Table of Contents

Dedication	V
Table of Contents	vii
Preface	xiii
Foreword	xv
Acknowledgments	xvii
Part I. Fundamental of two-phase flow	
1. Introduction	1
1.1. Relevance of the problem	1
1.2. Characteristic of multiphase flow	. 3
1.3. Classification of two-phase flow	5
1.4. Outline of the book	10
2. Local Instant Formulation	11
1.1. Single-phase flow conservation equations	13
1.1.1. General balance equations	13
1.1.2. Conservation equation	15
1.1.3. Entropy inequality and principle of constitutive law	18
1.1.4. Constitutive equations	20
1.2. Interfacial balance and boundary conditions	24
1.2.1. Interfacial balance (Jump condition)	24

1.2.2. Boundary conditions at interface	32
1.2.3. Simplified boundary condition	38
1.2.4. External boundary condition and contact angle	43
1.3. Application of local instant formulation to two-phase flow	
problems	46
1.3.1. Drag force acting on a spherical particle in a very slow	
stream	46
1.3.2. Kelvin-Helmholtz instability	48
1.3.3. Rayleigh-Taylor instability	52
Part II. Two-phase field equations based on time average	
3. Various Methods of Averaging	55
1.1. Purpose of averaging	55
1.2. Classification of averaging	58
1.3. Various averaging in connection with two-phase flow	
analysis	61
4. Basic Relations in Time Averaging	67
1.1. Time domain and definition of functions	68
1.2. Local time fraction – Local void fraction	72
1.3. Time average and weighted mean values	73
1.4. Time average of derivatives	78
1.5. Concentrations and mixture properties	82
1.6. Velocity field	86
1.7. Fundamental identity	89
5. Time Averaged Balance Equation	93
1.1. General balance equation	93
1.2. Two-fluid model field equations	98
1.3. Diffusion (mixture) model field equations	103
1.4. Singular case of $v_{ni}=0$ (quasi-stationary interface)	108
1.5 Macroscopic jump conditions	110
1.6 Summary of macroscopic field equations and jump	
conditions	113
1.7 Alternative form of turbulent heat flux	114
6. Connection to Other Statistical Averages	119
1.1. Eulerian statistical average (ensemble average)	119
1.2. Boltzmann statistical average	120
Part III. Three-dimensional model based on time average	
7. Kinematics of Averaged Fields	129
1.1. Convective coordinates and convective derivatives	129

Thermo-Fluid Dynamics of Two-Phase Flow

1.2. Streamline	132
1.3. Conservation of mass	133
1.4. Dilatation	140
8. Interfacial Transport	143
1.1. Interfacial mass transfer	143
1.2. Interfacial momentum transfer	145
1.3. Interfacial energy transfer	149
9. Two-fluid Model	155
1.1. Two-fluid model field equations	156
1.2. Two-fluid model constitutive laws	169
1.2.1. Entropy inequality	169
1.2.2. Equation of state	172
1.2.3. Determinism	177
1.2.4. Average molecular diffusion fluxes	179
1.2.5. Turbulent fluxes	181
1.2.6. Interfacial transfer constitutive laws	186
1.3. Two-fluid model formulation	198
1.4. Various special cases	205
10. Interfacial Area Transport	217
1.1. Three-dimensional interfacial area transport equation	218
1.1.1. Number transport equation	219
1.1.2. Volume transport equation	220
1.1.3. Interfacial area transport equation	222
1.2. One-group interfacial area transport equation	227
1.3. Two-group interfacial area transport equation	228
1.3.1. Two-group particle number transport equation	229
1.3.2. Two-group void fraction transport equation	230
1.3.3. Two-group interfacial area transport equation	234
1.3.4. Constitutive relations	240
11. Constitutive Modeling of Interfacial Area Transport	243
1.1. Modified two-fluid model for the two-group interfacial area	
transport equation	245
1.1.1. Conventional two-fluid model	245
1.1.2. Two-group void fraction and interfacial area transport	
equations	246
1.1.3. Modified two-fluid model	248
1.1.4. Modeling of two gas velocity fields	253
1.2. Modeling of source and sink terms in one-group interfacial	
area transport equation	257
1.2.1. Source and sink terms modeled by Wu et al. (1998)	259
1.2.2. Source and sink terms modeled by Hibiki and Ishii	
(2000a)	267

ix

1.2.3. Source and sink terms modeled by Hibiki et al.	
(2001b)	275
1.3. Modeling of source and sink terms in two-group interfacial	
Area Transport Equation	276
1.3.1. Source and sink terms modeled by Hibiki and Ishii	
(2000b)	277
1.3.2. Source and sink terms modeled by Fu and Ishii	
(2002a)	281
1.3.3. Source and sink terms modeled by Sun et al. (2004a)	290
12. Hydrodynamic Constitutive Relations for Interfacial Transfer	301
1.1. Transient forces in multiparticle system	303
1.2. Drag force in multiparticle system	308
1.2.1. Single-particle drag coefficient	309
1.2.2. Drag coefficient for dispersed two-phase flow	315
1.3. Other forces	329
1.3.1. Lift Force	331
1.3.2. Wall-lift (wall-lubrication) force	335
1.3.3. Turbulent dispersion force	336
1.4. Turbulence in multiparticle system	336
13. Drift-flux Model	345
1.1. Drift-flux model field equations	346
1.2. Drift-flux (or mixture) model constitutive laws	355
1.3. Drift-flux (or mixture) model formulation	372
1.3.1. Drift-flux model	372
1.3.2. Scaling parameters	373
1.3.3. Homogeneous flow model	376
1.3.4. Density propagation model	378
Part IV. One-dimensional model based on time average	
14. One-dimensional Drift-flux Model	381
1.1. Area average of three-dimensional drift-flux model	382
1.2. One-dimensional drift velocity	387
1.2.1. Dispersed two-phase flow	387
1.2.2. Annular two-phase Flow	398
1.2.3. Annular mist Flow	403
1.3. Covariance of convective flux	406
1.4. One-dimensional drift-flux correlations for various flow	
conditions	411
1.4.1. Constitutive equations for upward bubbly flow	412
1.4.2. Constitutive equations for upward adiabatic annulus a	nd
internally heated annulus	412

1.4.3. Constitutive equations for downward two-phase flow 1.4.4. Constitutive equations for bubbling or boiling pool	413
systems	413
1.4.5. Constitutive equations for large diameter pipe	
systems	414
1.4.6. Constitutive equations at reduced gravity conditions	415
15. One-dimensional Two-fluid Model	419
1.1. Area average of three-dimensional two-fluid model	420
1.2. Special consideration for one-dimensional constitutive	
relations	423
1.2.1. Covariance effect in field equations	423
1.2.2. Effect of phase distribution on constitutive relations	426
1.2.3. Interfacial shear term	428
References	431
Nomenclature	441
Index	457