

Contents

Preface	xi
I Transport phenomena	1
1 Conservation equations	3
1.1 Mass conservation equations	5
1.2 Navier-Stokes equations	10
1.3 Flow in a porous medium	18
1.4 Energy conservation equation	19
1.5 Bibliography	23
1.6 Examples and problems	23
2 Incompressible fluid dynamics	29
2.1 Bernoulli's equation	30
2.2 Generalized Bernoulli equation	33
2.3 The viscosity of fluids	37
2.4 The compressibility of a gas	38
2.5 Unsteady flows	40
2.6 Dimensional analysis	42
2.7 Poiseuille flow	43
2.8 Turbulent flow in a tube	45
2.9 Laminar boundary layer on a flat plate	49
2.10 Numerical solution, formulation	53
2.11 Bibliography	55
2.12 Examples and problems	56
3 Conduction heat transfer	65
3.1 Steady-state heat conduction	67
3.2 Thermal conductivity of matter	69
3.3 Composite wall	70
3.4 Cylindrical geometry	72
3.5 Fin theory	73
3.6 Heat sources	76

3.7	Unsteady-state heat conduction	78
3.8	Periodic regime	84
3.9	Bibliography	88
3.10	Examples and problems	88
4	Forced convection	95
4.1	Laminar flow in a cylindrical tube	96
4.2	Annular region between concentric tubes	101
4.3	Laminar boundary layer on a flat wall	107
4.4	Turbulent flow in a tube	111
4.5	Turbulent external boundary layer	118
4.6	Heat exchangers	120
4.7	Bibliography	128
4.8	Examples and problems	129
5	Natural convection	137
5.1	Dimensional analysis of natural convection	138
5.2	Natural convection in a porous medium	143
5.3	Natural convection in a fluid layer	149
5.4	Annular layer between horizontal cylinders	151
5.5	Mixed convection	158
5.6	Taylor instability	164
5.7	Experimental results	167
5.8	Bibliography	169
5.9	Problem	170
6	Radiation heat transfer	171
6.1	Black-body radiation	172
6.2	Radiation view factors	176
6.3	Radiation in enclosures of black bodies	180
6.4	Radiation of real bodies	181
6.5	Radiation between grey bodies	183
6.6	Radiation in absorbing media	186
6.7	Bibliography	193
6.8	Problems	193
7	Mass transfer	197
7.1	Definitions	197
7.2	Fick's law for a binary mixture	199
7.3	Molecular diffusion in gases	201
7.4	Molecular diffusion in liquids	203
7.5	Steady-state diffusion, examples	204
7.6	Molecular diffusion in solids	208
7.7	Falling liquid film, laminar flow	211
7.8	Convective mass transfer	213
7.9	Multi-component mixtures	219

7.10	Simultaneous heat and mass transfer	220
7.11	Interface mass transfer	222
7.12	Diffusion and reaction in homogeneous systems	228
7.13	Bibliography	235
7.14	Problems	236
II	Numerical solution	243
8	Finite differences	245
8.1	Partial differential equations, classification	246
8.2	Finite differences	248
8.3	A parabolic equation	250
8.4	Explicit scheme	251
8.5	Stability of a numerical scheme	252
8.6	Other explicit schemes	253
8.7	Implicit methods	254
8.8	Treatment of boundary conditions	258
8.9	Consistency of a numerical scheme	259
8.10	Cylindrical and spherical geometries	260
8.11	Non-linear equations	261
8.12	Interface between two media	262
8.13	Alternating direction methods	264
8.14	Methods for 3-D problems	265
8.15	Bibliography	266
8.16	Problems	267
9	Elliptic equations	273
9.1	Iterative methods of solution	274
9.2	Relaxation methods	277
9.3	Natural convection in a porous medium	278
9.4	Vorticity-stream function formulation	282
9.5	ω - ψ formulation, boundary conditions	287
9.6	Calculation of the pressure field	290
9.7	Alternating direction methods	291
9.8	Bibliography	294
9.9	Problems	295
10	Finite volume method	309
10.1	Finite volume technique	310
10.2	The basic rules	312
10.3	Boundary conditions	313
10.4	Unsteady regime	314
10.5	Staggered grids	316
10.6	Discretization of advection terms	317
10.7	The SIMPLE algorithm	322

10.8 Conclusion	326
10.9 Bibliography	326
A Equations in curvilinear coordinates	327
A.1 Cartesian coordinates	327
A.2 Cylindrical coordinates	328
A.3 Spherical coordinates	330
B Vector analysis	333
B.1 Vectors, elementary properties	333
B.2 Geometry of a curve in space	338
B.3 Orthogonal curvilinear coordinates	345
B.4 Bibliography	351
B.5 Problems	351
C An introduction to tensor analysis	355
C.1 Indicical notation	355
C.2 Definition and properties of a tensor	356
C.3 Bibliography	360
D Prediction of transport properties	361
D.1 Transport properties	361
E Laplace transforms	365
E.1 Properties	365
E.2 Laplace transforms	367
F The solution of Bessel's equation	375
F.1 Bessel's equation	376
F.2 Legendre's equation	383
F.3 Bibliography	385
G Radiative transfer in a cloud of particles	387
G.1 Introduction	387
G.2 Theory	388
G.3 Results and discussion	391
G.4 Conclusions	393
G.5 Nomenclature	393
G.6 Bibliography	394
H The Runge-Kutta method	397
H.1 Runge-Kutta algorithm	397
H.2 Bibliography	400
I Integration using Gaussian quadrature	401
Index	409