

Contents

Preface — VII

1 Introduction — 1

2 Desalination — 3

- 2.1 Reverse osmosis — 4
- 2.2 Saline distillation — 6
 - 2.2.1 Multistage flash evaporation — 7
 - 2.2.2 Multi-effect distillation — 8
 - 2.2.3 The EasyMED project — 9

3 Physical foundations — 13

- 3.1 Single phase flow — 13
 - 3.1.1 Four different descriptions of fluid flow — 13
 - 3.1.2 The substantial derivative — 13
 - 3.1.3 The divergence of the velocity — 14
 - 3.1.4 The continuity equation — 15
 - 3.1.5 The Navier–Stokes equations — 16
 - 3.1.6 The energy equation — 18
 - 3.1.7 Thermal diffusion — 19
 - 3.1.8 Mass transport — 20
- 3.2 Two phase flow — 21
- 3.3 Evaporation — 24
- 3.4 Turbulence — 26
 - 3.4.1 What is turbulence? — 27
 - 3.4.2 The k - ε model — 28
 - 3.4.3 Turbulence near a wall — 32
 - 3.4.4 Turbulence near a free surface — 34
 - 3.4.5 Extension of the k-epsilon model for a free surface — 37

4 Fundamentals of falling films — 41

- 4.1 Flow regimes — 42
- 4.2 The smooth film — 43
- 4.3 The entrance region — 47
 - 4.3.1 Hydrodynamic point of view — 48
 - 4.3.2 Thermal point of view — 49
- 4.4 Stability — 49
- 4.5 Flow patterns — 53
- 4.6 Experimental correlations — 54

4.7	Simulations —	58
4.8	Mixture effects —	59
4.9	Enhancement of heat transfer —	59
4.10	Harmonic waves —	60
4.11	Long waves —	61
4.12	Zero streamline —	62
4.13	Reasonable approximations —	62
5	Numerical methods —	65
5.1	Finite volumes —	65
5.1.1	Diffusion —	66
5.1.2	Convection —	67
5.1.3	Transient problems —	68
5.2	The finite difference method —	71
5.3	The finite element method —	72
5.4	Volume of fluid (VOF) —	72
5.5	Continuum surface force —	76
5.6	Flows with phase change —	77
6	Simulations with Star-CD —	79
6.1	Effect of entrance region —	80
6.2	Hydrodynamic studies with one wire —	82
6.3	Wake of a wire —	84
6.4	Thermal studies —	85
6.5	New turbulence model —	88
7	Employment of OpenFOAM —	91
7.1	2D periodically excited waves —	91
7.2	3D simulations —	93
7.3	Peculiarities of wavy falling films —	95
7.4	Numerical experiments with wires —	100
8	A Lesson from FS3D —	105
9	Original programs —	107
9.1	One-dimensional model with VOF —	107
9.1.1	Effect of salinity —	108
9.1.2	Boiling point elevation —	108
9.1.3	Outline of the program —	109
9.1.4	Results of 1D simulations —	113
9.1.5	Refinement of 1D model —	114
9.2	Two-dimensional simulations with adaptive grid —	116

9.2.1	Comparison of 1D and 2D models —	118
9.3	Conjugate heat transfer —	119
9.4	Long wave equations —	122
9.5	Harmonic waves —	124
9.5.1	An efficient algorithm —	125
9.5.2	A more complex program —	126
9.6	With input from OpenFOAM —	129
9.6.1	Reading out —	129
9.6.2	Without convection —	131
9.6.3	With convection —	132
9.6.4	Random excitation —	133
9.7	The evaporation rate —	133
10	Generalization —	137
11	Discussion and conclusion —	141
A	Proof of equation (9.30) —	143
B	interFoam —	145
B.1	The directory constant —	145
B.2	The directory system —	145
B.3	The directory $\emptyset$ —	149
B.4	Running the program —	151
C	thinter —	153
C.1	How to compile thinter —	155
C.2	Test case —	157
D	Wires —	161
E	Counterstatement —	169
F	List of symbols —	171
Bibliography —		177
Index —		185