

Table of Contents

1	Flow regime transition criteria.....	1
1.1	Introduction	1
1.2	Pool flow	3
1.3	Adiabatic flows	6
1.3.1	Two important velocity scales	6
1.3.2	Channel flow – vertical pipes	9
1.3.3	Channel flow – inclined pipes	13
1.4	Heated channels.....	21
1.5	Porous media.....	23
1.6	Particles in film boiling	24
1.7	Rod bundles.....	25
	Nomenclature	27
	References	29
2	Drag, lift, and virtual mass forces.....	31
2.1	Drag forces	31
2.1.1	Introduction	31
2.1.2	Drag coefficient for single bubble	32
2.1.3	Swarms of particles in a continuum.....	36
2.1.4	Droplets-gas.....	41
2.1.5	Solid particles-gas in the presence of a liquid. Solid particles-liquid in the presence of a gas	42
2.1.6	Annular flow.....	51
2.1.7	Inverted annular flow.....	61
2.1.8	Stratified flow in horizontal or inclined rectangular channels	62
2.1.9	Stratified flow in horizontal or inclined pipes	65
2.2	Lift force.....	70
2.3	Virtual mass force	75
	Nomenclature	77
	References	81
3	Friction pressure drop.....	87
3.1	Introduction	87
3.2	Single-phase flow	87
3.2.1	Circular pipes.....	87
3.2.2	Annular channels	90

3.2.3	Arbitrary channel form	90
3.2.4	Axial flow in rod bundles	92
3.2.5	Cross flow in rod bundles	96
3.2.6	Pressure drop at spacers for bundles in nuclear reactors	99
3.3	Two-phase flow	102
3.4	Heated channels	110
3.5	Three-phase flow	112
	Nomenclature	114
	References	115
4	Diffusion velocities for algebraic slip models	119
4.1	Introduction	119
4.2	Drag as a function of the relative velocity	120
4.2.1	Wall force not taken into account	120
4.2.2	Wall forces taken into account	124
4.3	Two velocity fields	125
4.3.1	Single bubble terminal velocity	125
4.3.2	Single-particle terminal velocity	129
4.3.3	Cross-section-averaged bubble rise velocity in pipes – drift flux models	131
4.3.4	Cross-section-averaged particle sink velocity in pipes – drift flux models	148
4.4	Slip models	150
4.5	Three velocity fields – annular dispersed flow	152
4.6	Three-phase flow	153
	Nomenclature	156
	References	158
5	Entrainment in annular two-phase flow	161
5.1	Introduction	161
5.2	Some basics	162
5.3	Correlations	163
5.4	Entrainment increase in boiling channels	171
5.5	Residual film thickness at DO?	172
5.6	Entrainment increase due to obstacles	173
5.7	Size of the entrained droplets	173
	Nomenclature	174
	References	177
6	Deposition in annular two-phase flow	181
6.1	Introduction	181
6.2	Analogy between heat and mass transfer	181
6.3	Fluctuation mechanism in the boundary layer	183
6.3.1	Basics	183
6.3.2	Deposition to boiling films	186
6.3.3	Steady-state boundary layer treatment	187

6.4	<i>Zaichik's</i> theory	188
6.5	Deposition correlations	189
6.6	Leidenfrost heat transfer to a droplet bouncing on to a hot wall	193
	Nomenclature	194
	References	197
7	Introduction to fragmentation and coalescence.....	199
7.1	Introduction	199
7.2	General remarks about fragmentation	201
7.3	General remarks about coalescence.....	203
7.3.1	Converging disperse field	203
7.3.2	Analogy to molecular kinetic theory.....	204
7.4	Superposition of different droplet coalescence mechanisms	208
7.5	Superposition of different bubble coalescence mechanisms	209
7.6	General remarks about particle size formation in pipes	210
	Nomenclature	214
	References	216
8	Acceleration-induced droplet and bubble fragmentation.....	219
8.1	Critical <i>Weber</i> number	219
8.2	Fragmentation modes	228
8.3	Relative velocity after fragmentation	231
8.4	Breakup time	234
8.5	Particle production rate correlations.....	241
8.5.1	Vibration breakup	241
8.5.2	Bag breakup	241
8.5.3	Bag and stamen breakup	243
8.5.4	Sheet stripping and wave crest stripping following by catastrophic breakup	243
8.6	Droplet production due to highly energetic collisions.....	250
8.7	Acceleration-induced bubble fragmentation	252
	Nomenclature	256
	References	258
9	Turbulence-induced particle fragmentation and coalescence.....	263
9.1	Homogeneous turbulence characteristics	263
9.2	Reaction of a particle to the acceleration of the surrounding continuum.....	267
9.3	Reaction of a particle entrained inside the turbulent vortex – inertial range	268
9.4	Stability criterion for bubbles in a continuum	269
9.5	Turbulence energy dissipation due to the wall friction	273
9.6	Turbulence energy dissipation due to relative motion.....	274

9.7	Bubble coalescence probability.....	276
9.8	Coalescence probability of small droplets.....	280
	Nomenclature.....	281
	References.....	283
10	Liquid and gas jet disintegration.....	287
10.1	Liquid jet disintegration in pools.....	287
10.2	Boundary of different fragmentation mechanisms	289
10.3	Size of the ligaments	291
10.4	Unbounded instability controlling jet fragmentation.....	292
10.4.1	No ambient influence.....	292
10.4.2	Ambient influence	294
10.4.3	Jets producing film boiling in the ambient liquid	296
10.4.4	An alternative approach.....	298
10.4.5	Jets penetrating two-phase mixtures	299
10.4.6	Particle production rate.....	299
10.5	Jet erosion by a high-velocity gas environment	299
10.6	Jet fragmentation in pipes	301
10.7	Liquid spray produced in nozzles.....	303
10.8	Gas jet disintegration in pools	303
	Nomenclature.....	306
	References.....	309
11	Fragmentation of melt in coolant.....	311
11.1	Introduction.....	311
11.2	Vapor thickness in film boiling	313
11.3	Amount of melt surrounded by continuous water	314
11.4	Thermo-mechanical fragmentation of liquid metal in water	315
11.4.1	External triggers	316
11.4.2	Experimental observations.....	321
11.4.3	The thermal fragmentation mechanism	326
11.5	Particle production rate during thermal fragmentation.....	342
11.6	<i>Tang's</i> thermal fragmentation model	344
11.7	<i>Yuen's</i> thermal fragmentation model	346
11.8	Oxidation.....	347
11.9	Superposition of thermal fragmentation.....	348
11.9.1	Inert gases.....	348
11.9.2	Coolant viscosity increase	348
11.9.3	Surfactants	349
11.9.4	Melt viscosity	350
	Nomenclature.....	350
	References.....	353
	Index.....	359