

Contents

	<i>Preface</i>	<i>page</i> xiii
	<i>List of Symbols</i>	xv
1	Introduction	1
	1.1 Momentum, Mass and Heat Transfer	1
	1.2 Prerequisites	4
	1.3 Notation	5
2	Hydrostatics	8
	2.1 Statics Kinematics Dynamics	8
	2.2 Pressure	8
	2.2.1 Pressure under the Sea	11
	2.2.2 Pressure in the Atmosphere	12
	2.3 Forced Vortex	14
	2.3.1 Newton's Pail	17
	2.4 Free Vortex	20
	2.5 Further Reading	24
	Exercises	24
3	Outline of Continuum Mechanics and Fluid Dynamics	26
	3.1 Introduction	26
	3.2 Deformation and Displacement	26
	3.3 Velocity and Acceleration	29
	3.4 Acceleration in Non-Inertial Frames	34
	3.4.1 Non-Inertial Frame	34
	3.4.2 Coriolis Force on Earth	38
	3.5 Displacement	40
	3.5.1 Finite Deformation	40
	3.5.2 Infinitesimal Deformation	42
	3.6 Kinematics	45

3.7	Cauchy Stress and Equilibrium	47
3.8	Generalised Hooke's Law for Isotropic Solids	50
3.9	Equations of Motion in Fluids	52
3.9.1	Kinematics	52
3.9.2	Dynamics	55
3.10	Incompressible Fluids, Navier–Stokes Equations	57
3.11	'No slip' or 'Stick-to-the-Wall' Rule	60
3.11.1	Slip Length	60
3.12	Ideal Fluids	63
3.13	Bernoulli's Equation	64
3.14	Hagen–Poiseuille Flow	66
3.15	Further Reading	69
	Exercises	70
4	Conservation and Dynamics in Fluids	71
4.1	Introduction	71
4.2	Conservations Laws	71
4.3	Reynolds's Theorem	73
4.4	Mass, Equation of Continuity	78
4.5	Momentum	81
4.5.1	Control Volume Method	81
4.5.2	Non-Inertial Frame	84
4.5.3	Differential Equation Method	85
4.6	Angular Momentum	88
4.7	Energy	90
4.8	The Infinitesimal Control Volume: Heat and Work	92
4.9	Energy Balance in Differential Form	96
4.10	Equations of Motion	98
4.10.1	Note about Pressure	101
4.11	Euler's Equations	105
4.12	Viscosity	107
4.13	Reynolds Number, Dynamical Similarity	109
4.14	Examples	113
4.14.1	Laminar Flow between Parallel Plates	113
4.14.2	Couette Flow	115
4.14.3	Fluid Flowing down a Vertical Wall	119
4.14.4	Stokes's Resistance Formula	121
4.14.5	Flow Past a Cylinder	124
4.14.6	Flow through Porous Media, the Darcy Law	126

<i>Contents</i>		ix
4.15	Boundary Layer	129
4.15.1	Prandtl's Equations	129
4.15.2	Boundary Layer at a Flat Plate	130
4.16	Energy and Momentum Theorems Combined	137
4.17	Further Reading	140
	Exercises	140
5	Bernoulli's Equation, Vorticity and Inviscid Flow	142
5.1	Applications of Bernoulli's Equation	142
5.1.1	Reminder of Bernoulli's Equation	142
5.1.2	Sharp Crested Weir	143
5.1.3	Sharp Enlargement of a Pipe	144
5.1.4	Venturi	146
5.2	Conservation of Circulation	149
5.3	Potential Flow	152
5.3.1	Flow Past a Ball	152
5.3.2	Flow Past a Cylinder	154
5.4	Drag, d'Alembert's Paradox	156
5.5	Caution	159
5.5.1	Solution Patching	160
5.6	Complex Variables	160
5.6.1	Free Vortex	163
5.6.2	Source and Sink	164
5.6.3	Cylinder Moving in a Stationary Fluid	166
5.6.4	Uniform Flow	166
5.6.5	Superposition	167
5.7	Further Reading	167
	Exercises	168
6	Mass Transfer in Fluids – Chemical and Materials Processing	169
6.1	Overview	169
6.2	In-Phase Transport	170
6.2.1	Heat Transfer	170
6.2.2	Mass Transfer	171
6.3	Inter-Phase Transport	172
6.4	Convection	172
6.5	Transport Equations and Transport Coefficients	172
6.6	Continuity Equations	175
6.7	Continuity of Solute Mass	178
6.8	Diffusion and Convection in Fluids	179

6.9	Special Cases in Diffusive and Convective Processing	183
6.9.1	Equimolar Counter Diffusion	184
6.9.2	Stagnant Solvent	185
6.9.3	Ternary Mixtures	186
6.10	Processes with Homogeneous Reaction	187
6.11	Steady State	191
6.11.1	Flux of Component A in a Stagnant Solvent	191
6.12	Enthalpy Flux Density	192
6.13	Further Reading	193
	Exercises	194
7	Diffusion in the Solid State	199
7.1	The Diffusion Equation	199
7.2	Diffusion from Fixed Concentration into a Semi Infinite Half Space	200
7.2.1	Depth of Penetration	204
7.3	A Model for Brazing	205
7.4	Diffusion Bonding	208
7.5	Approach to Equilibrium: Finite Spaces	210
7.6	Diffusion Coefficients	214
7.7	Fundamentals of Diffusion in Crystals	216
7.7.1	Fick's First Law	216
7.7.2	Mobility	217
7.7.3	Binary Alloy	219
7.7.4	Atomistic Aspects	224
7.7.5	Rate Theory Aspects	231
7.8	Appendix: Solution to the Finite Slab Problem	233
7.9	Further Reading	236
	Exercises	237
8	Heat Transfer	239
8.1	An Instance of Quenching	239
8.2	Conduction, Convection and Radiation	240
8.2.1	Conduction	240
8.2.2	Convection, Newton's Law of Cooling	241
8.2.3	Radiation	243
8.3	Steady State Conduction	244
8.3.1	First Type Boundary Condition	244
8.3.2	Convection Boundary Conditions	245
8.4	Heat Transfer across the Boundary Layer	245
8.4.1	Reynolds Analogy	246
8.4.2	Taylor–Prandtl Analogy	248

<i>Contents</i>		xi
8.5	Mass Transfer across the Boundary Layer	249
8.6	Further Reading	250
	Exercises	250
9	Dimensional Analysis	253
9.1	Dimensions and Units	253
9.2	Dimensionless Groups	254
9.3	The Buckingham Π -theorem	255
9.4	Drag	257
9.5	Pipe Flow	259
	9.5.1 Pipe Flow in Six Variables	259
	9.5.2 Pipe Flow in Four Variables	261
9.6	Dynamical Similarity, Open Channel Flow	264
9.7	Heat and Mass Transfer	267
	9.7.1 Heat Transfer across the Wall of a Pipe	268
9.8	Further Reading	269
	Exercises	270
	<i>Index</i>	271