978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

Index

acetone, in liquid-liquid mass contactors, 124-5, 137 adiabatic reactors, 48-9, 50 adsorption in liquid-gas mass contactors, 117 in solid-fluid mass contactors, 115 agitation nozzles, 68 Arnold cell, 225–30 binary diffusivity measurements with, in gases, 226 mole fraction profiles for, 229 in species mass conservation equations, 252 batch heat exchangers, 56-60, 63, 67, 68 equilibrium temperature in, 58-60 examples of, 56 mechanical mixers in, 57 heat load in, 60 Level I analysis of, 57-8 mixed-mixed fluid motion in, 56 mixed-plug fluid motion in, 68 model equations for, 136 pilot-scale, 66 with reactions, 111–13 batch mass contactors, 118-20, 135-7. See also two-phase mass contactors homogenous mixing for, 118 Level I analysis of, 119-20 conservation of mass in, 119 Level II analysis of, 120 model equations for, 136 two-phase systems for, 118-19 batch reactors, 10, 11, 34 chemical equilibrium in, 25-6 chemical reactor analysis for, 21-6 model equations for, 14, 28, 136 mole balance equations for, 24-5 rates of reaction in, 23-5 biomass concentrations, 30, 31 in pilot-scale bioreactors, 347-8 bioreactors, 29-30, 31. See also semibatch reactors air spargers in, 348-52 biomass concentrations in, 347-8

Candida utilis in. 345 gas hold-up equation in, 349 mass transfer rates in, 347 oxygen concentrations in, 346-8 pilot-scale, 345-52 plumes in, 349 semibatch, 346 Biot number, 195-9, 235 fin efficiency v., 199 in molecular diffusion, 206-8 lumped analysis of, 235 Birmingham wire gauge (BWG), 79, 101 Blasius solution, 255, 272 in tubular two-phase mass contactors, 316, 317 boundary conditions for boundary layer equations, 258 in countercurrent double pipe heat exchangers, 91, 92 in molecular diffusion, 206 in thermal conduction, 195, 197 constant temperature, 192-3 flux, 193 mixed, 194-5 for tubular two-phase mass contactors, 161 boundary layers, 185, 260 analysis of, 254-64 in convective heat transfer, 246-7 Navier-Stokes equations and, 247 for penetration theory, 275 Prandtl analogy for, 264 bubble breakage, 323-6 experimental data for, 325 Kolmogorov-Hinze theory and, 323 Levich force balance and, 326 Weber number in, 323, 326 bubble size, 302, 303 estimation of, 304-7 gas hold-up and, 312, 313 maximum, 304 orifices and, 303, 310-11 rise velocity and, 314 BWG. See Birmingham wire gauge

Cambridge University Press 978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index <u>More information</u>

364 Index

Candida utilis, 29 in pilot-scale bioreactors, 345 CFSTRs. See continuous-flow stirred tank reactors characteristic scales, 248 characteristic velocity, 248 Chemical Engineers' Handbook, 62, 94, 122, 219, 319, 328, 343 chemical equilibrium, 5 in batch reactors, 25-6 in Level II mathematical models, 5 chemical reactor analysis, 20-51 for acetic acid/sodium acetate, 52 for batch reactors, 21-6 chemical equilibrium in, 25-6 fluid motion in, 20 mole balance equations for, 24-5 rates of reaction in, 23-5 for CFSTRs, 20, 34, 37-41 constant density system in, 38 Level III analysis of, 39 residence time in, 20, 46, 48 steady-state operations in, 38 equipment classification for, 21 fermentor analysis and, 29-32, 140 biomass concentration in, 30, 31 Candida utilis in, 29 growth in bioreactors and, 29-30, 31 Monod-type relationships in, 32 for H₂SO₄ concentrations, 7, 29, 51 interfacial areas in. 20 in Level I models, 21 in Level II models, 21 in Level III models, 21 rates of reactions in, 26-33 reactor energy balance in, 47-51 adiabatic reactors and, 48-9, 50 energy of activation in, 50 exothermic reactions in, 50 heat of reaction in, 48 for semibatch reactors, 20, 34-7 for tubular reactors, 21, 42-47 Chilton-Colburn transport analogy, 260, 264, 265, 272 Lewis number in, 262 Pohlhausen solution in, 261 Stanton number in, 261 cocurrent double-pipe heat exchangers, 81-8 conservation of energy in, 83 driving force for heat transfer in, 82 energy balance in, 84, 114, 148 heat load in, 82, 85-7 temperature profiles in, 82 temperature v. position for, 82 cocurrent tubular solid-fluid mass contactors, 116 coefficient of skin friction, 250 coefficients. See coefficient of skin friction: heat transfer coefficients; mass transfer coefficients

coils in heat exchanger design, 79, 98-9 residence time in, in semibatch heat exchangers, 72, 73-4 component mass balance, 36 in tubular reactors, 44 conduction. See thermal conduction conservation of energy in cocurrent flow, 83 in heat exchanger analysis, 56 in Level I mathematical models, 3-5 in thermal conduction, 188, 210 conservation of mass in batch mass contactors, 119 in continuity equations, 294 in continuous-flow two-phase mass contactors, 144 in heat exchanger analysis, 56 in Level I mathematical models, 3-5 in molecular diffusion, 202 in rate of reactions, for mass transfer, 125 in tubular reactors, 43 in tubular two-phase mass contactors, 158 constitutive equations Fick's constitutive equation, 202 in molecular diffusion, 200, 201-6, 211-12 in penetration theory, 276 Sherwood number and, 208 Fourier's constitutive equation, 187-95 differential forms of, 191 in penetration theory, 276 in heat exchanger analysis, 60 in thermal conduction, 189 constitutive relationships Fick's "Law," 16 Fourier's "Law," 16 for heat transfer. 15 in Level III mathematical models, 15 for mass transfer rates, 127 for mass transfer, 16 for momentum transfer, 16 Newton's "Law" of viscosity, 16 in phase equilibria, 6 for rate of reaction, 16 continuity equations in convective heat transfer, 248-9 in tubular reactions, 43 continuous-flow stirred tank reactors (CFSTRs), 20, 34, 37-41 constant density system in, 38 Level III analysis of, 39 plug flow rates in, 41 residence time in, 20, 46, 48 steady-state operations in, 38 continuous-flow tank-type heat exchangers, 74-9 heat loads in, 75 heat transfer coefficient in, 77-8

mixed-mixed fluid motions in, 74-8

Cambridge University Press 978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index More information

Index

365

mixed-plug fluid motions in, 78-9 steady-state operations in, 74 continuous-flow two-phase mass contactors, 143-56 design summary for, 168-74 evaluation/iteration of, 172 flow rate determination in, 170-1 interfacial area determination in, 171-2 mass transfer agent choice in, 169-70 mass transfer coefficient estimation in, 171 mass transfer load calculations in, 169 stage efficiency in, 171 thermodynamic property information in, 170 equilibrium stage in, 146 gas-liquid, 154 mixed-mixed fluid motion in, 144-6 conservation of mass and, 144 mixed-plug fluid motion in, 153-6 control volumes in differential transport equations, 293 in Level III mathematical models, 12 in Level I mathematical models, 3 selection of 12 in semibatch heat exchangers, 73 in single-phase reactors, 21 for thermal conduction, 210 in tubular reactors, 42 in word statement of conservation laws, 11 convective flux, 203, 226, 228 countercurrent double-pipe heat exchangers, 55, 81,88-94 boundary conditions in, 91, 92 log-mean differences in, 101 steady-state operations in, 91 technically feasible design for, 92, 96, 328 temperature profiles in, 89, 90, 95 countercurrent tubular mass contactors, 117 flooding limits in, 339 flow rate determinations in, 337-42 interfacial area determination for, 343-5 liquid distributors and, 319, 344 mass transfer coefficients in, 342 mass transfer load calculations in, 336 packed towers and, 336, 344 packing in, 335 penetration theory model and, 342 Raschig rings in, 341, 342, 343 stage efficiency in, 339 technically feasible design for, 335-45 crystallinity, 190 cylindrical fin, 196 Damköhler number, 299 design, for mathematical models, 17 logic required for, 8, 10 desorption, 115 deviatoric stress, 295

diffusive flux, 226 distillation columns in Level I mathematical models, 5 in Level II mathematical models, 6 distribution coefficients, in liquid-liquid mass contactors double pipe heat exchangers, 55, 79, 80, 86 cocurrent, 81-8 conservation of energy in, 83 cross-sectional slice of, 83 driving force for heat transfer in, 82 energy balance in, 84, 114, 148 heat load in, 82, 85-7 limiting behavior for, 84 temperature profiles in, 82 temperature v. position for, 82 countercurrent, 55, 81, 88-94 boundary conditions in, 91, 92 cross-sectional slice of, 90 log-mean differences in, 101 steady-state operations in, 91 technically feasible design for, 92, 96 temperature profiles in, 89, 90, 95 plug-plug heat exchangers and, 56 technically feasible design for, 334 driving forces, for heat transfer, 66 drop breakage, 323-6 experimental data for, 325 Kolmogorov-Hinze theory and, 323 Levich force balance and, 326 Weber number in, 323 drop size, 157, 302, 303 control volume and, 306 estimation of, 304-7 maximum stable size, 304 surface tension force and, 304 Weber number and, 304 efficiency of separation, 147 energy balance in cocurrent double-pipe heat exchangers, 84, 114, 148 constant volume and, 110 in heat exchanger analysis, 109-10 in semibatch heat exchangers, 70 energy conservation equations in convective heat transfer, 250-2 Fourier's constitutive equation and, 251 - 81heat transfer coefficients in, 251 Nusselt number in, 251 Prandtl number in, 251, 252 Reynolds number in, 251, 252 in Navier-Stokes equations, 251 energy of activation, 50 enthalpy, 58 in heat exchanger analysis, 61, 111 in thermal conduction, 210 equilibrium stage, 146

diffusion. See molecular diffusion

978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

366 Index

equilibrium temperature

in batch heat exchangers, 58-60 in heat transfer, 65 equimolar counterdiffusion, 273 exothermic reactions, 50 Fanning friction factor, 255 fermentor analysis, 29-32, 140 biomass concentration in, 30, 31 Candida utilis in, 29 equilibrium values in, 32-3 exponential growth in, 32 glucose in, 30 growth in bioreactors and, 29-30, 31 Monod-type relationships in, 32 substrates in, 30-1 Fick, Adolf, 201 Fick's "Law" constitutive equation, 17, 185, 202 control volume for analysis of, 202 in molecular diffusion, 200, 201-6, 211-12 in penetration theory, 276 Sherwood number and, 208 species mass conservation equations and, 252 film theory, in fluid-fluid systems, 273 equimolar counterdiffusion in, 273 fin efficiency, 198 Biot number v., 199 temperature profile in, 197 flooding limits, 339 in packed towers, 340 flow of complex mixtures in pipes, 156 fluid motion. See also mixed-mixed fluid motion; mixed-plug fluid motion; plug-flow fluid motion; well-mixed fluid motion in batch heat exchangers, 56, 68 in batch reactors, 20 cocurrent double-pipe heat exchangers, 81 in continuous-flow two-phase mass contactors, 144-6, 153-6 countercurrent flow, 81 equipment classification for, 115 in Level III mathematical models, 7 in Level IV mathematical models, 7 plug flow, 81 in semibatch heat exchangers, 68, 69-74 in semibatch mass contactors, 138-9 tubular-tubular plug flow, 81 in tubular two-phase mass contactors, 156 fluid velocity gradients, 247 fouling, 219 Fourier, Jean-Baptiste-Joseph, 190 Fourier number, Biot number v., in transient conduction/diffusion, 232 Fourier's constitutive equation, 187-95 through composite layered materials, in thermal conduction, 214 differential forms of, 191 energy conservation equations and, 251-81

Nusselt number v., 199, 201-9 for one-dimensional thermal conduction, 210 in penetration theory, 276 Fourier's "Law", 16, 185, 190 Fourier's "Second Law", 192, 195 in molecular diffusion, 204 Frössling equation, 267 gas flow rates in countercurrent mass contactor design, 339 for molar gases, 165 in tubular two-phase mass contactors, 319 gas hold-up, 312, 313 in pilot-scale bioreactors, 349 gas phase reactions, 27 gas plumes. See plumes Gilliland's equation, 269 Handbook of Industrial Mixing, 309 heat capacity for batch heat exchangers, 58 in heat exchanger analysis, 61 in heat exchanger design, 96 heat exchanger analysis, 55-102 for batch heat exchangers, 56-60, 63, 67, 68 equilibrium temperature in, 58-60 heat load in, 60 Level I analysis of, 57-8 mixed-mixed fluid motion in, 56 pilot-scale, 66 with reactions, 111-13 for continuous-flow tank-type exchangers, 74-9 heat transfer coefficient in, 77-8 mixed-mixed fluid motions in, 74-8 mixed-plug fluid motions in, 78-9 steady-state operations in, 74 for CSTR, 113 for double pipe heat exchangers, 55, 79, 80, 86 energy balance in, 109-10 enthalpy in, 61, 111 law of conservation of energy/mass an, 56 mixture approximations in, 110-11 for rate of heat transfer, 60-7 for semibatch heat exchangers, 67, 68-74 agitation nozzles in, 68 coil residence time in, 72, 73-4 control volumes in, 73 energy balance in, 70 heat load for, 70 mixed-mixed fluid motion in, 69-72 mixed-plug fluid motion in, 68, 72-4 well-mixed fluid motion in, 68 for tubular heat exchangers, 79-94 cocurrent, 81 double pipe, 55, 79, 86 plate and frame, 80-1 shell and tube, 79-80 steady-state operations for, 84

Cambridge University Press 978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

Index

367

heat exchangers, 67-79. See also batch heat exchangers; cocurrent double-pipe heat exchangers; countercurrent double-pipe heat exchangers; shell and tube heat exchangers analysis of, 55-102 for batch exchangers, 56-60, 63, 68 for continuous-flow tank-type exchangers, 74-9 for semibatch exchangers, 67, 68-74 for tubular, 79-94 batch, 56-60, 63, 68 equilibrium temperature in, 58-60 heat load in, 60 Level I analysis of, 57-8 mixed-mixed fluid motion in, 56 pilot-scale, 66 continuous-flow tank type, 74-9 heat loads in, 75 heat transfer coefficient in, 77-8 mixed-mixed fluid motions in, 74-8 mixed-plug fluid motions in, 78-9 steady-state operations in, 74 convective transport coefficient estimations for, 281 - 4for mixed-mixed tank type, 282-3 for mixed-plug tank type, 284 for tubular tank type, 284 designs of double pipe, 55, 79, 80, 86 cocurrent, 81-8 countercurrent, 55, 81, 88-94 plug-plug heat exchangers and, 56 model equations for, 15 plate and frame, 80-1 semibatch, 67, 68-74 agitation nozzles in, 68 coil residence time in, 72, 73-4 control volumes in, 73 energy balance in, 70 heat load for, 70 mixed-mixed fluid motion in. 69-72 mixed-plug fluid motion in, 68, 72-4 well-mixed fluid motion in, 68 technically feasible design for, 94-102, 328-34 coils in, 98-9 double-pipe exchangers, 334 local heat transfer coefficients in, 330 log-mean differences in, 98 overall heat transfer coefficients in, 330 pipe diameter/velocities in, 99, 102 pipe schedule in, 332 Prandtl numbers in, 330 Reynolds number in, 328, 330 tubular, 79-94 BWG measurements for, 79 cocurrent flow in, 81 cross section of, 217 double pipe, 55, 79

plate and frame, 80-1 shell and tube, 79-80 steady-state operations for, 84 heat load in batch heat exchangers, 60 in cocurrent double-pipe heat exchangers, 82, 85 - 7in continuous-flow tank-type heat exchangers, 75 for semibatch heat exchangers, 70 heat of reaction, 48 heat transfer coefficients in cocurrent double-pipe heat exchangers, 87 through composite layered materials, 212-17 in continuous-flow tank-type heat exchangers, 77 - 8Nusselt number and, 200, 201-6 in shell and tube heat exchanger design, 332-4 for tubular exchangers, 217 Heat Transfer Research Institute (HTRI), 94 design procedures of, for shell and tube heat exchangers, 331 heat transfer. See also boundary layers; transport analogies; transport coefficient models, in fluid-fluid systems area available for, 55 in batch heat exchangers, properties for, 63 in batch reactors, 15 Biot number for, 195-9 constitutive relationships for, 15-16 convective, 246 boundary layers in, 246-7, 248, 254-64 central hypothesis in, 246 coefficient of skin friction in, 250 continuity equations in, 248-9 energy conservation equations in, 250-2 friction factors for, 256, 267 Frössling equation in, 267 Gilliland's equation in, 269 in heat exchangers, 281-4 in mass contactors, 284-5 Navier-Stokes equations in, 249-50, 251 transport analogies in, 247, 254-60, 264, 265, 2.72transport coefficient models in, 273 in wet bulb experiment, 261 in wetted wall column, 269 heat exchanger analysis for, 60-7 mathematical models for, 8, 15 plug-flow fluid motion in, 7 in thermal conduction, 194 Henry's "Law", 6 constants, for gases, 122 in countercurrent mass contactor design, 337 in liquid-gas mass contactors, 122 liquid-liquid mass contactors and, 123 in semibatch mass contactors, 142 horizontal mass contactors, 158 HTRI. See Heat Transfer Research Institute

978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

368 Index

impeller diameter, 307 Reynolds number for, 309 Weber number for, 308 interfacial areas, 301-20 in chemical reactor analysis, 20 in continuous-flow two-phase mass contactors, 171 - 2in countercurrent mass contactor design, 343-5 experimental technique summary for, 324 for mass transfer, 130 for plumes, 312, 315 in tank-type mass contactors, 306, 307-15 separators in, 309 in tubular two-phase mass contactors, 162, 316-20 cocurrent area estimation. 316 cocurrent K_m estimation, 318 interphase mass transfer, in fluid-fluid systems, 279 - 81oxygenation of water in, 281 Introduction to Chemical Engineering Analysis (Denn/Russell), 8, 9, 18, 20, 114 Kolmogorov-Hinze theory, 316 bubble/drop breakage and, 323 laminary boundary layer, 248, 254-6, 259 Blasius solution in, 255, 272 Fanning friction and, 255 Reynolds number and, 256 leaching, 115, 116 Level I (mathematical) models chemical reactor analysis in, 21 component balance relations in, 5 conservation of mass and/or energy, 3-5 control volumes in, 3 definitions within. 4 distillation columns in, 5 simple mass balance in, 3 in single-phase reactors, 14 tubular reactors and, analysis through, 43-4 in two-phase reactors, 14 Level II (mathematical) models, 5-6 chemical equilibrium in, 5 chemical reactor analysis in, 21 distillation columns in, 6 Henry's "Law" in, 6 Nernst's "Law" in, 6 phase equilibrium in, 5,6 thermal equilibrium in, 5 transport phenomena in, 5 Level III (mathematical) models, 6-7 CFSTRs and, analysis through, 39 chemical reactor analysis in, 21 constitutive relationships in, 15 control volumes in, 11-12 fluid motion in, 6-7 rate of reactions in, 15 transport rates for mass and/or energy in, 6-7

Level IV (mathematical) models, 7 fluid motion in, 7 Level V (mathematical) models, 7 Level VI (mathematical) models, 8-9 time constraints in, 8 Levich force balance, 326 Lewis number, 239 liquid distributors, 319, 344 liquid-gas mass contactors, 117, 121-2 adsorption in, 117 contactor/separators in, 135 Henry's "Law" in, 122 oxygen concentration in, 122, 143 partial pressure in, 122 photograph of, 154 scrubbing in, 117 stripping in, 117 liquid-liquid mass contactors, 116-17, 122-5, 135 - 7acetone in, 124-5, 137 continuous flow, 144 distribution coefficients in equilibrium in, 133-4 Henry's "Law" and, 123 ideal behavior in, 123 mixer-settlers in, 116 log-mean differences, 178-80 in countercurrent double-pipe heat exchangers, 101 in heat exchanger design, 98 in tubular two-phase mass contactors, 167 mass, word statements of conservation laws for, 13 - 14mass balance. See also component mass balance in tubular reactors, 43 mass contactor analysis, 114, 148, 173 for batch mass contactors, 118-20, 135-7 homogenous mixing for, 118 Level I analysis of, 119-20 Level II analysis of, 120 two-phase systems for, 118-19 for liquid-gas systems, 117, 121-2, 135 adsorption in, 117 contactor/separators in, 135 Henry's "Law" in, 122 oxygen concentration in, 122 for liquid-liquid systems, 116-17, 122-5, 135-7 acetone in, 124-5, 137 continuous flow, 144 distribution coefficients in equilibrium in, 133-4 Henry's "Law" and, 123 ideal behavior in, 123 mixer-settlers in, 116 for rate of mass transfer, 125-34 approach to equilibrium and, 132-4 conductivity probes for, 129 conservation of mass in, 125

978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

Index

369

constitutive relationships in, 127 expression rates in, 127-32 interfacial area in, 130 overall resistance in, 128 reaction rate expression in, 114 for single-phase systems, 114 for solid-fluid systems, 115-16, 135 cocurrent tubular, 116 countercurrent tubular, 117 unit operations for, 115 for solid-liquid systems, 121, 132 surface to volume factors in, 131 for tank-types, mixed-mixed, 117 mixed-plug mass contactors, 117 semibatch mixed-plug contactors, 116 for two-phase systems, 114, 134-56 batch contactors as, 118, 134-5 continuous flow, 143-56, 168-74 isothermal, 114 semibatch contactors as, 134-5, 137-43 tubular contactors, 156-68 mass contactors, See also batch mass contactors; cocurrent tubular solid-fluid mass contactors; continuous-flow two-phase mass contactors; countercurrent tubular mass contactors; liquid-gas mass contactors; liquid-liquid mass contactors; semibatch mass contactors; single-phase contactors; solid-fluid mass contactors; solid-liquid mass contactors; tank-type mixed-mixed mass contactors; tank-type mixed-plug mass contactors; tank-type semibatch mixed-plug contactors; two-phase mass contactors analysis of, 114, 148, 173 for batch mass contactors, 118-20, 135-7 for liquid-gas systems, 117, 121-2, 135 for liquid-liquid systems, 116-17, 122-5, 135 - 7for rate of mass transfer, 125-34 reaction rate expression in, 114 for single-phase systems, 114 for solid-fluid systems, 115-16, 135 for solid-liquid systems, 121, 132 for tank-types, 116, 117 for two-phase systems, 114, 134-56 continuous-flow two-phase, 143-56, 168-74 design summary for, 168-74 equilibrium stage in, 146 mixed-mixed fluid motion in, 144-6 mixed-plug fluid motion in, 153-6 convective transport coefficient estimations for, 284-5 Chilton-Colburn analogy in, 284 for mixed-mixed tank type, 285 for mixed-plug tank type, 285 for tubular tank type, 285 interfacial area estimation for, 306, 307-15

for mixed-mixed K_m systems, 309 for mixed-mixed systems, 307-9 for mixed-plug systems, 309-13 mixed-mixed, 146-52 efficiency of separation in, 147 feasible design for, 146-52 stage efficiency in, 147, 148 TCE in, 149 model equations for, 15 semibatch, 134-5, 137-43 mixed-mixed fluid motion in, 138-9 mixed-plug fluid motion in, 139-42 Penicillin production in, 139, 141 technically feasible design for countercurrent systems, 335-45 tubular two-phase, 156-68 cocurrent flow in, 158-9 countercurrent flow in, 157-8, 159-64 drop size in, 157 fluid motion systems in, 156, 157 as membrane contactor, 156 mass transfer coefficients, 171, 301-20 in species mass conservation equations, 253 mass transfer. See also boundary layers; transport analogies; transport coefficient models, in fluid-fluid systems in batch reactors, 15 constitutive relationships for, 16 convective, 246-85 boundary layers in, 246-7, 248 continuity equations in, 248-9 dimensional analysis of, 247 energy conservation equations in, 250-2 Frössling equation in, 267 Gilliland's equation in, 269 in mass contactors, 284-5 Navier-Stokes equations in, 249-50, 251 species mass conservation equations in, 252-4, 298-9 transport analogies in, 247, 254-60, 264, 265, 272 transport coefficient models in, 273 vector notations for, 299-300 in wetted wall column, 269 mathematical models for, 8, 15 in pilot-scale bioreactors, 347 plug-flow fluid motion in, 7 rate of reactions for, 16, 125-34 Material Safety Data Sheets (MSDS), 125 mathematical models, 3 laboratory scale experiments, 12 Level I, 3-5 component balance relations in, 5 conservation of mass and/or energy, 3-5 control volumes in, 3 definitions within, 4 distillation columns in, 5 simple mass balance in, 3

978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

370 Index

mathematical models (cont.) Level II, 5-6 chemical equilibrium in, 5 distillation columns in, 6 Henry's "Law" in, 6 Nernst's "Law" in, 6 phase equilibrium in, 5,6 thermal equilibrium in, 5 transport phenomena in, 5 Level III, 6-7 constitutive relationships in, 15 control volumes in, 11-12 fluid motion in, 6-7 rate of reactions in, 15 transport rates for mass and/or energy in, 6-7 Level IV, 7 fluid motion in, 7 Level V, 7 Level VI, 8-9 for mass transfer, 8, 15 technically feasible designs for, 17-18 mechanical mixers, 57 membrane contactors. See tubular two-phase mass contactors membrane diffusion. See sorption-diffusion model mixed-mixed fluid motion in batch heat exchangers, 56 in continuous-flow tank-type heat exchangers, 74 - 8in continuous-flow two-phase mass contactors, 144 - 6in semibatch heat exchangers, 69-72 in semibatch mass contactors, 138-9 mixed-mixed heat exchangers, 55 reactor jackets in, 55, 62 mixed-mixed mass contactors, 146 efficiency of separation in, 147 feasible design for, 146 stage efficiency in, 147, 148 TCE in, 149 mixed-plug fluid motion in continuous-flow tank-type heat exchangers, 78 - 9in continuous-flow two-phase mass contactors, 153-6 Henry's "Law" in, 142 in semibatch heat exchangers, 72-4 in semibatch mass contactors, 139-42 mixed-plug heat exchangers, 55 mixer-settlers, 116 molar flux, 202, 203, 205, 226 mole balance equations, for batch reactors, 24-5 molecular diffusion, 199, 201-9 Arnold cell and, 225-30 Biot number in, 232 through composite layered materials, 212-22 Fick's constitutive equation in, 200, 201-6, 211-12 geometric effects on, 209-212

one-dimensional, 211 molar flux in, 202, 203, 205, 226 sorption-diffusion model, 231 transient, 231-9 Fourier number v. Biot number in, 232 short time penetration solution for, 233-5 in various gases, 204 momentum transfer, equations for, 13, 294-6 MSDS. See Material Safety Data Sheets multiple phase transport phenomena, in Level VI models. 8-9 multistage agitator towers, 337 Navier-Stokes equations, 296 boundary layers and, 247 in convective heat transfer, 249-50, 251 energy conservation equations and, 251 Reynolds number and, 249, 250 in Reynolds transport analogy, 257 Nernst's "Law," 6 Newton's "Law" of cooling, 190, 194, 199 Newton's "Law" of viscosity, 16 Nusselt number, 186, 238 in energy conservation equations, 252 Fourier's constitutive equation v., 199, 201-9 heat transfer coefficient and, 200, 201-6 heat transfer correlation and, 200, 201-6 Prandtl number and, 270 Reynolds number v., 268 in shell and tube heat exchanger design, 333 in thermal conduction, 199-201 transport correlations for, 264 Ohm's "Law," 128 orifices bubble size and, 303, 310-11 gas flow power input in, 307, 311 in gas spargers, 303 oxidation units, 154 oxygenation of water, 281 oxygen concentrations in liquid-gas mass contactors, 122, 143 in mixed-plug fluid motion, 142 in pilot-scale bioreactors, 346-8, 350, 351 stripping of, 117 in water in contact with air, 121 packed towers, 336, 338 flooding/pressure drops in, 340 height of. 344 operability limits for, 339 technically feasible design for, 335, 344 volume of, 344 packing, 335 random, 341 partial pressure, in liquid-gas mass contactors,122 PDF model. See probability distribution function model penetration theory, in fluid-fluid systems, 273-8

Cambridge University Press 978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

Index

371

in countercurrent mass contactor design, 342 Fick's constitutive equation in, 276 Fourier's constitutive equation in, 276 local boundary layer for, 275 surface renewal theory and, 278 surface renewal time in, 274 penetration time, 274 penicillin, 139, 141 permeance, 231 phase equilibrium, 6 pilot-scale batch heat exchangers, 66 pilot-scale bioreactors, 345-52 air spargers in, 348-52 biomass concentrations in, 347-8 Candida utilis in, 345 gas hold-up equation in, 349 mass transfer rates in, 347 oxygen concentrations in, 346-8, 350, 351 plumes in, 349 pipe schedules, 332 plate and frame heat exchanger, 80-1 plug-flow fluid motion, 81 in CFSTRs, 41 in Level III mathematical models, 7 in Level IV mathematical models, 7 in mass and/or heat transfer, 7 plug-flow rates, for CFSTRs, 41 plug-flow reactors (PFRs), 42 heat exchanger analysis and, 113 plug-flow velocity, 42, 43 plug-plug heat exchangers, double pipe exchangers and, 56 plumes, 302 diameter of, 313 in gas spargers, 311 interfacial areas for, 312, 315 liquid circulation model and, 312 in pilot-scale bioreactors, 349 volume equation of, 313 Pohlhausen solution, 261 Poisson process, 278 power input, 307, 311 Prandtl analogy, 264 Prandtl number, 186, 239 in energy conservation equations, 251, 252 in heat exchanger design, 330 Nusselt number and, 270 transport correlations for, 264 pressure drops, 340 probability distribution function (PDF) model, 301 raffinates, 116 Raoult's "Law," 165 Raschig rings, 341, 342, 343 rates of reaction in batch reactors, 23-5 in chemical reactor analysis, 26-33 rate expression of, 26-8

constants for. 20, 29 constitutive relationships for, 16 for gas phases, 27 in Level III mathematical models, 15 for mass transfer, 16 in semibatch reactors, 36 in tank type reactors, 33-41 reactor energy balance, 47-51 adiabatic reactors and, 48-9, 50 energy of activation in, 50 exothermic reactions in. 50 heat of reaction in, 48 reactors. See adiabatic reactors; batch reactors; bioreactors; chemical reactor analysis; continuous-flow stirred tank reactors; continuous mode tank reactors; pilot-scale bioreactors; semibatch reactors; single-phase reactors; tank types, for reactors; tubular reactors; two-phase reactors residence time in CFSTRs, 20, 46, 48 in coils, in semibatch heat exchangers, 73-4 Reynolds number, 186 in energy conservation equations, 251, 252 in heat exchangers design, 328 laminary boundary layer and, 256 in Navier-Stokes equations, 249, 250 Nusselt number v., 268 in shell and tube heat exchanger design, 332, 333 in species mass conservation equations, 253 transport correlations for, 264 in tubular two-phase mass contactors, 317 Reynolds transport analogy, 257-60 Sauter mean diameter, 302 schedule. See pipe schedules Schmidt number, 186, 236-9 in species mass conservation equations, 253 transport correlations for, 264 semibatch bioreactors, 346 semibatch heat exchangers, 67, 68-74 agitation nozzles in, 68 coil residence time in, 72, 73-4 energy balance in, 70 heat load for, 70 mixed-mixed fluid motion in, 69-72 mixed-plug fluid motion in, 68, 72-4 well-mixed fluid motion in, 68 semibatch mass contactors, 134-5, 137-43 mixed-mixed fluid motion in, 138-9 mixed-plug fluid motion in, 139-42 penicillin production in, 139, 141 semibatch reactors, 20, 34-7 component mass balance equations for, 36 model behavior for, 36 rate expression in, 36 reactants' introduction into, 34 species concentrations in, 34

978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

372 Index

separators in liquid-gas systems, 135 in liquid-liquid systems, 135 shell and tube heat exchangers, 79-80 technically feasible design for, 331, 334 heat transfer coefficients in, 332-4 HTRI procedures in, 331 Nusselt number in, 333 Reynolds number in, 332, 333 shell diameter in, 331-2 velocity factors in, 333 Sherwood number, 186, 238 Fick's constitutive equation and, 208 in molecular diffusion, 208-9 transport correlations for, 264 short time penetration solution for thermal conduction/diffusion, 233-5 thermal penetration depth in, 233, 234 sieve tray towers, 337 single-phase contactors, isothermal, 114 single-phase reactors control volume in, 21 Level I analysis for, 14 single-phase transport phenomena, in Level V models, 7 sodium acetate, 52 solid-fluid mass contactors, 115-16, 135 cocurrent tubular, 116 unit operations for, 115 adsorption, 115 desorption, 115 leaching, 115, 116 washing, 115, 116 solid-liquid mass contactors, 121, 132 sorption-diffusion model, 231 geometry in, 230 permeance in, 231 spargers, 303, 311 in pilot-scale bioreactors, 348-52 plumes and, 311 species mass conservation equations, 298-9 in convective heat transfer, 252-4 spray towers, 336 stage efficiency in continuous-flow two-phase mass contactors, 171 in countercurrent mass contactor design, 339 in mixed-mixed mass contactors, 147, 148 Stanton number, 239, 261 steady-state operations in CFSTRs, 38 in continuous-flow tank-type heat exchangers, 74 in continuous-flow two-phase mass contactors, 144 in countercurrent double pipe heat exchangers, 91 for thermal conduction, 192

for tubular heat exchangers, 84 in tubular two-phase mass contactors, 159 stripping, in liquid-gas mass contactors, 117 Sturm-Liouville Problem, 195 surface reaction, 299 surface renewal theory, in fluid-fluid systems, 273-8, 279 penetration theory and, 278 Poisson process in, 278 surface renewal time, 274 surface tension force, 304 tank-type mixed-mixed mass contactors, 117 tank-type mixed-plug mass contactors, 117 tank-type semibatch mixed-plug contactors, 116 tank types, for heat exchangers, 67-79 batch, 56-60, 63, 67, 68 continuous-flow, 74-9 fluid motion in, 55 mixed-mixed, 55 mixed-plug, 55 plug-plug, 55 semibatch, 67, 68-74 temperature controls in, 68 tank types, for reactors, 22 batch, 10, 11, 34 in chemical reactor analysis, 21-6 fluid motion in, 20 heat transfer in, 15 mass transfer in. 15 model equations for, 14, 28 CFSTRs, 20, 34, 37-41 constant density system in, 38 Level III analysis of, 39 residence time in, 20, 46, 48 steady-state operations in, 38 height to diameter ratio for, 34 rates of reactions in, 33-41 semibatch, 20, 34-7 component mass balance equations for, 36 model behavior for, 36 rate expression in, 36 reactants' introduction into, 34 species concentrations in, 34 tubular, 21, 42-7 conservation of mass in, 43 continuity equations in, 43 control volume in, 42 Level I analysis in, 43-4 mass balance in, 43 plug-flow velocity in, 42, 43 TCE. See trichloroethane technically feasible design, 327-52 for cocurrent double-pipe heat exchangers, 83 for countercurrent double-pipe heat exchangers, 92, 96, 328

Cambridge University Press 978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

Index

flooding limits in, 339 flow rate determinations in, 337-42 for gases, 339 interfacial area determination for, 343-5 liquid distributors, 319, 344 mass transfer coefficients in, 342 mass transfer load calculations in, 336 packed towers and, 336, 344 packing in, 335 penetration theory model and, 342 Raschig rings in, 341, 342, 343 stage efficiency in, 339 for heat exchangers, 94-102, 328-34 area estimation as part of, 98 coils in, 79, 98-9 density in, 96 double pipe, 334 feed temperature in, 96 heat capacity in, 96 heat transfer coefficient in local heat transfer coefficients in, 330 log-mean differences in, 98 overall heat transfer coefficients in, 330 pipe diameter/velocities in, 99, 102 Prandtl numbers in, 330 procedures for, 96-102 resources for, 96 Reynolds number in, 328, 330 viscosity in, 328 for multistage agitator towers, 337 for packed towers, 335, 344 procedures in, 345 for pilot-scale bioreactors, 345-52 air spargers in, 348-52 biomass concentrations in, 347-8 Candida utilis in, 345 gas hold-up equation in, 349 mass transfer rates in, 347 oxygen concentrations in, 346-8 plumes in, 349 for shell and tube heat exchangers, 331, 334 heat transfer coefficients in, 332-4 HTRI procedures in, 331 Nusselt number in, 333 Reynolds number in, 332, 333 shell diameter in, 331-2 velocity factors in, 333 for sieve tray towers, 337 for spray towers, 336 for tray towers, 335 for wetted wall columns, 336 thermal conduction, 187 composite layered materials, 212-22 Fourier's constitutive equation and, 214 heat transfer coefficients for, 212-17 one-dimensional, with convection, 215-20

for countercurrent mass contactors, 335-45

373

constant temperature boundary conditions in, 192 - 3constitutive equations in, 189 definition of, 188 experimental determination of, 187-95 Fourier's constitutive equation in, 187-95 differential forms of, 191 for one-dimensional non-planar geometries, 210 transient heat flow measurements for, 191 flux boundary conditions in, 193 general boundary conditions, 195, 197 with generation, 222-5 geometric effects on, 209-212 heat transfer coefficient in, 195, 220, 225, 230 heat transfer rates in, 194 mathematical considerations in, 195 measurement of, 191 mixed boundary conditions in, 194-5 Newton's "Law" of cooling in, 190, 194, 199 Nusselt number in, 186, 199-201 permeability values in, 231 Sturm-Liouville Problem and, 195 temperature profile in, 188 transient, 231-9 Fourier number v. Biot number in, 232 short time penetration solution for, 233-5 thermal conductivity crystallinity and, 190 of liquids, 190 material property definitions for, 189-90 of solids, 190 thermal diffusivity, 192 thermal equilibrium, 5 in Level II mathematical models, 5 thermodynamic property information, 170 time constraints, in Level VI mathematical models, 8 transient heat flow, 191 transport analogies, 247, 254-64 Chilton-Colburn, 260, 264, 265, 272 Lewis number in, 262 Pohlhausen solution in, 261 Stanton number in, 261 Reynolds, 257-60 Navier-Stokes equation in, 257 transport coefficient models in fluid-fluid systems. See also film theory, in fluid-fluid systems; interphase mass transfer, in fluid-fluid systems; penetration theory, in fluid-fluid systems; surface renewal theory, in fluid-fluid systems for heat/mass transfer, 273 film theory, 273 interphase mass transfer, 279-81 penetration theory, 273-8 surface renewal theory, 273-8, 279 transport correlations, 186

temperature profiles in, 216

tubular exchangers, 217

978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index

More information

374 Index

transport equations, 247-54 boundary layer analysis in, 254-64 for laminar boundary layer, 254-6, 258 derivation of, 293-9 for conservation of mass, 294 for energy, 296-8 for momentum, 294-6 for species mass, 298-9 differential, 259 control volume in, 293 for specific geometries, 264-73 transport phenomena, 5 multiple phase, in Level VI models, 8-9 single phase, in Level V models, 7 tray towers, technically feasible design for, 335 trichloroethane (TCE), 149 tubular cocurrent extractors, 117 tubular heat exchangers, 79-94. See also cocurrent double-pipe heat exchangers; countercurrent double-pipe heat exchangers; shell and tube heat exchangers BWG measurements for, 79, 101 cocurrent flow in, heat load in, 85-7 cross section of, 217 design procedures for, 334 double pipe, 55, 79 cocurrent, 81-8 countercurrent, 55, 81, 88-94 plug-plug heat exchangers and, 56 tubular-tubular plug flow in, 81 plate and frame, 80-1 shell and tube, 79-80 steady-state operations for, 84 thermal conduction/diffusion in, 217 tubular reactors, 21, 42, 47 conservation of mass in, 43 continuity equations in, 43 control volume in, 42 Level I analysis in, 43-4 mass balance in, 43 PFRs in. 42 plug-flow velocity in, 42, 43 tubular-tubular plug flow, 81 tubular two-phase mass contactors, 156-68 cocurrent flow in, 158-9 concentration profiles in, 163 conservation of mass in, 158 cross-sectional slice of, 158 Level II analysis for, 158 steady-state operations in, 159 countercurrent flow in, 157-8, 159-64 boundary conditions for, 161 concentration profiles in, 163 contactors in, 159-60 cross-sectional slice of, 161 equilibrium analysis for, 161-2 fluid velocity in, 159 for gas-liquid systems, 164 interfacial area in, 162

Level I analysis for, 160 Level II analysis for, 160 log-mean differences in, 167 molar gas flow rates in, 165 oil flow rates in, 167-8 operating diagram for, 153-74 Raoult's "Law" in, 165 technically feasible design for, 335-45 drop size in, 157 fluid motion systems in, 156, 157 interfacial areas in, 162, 316-20 Blasius solution and, 316, 317 cocurrent area estimation, 316 cocurrent K_m estimation, 318 continuous phase turbulent flow for, 317 countercurrent estimation, 318-19 countercurrent K_m estimation, 320 equilibrium bubble/drop distribution in, 317 gas flow rates in, 319 Kolmogorov-Hinze theory and, 316 low dispersed phase concentrations in, 317 Reynolds number in, 316 as membrane contactor, 156 turbulence, 302 two-phase mass contactors, 114, 118-19 batch, 118, 134-5 agitation in, 134-5 as continuous, 119 as dispersed, 119, 155 isothermal, 118 nonisothermal, 118 continuous flow, 143-56 design summary for, 168-74 isothermal, 114 semibatch, 134-5 tubular, 156-68 cocurrent flow in, 158-9 countercurrent flow in, 157-8, 159-64 drop size in, 157 fluid motion systems in, 156, 157 as membrane contactor, 156 two-phase reactors Level I analysis for, 14 unit operations, for solid-fluid mass contactors,

velocity, in shell and tube heat exchanger design, 333 vertical mass contactors, 160 viscosity in heat exchanger design, 328 Newton's "Law" of viscosity, 16 of water, 329 water bath batch heat exchangers, 57 Weber number 304

Weber number, 304 in bubble/drop breakage, 323 for impeller diameter, 308 modified, 304

115

Cambridge University Press 978-0-521-88670-3 - Mass and Heat Transfer: Analysis of Mass Contractors and Heat Exchangers T. W. Fraser Russell, Anne Skaja Robinson and Norman J. Wagner Index More information

Index

375

well-mixed fluid motion in Level III mathematical models, 6–7 in Level IV mathematical models, 7 in semibatch heat exchangers, 68 wetted wall columns, 336 wind-chill factors, 246 word statement of conservation laws, 13 for batch heat exchangers, 57 control volumes in, 11 in heat exchanger analysis, 60 for mass, 13–14 in tubular reactors, 44