

Contents

<i>Preface</i>	ix
<i>Acknowledgements</i>	xiv
<i>Nomenclature</i>	xv
1 Some general considerations	
1.1 Introduction	1
1.2 Tray types	2
1.3 Classifying distillation systems	3
1.3.1 Variation of physical properties with flow parameter	3
1.3.2 Change of flow regime with flow parameter	7
1.3.3 Variation of column diameter and number of passes with loading	8
1.4 An outline design procedure	8
2 Bubbles, froth, spray and foam	
2.1 Introduction	12
2.2 Bubbling from single holes	14
2.2.1 Qualitative description of bubbling from single holes	14
2.2.2 Simple model for ideal bubbling from a single hole	18
2.2.3 Bubble sizes on formation from single holes	21
2.3 Bubbling from multiple holes	23
2.3.1 Bubble sizes on formation from multiple holes	23
2.4 Froths	23
2.4.1 The bubble regime on sieve trays	23
2.4.2 The froth regime	24
2.5 Emulsion flow regime	29
2.6 The froth–spray transition	30
2.6.1 Experimental determination of the froth–spray transition	31
2.6.2 Bubbling and jetting at a single hole	32

vi	<i>Contents</i>	
	2.6.3 Correlations for the froth–spray transition on sieve trays	34
	2.6.4 Froth–spray transition on trays other than sieve trays	37
2.7	Spray regime	38
	2.7.1 Introduction	38
	2.7.2 Free trajectory model	39
	2.7.3 Correlations for use in the free trajectory model	40
2.8	Foam	44
	2.8.1 Introduction	44
	2.8.2 Film stabilisation by the Marangoni effect	45
	2.8.3 Other causes of film stabilisation	49
	2.8.4 Hydrodynamic conditions for foam stability on trays	49
	2.8.5 Mathematical models for foam	50
	2.8.6. Dealing with foaming systems	51
	3 Clear liquid height, dispersion height and density	
3.1	Introduction	54
3.2	Measurement of clear liquid height	54
3.3	Prediction of dispersion density	56
3.4	Prediction of clear liquid height	58
	3.4.1 Francis’s equation for flow over the exit weir	58
	3.4.2 Clear liquid height on sieve trays	59
3.5	Prediction of dispersion height	61
3.6	Which correlations to use?	61
3.7	The influence of liquid exit and entry conditions	61
	3.7.1 Exit calming zones	61
	3.7.2 Splash baffles	67
	3.7.3 Converging flow over the exit weir	68
	3.7.4 Liquid entry effects	68
3.8	Hydraulic gradient	72
3.9	Clear liquid height on valve trays	73
	4 Pressure drop	
4.1	Basic equations	76
4.2	Dry tray pressure drop – sieve trays	77
	4.2.1 Orifice coefficients	77
	4.2.2 Effect of entrainment on dry tray pressure drop	80
4.3	Residual pressure drop – sieve trays	80
4.4	Valve tray pressure drop	82
	4.4.1 Dry tray pressure drop – valve trays	82
	4.4.2 Residual pressure drop – valve trays	86
	5 Maximum capacity	
5.1	Flooding	87
	5.1.1 Introduction	87
	5.1.2 Flooding correlations	87
	5.1.3 Variables used in jet flooding correlations	92

<i>Contents</i>	vii
5.2 Liquid entrainment	94
5.2.1 Mechanism of entrainment	94
5.2.2 Measurement of entrainment	95
5.2.3 Prediction of entrainment	96
5.3 Downcomer hydraulics	98
5.3.1 Downcomer backup	98
5.3.2 Downcomer froth density	100
5.4 Empirical guidelines for downcomer design	102
5.4.1 Liquid velocity	103
5.4.2 Liquid weir load	103
5.4.3 Choking of the downcomer mouth	104
5.4.4 Clearance under the downcomer	105
5.4.5 Minimum weir length	105
5.5 Oscillations at high vapour flow rates	105
6 Weeping	
6.1 Turndown ratio	107
6.2 Weep point	108
6.2.1 Definition of weep point	108
6.2.2 Theoretical prediction of the weep point	110
6.2.3 Empirical correlations for the weep point	112
6.3 Empirical correlations for the weep rate	114
6.3.1 Dump point	116
6.4 Oscillation at low vapour flow rates	116
7 Tray efficiency	
7.1 The use of efficiencies in column design	118
7.2 Murphree tray efficiencies	119
7.2.1 Relationship between E_{ML} and E_{MV}	120
7.2.2 Relationship between E_{MV} and E_0	121
7.3 Hausen tray efficiency	121
7.3.1 Relationship between E_H and E_{MV}	122
7.4 Phase temperatures and saturation	123
7.5 Standart efficiency	124
7.6 Holland's vaporisation efficiency	124
7.7 Measurement of efficiency	125
7.8 Empirical correlations for efficiency	126
8 Point efficiency	
8.1 Basic equations for predicting efficiency for a binary mixture	128
8.2 Transfer unit definitions	129
8.2.1 Definitions of N_{OG} , N_G and N_L	129
8.2.2 N'_L – an alternative liquid-phase transfer unit	131
8.3 Relationship between E_{OG} and N_{OG}	133
8.4 Estimation of E_{OG} using an Oldershaw column	137
8.5 Estimation of E_{OG} from correlations	138
8.5.1 The slope and intercept method	138

viii	<i>Contents</i>	
	8.5.2 Correlations based on absorption, stripping and humidification	141
	8.5.3 Percentage liquid-phase resistance in distillation	143
	8.5.4 Chan & Fair's correlation	145
	8.5.5 Estimation of E_{OG} from individual values of k' and a	146
	8.5.6 Estimation of k'_G , k'_L and a using mass transfer with chemical reaction	148
8.6	Point efficiency and heat transfer	149
	8.6.1 Introduction	149
	8.6.2 Empirical equations	151
	8.6.3 Film theory model	152
	8.6.4 Other approaches	155
	8.6.5 Inter-tray heat transfer	155
8.7	Use of point efficiency models in design	157
	9 Relationship between point efficiency and tray efficiency	
9.1	Introduction	158
9.2	Lewis's three cases	159
9.3	A general equation for local liquid concentration	160
9.4	Simple backmixing model for Lewis's case 1	163
9.5	Simple backmixing model for Lewis's cases 2 and 3	163
9.6	Mixed pools model for liquid mixing	166
9.7	Measurement and correlation of eddy diffusivity	166
9.8	Horizontal vapour mixing between trays	170
9.9	Exploitation of Lewis's case 2	171
9.10	Effect of liquid entrainment on tray efficiency	172
9.11	Effect of weeping on tray efficiency	174
9.12	Effect of vapour entrainment on tray efficiency	177
9.13	Effect of liquid flow maldistribution on tray efficiency	177
	9.13.1 Bulk liquid velocity profiles	178
	9.13.2 How liquid maldistribution reduces tray efficiency	178
	9.13.3 The stagnant regions model (SRM)	180
	9.13.4 Other liquid maldistribution models	183
	9.13.5 Experimental evidence for efficiency reduction due to liquid flow maldistribution	184
	9.13.6 Control of the liquid velocity profile	185
	9.13.7 Non-uniform vapour flow	186
9.14	Multipass tray efficiency	186
	10 Prediction of efficiency for multicomponent mixtures	
10.1	Introduction	188
10.2	Pseudo-binary approach – method 1	189
10.3	Prediction of individual component efficiencies with no diffusional interactions – method 2	190
10.4	Prediction of individual component efficiencies including diffusional interactions – method 3	191

<i>Contents</i>	ix
10.5 Numerical example	194
10.6 Conclusion	197
Appendix A	
Horizontal momentum balance over the exit calming zone	198
Appendix B	
Apparent Murphree vapour-phase tray efficiency in the presence of entrainment and weeping	200
<i>References</i>	207
<i>Index</i>	225