
Contents

Preface	xv
Raj Kumar ARYA, George D. VERROS and J. Paulo DAVIM	
Part 1. Fundamental Principles	1
Chapter 1. Overview of Chemical Engineering	3
Devyani THAPLIYAL, Kshitij TEWARI, Chitresh Kumar BHARGAVA, Avinash CHANDRA, Pramita SEN, Rahul KUMAR, Amit K. THAKUR, George D. VERROS and Raj Kumar ARYA	
1.1. Introduction	3
1.2. History of chemical engineering	4
1.3. Chemical engineering profession.	5
1.4. Features and challenges in chemical engineering.	6
1.5. Conclusions	14
1.6. References	15
Chapter 2. Fundamentals of Material and Energy Balances	17
Kshitij TEWARI, Devyani THAPLIYAL, Chitresh Kumar BHARGAVA, Avinash CHANDRA, Pramita SEN, Rahul KUMAR, Amit K. THAKUR, George D. VERROS and Raj Kumar ARYA	
2.1. Introduction	17
2.2. Process term definitions.	18
2.3. Engineering calculations – introduction	21
2.4. International system of units (SI).	22
2.5. Analysis of processes and variables affecting density	25
2.5.1. Measurement of flow rate (using a rotameter and an orifice meter)	25
2.5.2. Measurement of fluid pressure.	28

2.6. Classification of material balances in process fundamentals.	29
2.6.1. State of processes	30
2.6.2. Applications and selection criteria.	30
2.7. General balance equation	30
2.7.1. Types of balances	31
2.7.2. Applications	31
2.8. Flow charts and process balancing	33
2.8.1. Flow chart scaling and basis of calculation.	33
2.8.2. Guidelines for balancing non-reactive processes.	33
2.9. Degree-of-freedom analysis.	33
2.9.1. Case analysis	34
2.9.2. Sources of equations to establish relationships between unknown variables	34
2.10. Procedure for calculating material balances in single unit processes	35
2.11. Recycling and bypassing	35
2.12. Limiting reactant	36
2.13. Product separation and recycling	37
2.14. Combustion	37
2.15. Single-phase systems.	38
2.15.1. Liquid and solid densities.	38
2.15.2. Ideal gases	38
2.15.3. Ideal gas mixture	39
2.16. Clausius–Clapeyron equation	39
2.17. Mass balance problem	42
2.18. Energy and the concept of energy balance	46
2.18.1. Energy balances for closed systems	46
2.19. Energy balances on open systems in the steady state	47
2.19.1. Steady-state energy balance of the open system	48
2.19.2. Procedures for energy balance	48
2.19.3. Mechanical energy balance.	48
2.19.4. Balances on non-reactive processes	49
2.19.5. Hypothetical process paths	49
2.19.6. Methodology for calculating energy balance	49
2.19.7. Variations in pressure under constant temperature conditions.	50
2.19.8. Sensible heat	50
2.20. Estimation of heat capacity	51
2.20.1. Energy balances on single-phase systems	52
2.21. Estimation and correlation of latent heat	52
2.22. Heats of solution and mixing	53
2.22.1. Reactive process balances	54
2.23. Heat of reaction measurement.	55
2.23.1. Formation reactions and heats of formation.	55

2.23.2. Energy balances for reactive processes	56
2.23.3. Method for determining the heat of reaction	56
2.23.4. Thermochemistry of solutions	58
2.23.5. Characteristics and properties of fuels	58
2.23.6. Heating value	59
2.23.7. Adiabatic flame temperature	59
2.23.8. Ignition	60
2.24. Energy balance problem	60
2.25. References	63
Chapter 3. Laws of Thermodynamics	65
Girish GUPTA and Neha DHIMAN	
3.1. Introduction	65
3.2. Thermodynamical systems	66
3.2.1. System	66
3.2.2. Surrounding	67
3.2.3. System boundary	67
3.3. Types of system	68
3.4. Macroscopic system and properties	69
3.5. State of system and state variables	70
3.6. Zeroth law of thermodynamics	71
3.6.1. Applicability of zeroth law	72
3.7. Heat	72
3.8. Work	73
3.9. State functions and path functions	73
3.10. First law of thermodynamics	74
3.11. Internal energy is a state function	74
3.12. Work and heat are path functions	75
3.13. Second law of thermodynamics	76
3.14. Thermal energy reservoir	76
3.15. Heat engines	77
3.16. The second law: Kelvin–Planck statement	77
3.17. The second law: Clausius’ statement	78
3.18. Refrigerator and heat pumps	78
3.19. References	78
Chapter 4. Thermodynamic Properties and Equations of States	79
Dipaloy DATTA	
4.1. Thermodynamic property relations of pure substances	80
4.1.1. Criteria of exactness	81
4.1.2. Maxwell equations	82

4.1.3. Enthalpy and entropy as functions of temperature and pressure	83
4.1.4. Volume expansivity and isothermal compressibility.	85
4.1.5. Acentric factor	87
4.1.6. Specific heat at constant volume and constant pressure	88
4.1.7. Clapeyron equation	92
4.1.8. Relation between vapor pressure and temperature	93
4.1.9. Residual property	94
4.1.10. Fugacity and its coefficient	97
4.1.11. Excess property	99
4.2. Equations of states	99
4.2.1. Virial equations of states	99
4.2.2. Cubic equations of states	100
4.3. References	102
Chapter 5. Thermodynamics and Phase Equilibrium	103
Vyomesh M. PARSANA, Abhishek GUPTA, Dharmesh SUR and Kedar JOSHI	
5.1. Introduction	103
5.2. Fundamentals of thermodynamics	104
5.2.1. Phase rule and degree of freedom	104
5.2.2. Fundamental laws and related equations	105
5.2.3. Chemical potential and equilibrium	107
5.2.4. Total and specific properties	108
5.2.5. Partial molar properties.	110
5.2.6. Excess and residual properties	110
5.3. Vapor–liquid equilibrium	111
5.3.1. Equilibrium in general; and vapor–liquid equilibrium.	111
5.3.2. Types of VLE data/diagrams.	111
5.3.3. Basic laws and properties	114
5.3.4. Gamma-phi formulation	116
5.3.5. Azeotropic mixtures	117
5.3.6. Classification of VLE calculations	118
5.3.7. Flash calculations	119
5.3.8. Activity coefficients models to correlate VLE data	120
5.3.9. Prediction and measurement of vapor–liquid equilibrium.	123
5.3.10. The Gibbs–Duhem equation and thermodynamic consistency.	126
5.4. Solid–liquid equilibrium	128
5.5. Liquid–liquid equilibrium.	130
5.5.1. Introduction	130
5.5.2. Binary LLE system	131

5.6. References	132
5.7. Further reading.	133
Part 2. Fluid Mechanics and Transport Phenomena	135
Chapter 6. Basics of Flow Through Equipment	137
Devyani THAPLIYAL, Kshitij TEWARI, Chitresh Kumar BHARGAVA, Avinash CHANDRA, Pramita SEN, Rahul KUMAR, Amit K. THAKUR, George D. VERROS and Raj Kumar ARYA	
6.1. Fundamental laws of fluid mechanics	137
6.1.1. The general balance laws of continuum physics	137
6.1.2. The one-component system	138
6.1.3. Nonequilibrium thermodynamics and flow.	142
6.1.4. Definitions in fluid flow	147
6.2. Pumps, compressors and flowmeters.	153
6.2.1. Pumps	153
6.2.2. Compressors.	157
6.2.3. Flowmeters	161
6.3. Pressure drop in designing equipment	164
6.3.1. Pressure drop in single-phase flow	164
6.3.2. Two-phase gas–liquid flow in chemical industry	171
6.3.3. Particle motion in fluids	174
6.4. Computational fluid dynamics	175
6.4.1. A tutorial example: flow over a step	176
6.4.2. Recent advancements in CFD	179
6.5. Conclusions	183
6.6. References	183
Chapter 7. Conduction, Convection and Radiation.	189
Thangallapalli SRINIVAS, G. SRINIVAS, B.K. PUROHIT and A.V. RAGHAVENDRA RAO	
7.1. Fundamentals of heat transfer mechanisms	189
7.1.1. Introduction to conduction, convection and radiation	190
7.1.2. Relationship to thermodynamics.	192
7.2. Conduction	193
7.2.1. Fourier’s heat conduction law	193
7.2.2. The matter’s thermal properties	193
7.2.3. Heat conduction through solids and composite materials	195
7.3. Convection heat transfer	207
7.3.1. Classification of convection heat transfer.	207
7.3.2. Newton’s law of cooling	208
7.3.3. Local and average convection coefficients	209

7.3.4. Boundary layers, Nusselt number and Prandtl number	211
7.4. Radiation heat transfer	220
7.4.1. Fundamental concepts	220
7.4.2. Radiation heat fluxes – different laws of thermal radiation	223
7.4.3. View factor	225
7.5. References	226
Chapter 8. Diffusion and Mass Transfer Coefficients	229
A.V. RAGHAVENDRA RAO, Rompicherla SRIVIDYA, V. Sravani SAMEERA, K.S.N.V. PRASAD and Thangallapalli SRINIVAS	
8.1. Introduction	229
8.2. Diffusion mass transfer	231
8.2.1. Diffusion in gases	232
8.2.2. Diffusion in liquids	237
8.2.3. Diffusion in solids	241
8.3. Mass transfer coefficients	244
8.3.1. Interphase mass transfer	245
8.3.2. Concentration profiles at the interface	246
8.3.3. Overall mass transfer coefficient (K)	246
8.3.4. Mass transfer theories: unveiling the mechanisms of interphase transport	247
8.3.5. Factors affecting mass transfer coefficients	248
8.3.6. Measurement of mass transfer coefficients	250
8.3.7. Advances in mass transfer coefficients	251
8.4. Nomenclature	252
8.5. References	253
Part 3. Separation Processes	263
Chapter 9. Extraction	265
Juli DAS, Diptanu DE, Aanchal MITTAL, G.C. JEEVITHA and Sangeeta GARG	
9.1. Introduction	265
9.2. Conventional extraction methods.	266
9.2.1. LLE	267
9.2.2. SPE.	268
9.2.3. Solvent extraction.	269
9.2.4. Maceration.	271
9.2.5. Infusion and percolation	273
9.2.6. Hydrodistillation	274
9.2.7. Hydrodiffusion	276
9.2.8. Decoction	277

9.2.9. Steam distillation	277
9.2.10. Extractive distillation	279
9.2.11. Sublimation	281
9.2.12. Chromatography	282
9.2.13. Extraction by soxhlet	283
9.2.14. Solvent-free microwave extraction.	285
9.2.15. Magnetic extraction	286
9.3. Modern extraction methods	286
9.3.1. Accelerated solvent extraction	287
9.3.2. MAE	288
9.3.3. UAE	289
9.3.4. Enzyme-assisted extraction	290
9.3.5. SFE.	291
9.3.6. Pressurized hot water extraction	292
9.3.7. Pulsed electric field-assisted extraction	293
9.4. Conclusion	294
9.5. References	295
Chapter 10. Distillation	303
Neha DHIMAN and Girish GUPTA	
10.1. Introduction	303
10.2. Applications of distillation process	304
10.3. Relative volatility	305
10.4. Classification of distillation	307
10.4.1. Simple distillation	307
10.4.2. Equilibrium or flash distillation	309
10.4.3. Steam distillation	311
10.4.4. Azeotropic and extractive distillation	312
10.4.5. Fractional distillation	316
10.4.6. McCabe–Thiele method: calculation of the number of theoretical plates	318
10.4.7. McCabe–Thiele method (binary mixtures)	325
10.4.8. Fenske–Underwood–Gilliland (FUG) method (multicomponent mixtures)	326
10.4.9. Practical application and software tools	327
10.4.10. Flooding velocity and calculation	328
10.4.11. Tray types.	328
10.5. References	330

Chapter 11. Mathematical Modeling of Binary and Multicomponent Distillation.	331
Ananya MUNNANGI, MUTHAMIZHI K., KARTHIKEYAN C., K. TAMILSELVI and A.B. MOHAMMED BASITH	
11.1. Introduction	331
11.2. Ideal simple distillation	332
11.3. Nonideal multicomponent distillation	337
11.4. Batch distillation	340
11.5. Applications and advancements.	342
11.6. Conclusion	343
11.7. References	343
Chapter 12. Filtration and Membrane Processes	345
Esmail ALLAHKARAMI and Ebrahim ALLAHKARAMI	
12.1. Introduction	346
12.2. Types of membranes	349
12.2.1. Microfiltration (MF)	351
12.2.2. Ultrafiltration (UF)	356
12.2.3. Nanofiltration (NF)	359
12.2.4. Reverse osmosis (RO).	361
12.3. Membrane fabrication techniques.	363
12.4. Application of membrane processes	367
12.4.1. Water and wastewater treatment	368
12.4.2. Desalination	369
12.4.3. Membrane processing in the food industry	371
12.4.4. Pharmaceutical and biotechnology.	372
12.4.5. Gas separation	373
12.4.6. Medical applications	374
12.5. Membrane fouling	374
12.6. Conclusion	380
12.7. References	381
Chapter 13. Pervaporation	393
Tapas PALAI, Abhishek KUMAR and Leela Manohar AESHALA	
13.1. Introduction	393
13.2. Basics of membrane separation processes	394
13.2.1. Classification of membrane processes	395
13.2.2. Conventional membrane separation processes	397
13.2.3. Advanced membrane separation processes	400
13.3. Pervaporation	401
13.3.1. Theory of pervaporation	402
13.3.2. Selectivity of pervaporation	407

13.3.3. Pervaporation laboratory scale set-up	408
13.3.4. Applications	409
13.3.5. Models	412
13.4. Selection of membrane.	413
13.4.1. Affinity for target components	414
13.4.2. Permeability and selectivity	414
13.4.3. Stability and durability	414
13.4.4. Material compatibility.	415
13.4.5. Thickness.	415
13.4.6. Resistance to fouling	416
13.4.7. Cost and scalability	417
13.5. Recent developments.	418
13.5.1. Advanced membrane materials.	418
13.5.2. Customized membrane module design	418
13.5.3. Integration with different technologies	419
13.5.4. Scalability and process optimization.	420
13.6. Future scope and emerging trends	420
13.7. References	421
List of Authors	427
Index.	431
Summary of Volume 2	435

