - Navier–Stokes equations for, 162
 - particle dispersion in, 111–114
 - phase volume fractions in, 97–99
 - Rayleigh–Taylor instability in, 119
 - in situ properties for, 102
 - size classification for, 118–121
 - slip ratio in, 103
 - slip velocity in, 101
 - small flow passage in, 120
 - time averaging in, 97–100
 - turbulence in, 106–110
- two-phase mixtures, flow regimes for, 135, 159, 221–242. *See also* adiabatic pipe flow; annular-dispersed flow regimes; choking; minichannels; pressure drops, in single-phase flow regimes; pressure drops, in two-phase flow regimes
 - in adiabatic pipe flow, 136–143
 - annular-dispersed, 137
 - annular-mist 137
 - bends, and, 150–153
 - choking in, 644–646
 - curved flow passages, and, 149–157
 - DFM and, 225–227
 - dispersed-droplet, 138
 - dynamic models for, 234–242
 - empirical maps, comments on, 158–159
 - finely dispersed bubbly flow, 138, 139, 223–224
 - helicoidally coiled tubes, and, 154–157
 - in inclined tubes, 232–234
 - interfacial area transport equations in, 234–242
 - internal flow condensation in, 591–596
 - inverted-annular, 138
 - Kelvin–Helmholtz instability in, 229
 - maps of, pipe flow, 143–144
 - in microchannels, 314–316
 - in minichannels, 307–314
 - plug-elongated bubbles, 139, 141
 - pressure drops in, 246–258, 262–269, 274–284
 - in rectangular channels, 310, 311
 - RELAP5–3D code schematics, 147–149
 - slug flow, 137, 139
 - in small flow passages, 306–354, 360
 - stratified-smooth flow, 139
 - stratified-wavy flow, 139
 - in vertical rod bundles, 145–149
 - void fractions in minichannels and, 314–316
- two-phase mixtures, modeling for, 162–198. *See also* homogenous-equilibrium mixture model; separated flow models, for two-phase mixtures
 - for diffusion models, 167
 - Fick’s law in, 164
 - flow area averaging for, 167–169
 - gas–liquid interphase schematic in, 164
 - for homogenous mixtures, 167
 - interphase balance equations in, 163–166
 - local instantaneous equations in, 163–166
 - for multi-fluid models, 167
 - with separated flow, 175–184
- two-phase multipliers, 247–250, 262, 326
- unit conversions, 701–703
- universal equilibrium range, 107
 - dissipation range within, 107
 - inertial size range within, 107
- Van Driest eddy diffusivity model, 30
- vapor(s). *See also* fog
 - backflow for, in minichannels, 549
 - of laminar film condensation, 574–577
 - thermodynamic properties of, for selected refrigerants, 681–689
- vapor–liquid systems
 - binary systems, of, 15–17
 - bubble point lines in, 16
 - disturbed interphases in, 72
 - dew point lines in, 16
 - as gas–liquid interfacial phenomena, 5–7
 - Gibbs free energy in, 51, 52
 - Laplace–Kelvin relations and, 52
 - mass fraction profiles in, 60
 - temperature glides in, 16, 17
 - tie lines in, 17
 - vapor–partial pressure in, 52
 - Young–Laplace equations and, 51
- vapor–noncondensable gas mixtures, 17–21
 - Clapeyron’s relations in, 5
- velocity
 - choking and, in single-phase fluids, 645–646
 - in interfacial mass transfers, 54
 - surface tension and, as factor in, 44, 45
 - superficial in one-dimensional two-phase mixtures, 102
- vertical flow
 - in adiabatic pipes, 136–143
 - CCFL and, 285–290, 301
 - correlations for, 290–293
 - film boiling and, 382–384
 - internal flow condensation and, correlations for, 597–599
 - in rectangular channels, 320–322
- vertical rod bundles, 145–149
- vertical surface, film boiling, 379–381
- void fractions, 98
 - minichannels, in, 314–316
 - microchannels, in, 316–319
- void-quality correlations, 213–218

Armand's flow parameter in, 213	Eötvös numbers and, 84
CISE correlation in, 213, 314	Morton numbers and, 84
von Kármán's constant, 30	Reynolds numbers and, 84
	wavy-annular flow, 308
wall friction, annular flow, 616–617	wavy-laminar condensation, 571–573
water, saturated. <i>See also</i> flow boiling, saturated	
diffusion coefficients for, at infinite dilution, 697	Young–Dupré equations, 42
thermodynamic properties of, 678	Young–Laplace equations, 40
transport properties of, 680	vapor–liquid systems and, 51
waves, 83. <i>See also</i> bubbles; capillary waves;	
gravity waves; roll waves; small-amplitude	zeotropic mixtures, 15–17
waves; two-dimensional surface waves	phase diagrams for, 16
bubbles and, 84	zero liquid penetration point, 289