Contents

Foreword		x
Preface		xi
Strands		xiv
1	**Single sphere resistance**	1
	Symbols	5
	References	6
2	**Resistance of particle beds**	7
2.1	Introduction	7
2.2	Comparison between particulate fluidization and flow through fixed beds	8
2.3	Definition of consistent, non-dimensional groups	10
2.4	An appropriate cell model	11
2.5	Results from investigation of the Navier–Stokes equations	13
2.6	Dependence of the drag of a sphere on the packing geometry	19
2.7	Experimental proof of the proposed concept	23
2.8	Approximation formula for beds of monodisperse spherical particles	26
2.9	Approximation formula for the pressure drop across fixed beds of polydisperse non-spherical particles	32
2.10	A practical concept to evaluate the pressure drop shape factor Φ_D	36
2.11	Comparison of equation (2.56) with other approximation formulae	38
	Symbols	41
	References	43
3	**Suspension of solid particles in agitated vessels**	44
3.1	Introduction	44
3.1	Boundary layer flow in an agitated vessel	44
3.3	Forces acting on solid particles settled in the boundary layer	49
3.4	Experimental set-up for the detection of complete suspension of solid particles	52

3.5	Evaluation of experiments: suspension of solid particles	53
3.6	Prediction of minimum angular velocities of the stirrer at $Ar \leqslant 40$	55
3.7	Limits of applicability	56
3.8	Fluidization of solid particles in an agitated vessel	56
3.9	Pump characteristics of an agitated vessel	60
3.10	Experimental proof of the proposed concept	62
3.11	Limits of applicability	64
3.12	Comparison of the different criteria	65
3.13	Reliable prediction of required minimum angular velocity of the stirrer	66
	Symbols	68
	References	69
4	**Hydrodynamics of bubble columns**	70
4.1	Introduction	70
4.2	Uniform bubbling regime: theory	71
4.3	Predictions of the theory	73
4.4	State diagram for homogeneous bubbling	75
4.5	Confirmation of equation (4.1) for low density ratios	76
4.6	Experimental set-up	77
4.7	Uniform bubbling regime: results and discussion	78
4.8	Prediction of bubble size in the homogeneous bubbling regime	81
4.9	Uniform bubbling regime: conclusions	82
4.10	Liquid circulation regime: state of the art	83
4.11	Liquid circulation regime: assumptions and definitions	84
4.12	Gas throughput due to the rise of small bubbles	88
4.13	Gas throughput due to the rise of large bubbles	89
4.14	Gas throughput due to liquid circulation	90
4.15	Non-dimensional representation of the amount of gas carried by large bubbles	93
4.16	Determination of the constant C from experiments	93
4.17	State diagram for the liquid circulation regime: comparison with experiments	95
4.18	Use of the state diagram for predictions	97
4.19	A three-parameter model for the residence time distribution of the gas phase	100
4.20	Experimental set-up	102
4.21	Data processing	103
4.22	Verification of the three-parameter model	105
	Symbols	108
	References	110

5 Non-dimensional groups for the representation of flow phenomena of disperse systems 112
5.1 Introduction 112
5.2 Presuppositions 112
5.3 Equations of motion of solid bodies 113
5.4 Forces and moments exerted by the fluid on a suspended particle 114
5.5 Non-dimensional groups which define the motion of suspended particles 115
5.6 Equivalent non-dimensional groups 116
5.7 Fluidization 117
5.8 Prediction of pressure drop with fully suspended flow in horizontal pipes 119
5.9 Hydraulic conveying: evaluation of experiments 121
5.10 Prediction of pressure drop over the full range of transportable concentrations 123
5.11 Pneumatic conveying with fully suspended flow 124
Symbols 130
References 132

6 Gas/solid flows with partial phase separation 133
6.1 Introduction 133
6.2 Pneumatic conveying in horizontal pipes: experimental results 135
6.3 Requirements for a rational model resulting from the experimental observations 135
6.4 Theoretical state diagram of stable strand flow 136
6.5 Plugging limit of pneumatic conveying 149
6.6 Strand flow type pneumatic conveying: comparison of prediction and measurements 152
6.7 Conclusions with respect to pneumatic conveying in horizontal tubes 154
6.8 Fast fluidization and circulating fluidized beds 156
6.9 Axial pressure profiles in the upstream part of a circulating fluidized bed 157
6.10 Pressure gradients in the steady-state sections of a circulating fluidized bed 159
6.11 Partial phase separation, the essential feature of circulating fluidized beds 161
6.12 Modelling the fluid dynamics of circulating fluidized beds 162
6.13 Momentum transfer between lean phase and strands 163
6.14 Mass and momentum balances 164
6.15 State diagrams for segregated gas–solid flows moving vertically upwards 167

6.16	Comparison with experimental results	178
6.17	Modes of operation of circulating fluidized beds with siphon	181
6.18	Modelling of circulating fluidized beds: conclusions	182
	Symbols	183
	References	184
7	**The use of synergetic effects: vibration-induced pneumatic conveying of fragile materials**	185
7.1	Introduction	185
7.2	Preliminary experiments	185
7.3	Theoretical foundation of vibration-induced pneumatic conveying	186
7.4	Evaluation of preferable operational regimes	188
7.5	Particulate material damage experiments	192
	Symbols	196
	References	196
8	**Flow behaviour of powders**	197
8.1	Introduction	197
8.2	Dependence of cohesion on influencing forces	199
8.3	Consequences for theory and experiment	203
8.4	Transmission of stresses in a randomly packed bed of monodisperse spheres	204
8.5	Dependence of the adhesive forces on previous compression	210
8.6	Theory of yield of cohesive materials	215
8.7	Comparison with experiments	226
8.8	Influence of the fine particle content on the flow behaviour	229
	Symbols	233
	References	235
9	**Heat transfer mechanisms in gas fluidized beds**	236
9.1	Introduction	236
9.2	General features of heat transfer in gas fluidized beds	236
9.3	State of the art	238
9.4	Heat transfer and fluid dynamics	239
9.5	Visual observation of particle motion close to solid surfaces	242
9.6	Basic features of particle convective heat transfer	243
9.7	Particle convective type of heat transfer in fluidized beds of fine-grained particles	247
9.8	Gas-to-particle heat transfer in fluidized beds of fine-grained particles	248
9.9	Correlations for gas convective heat transfer	249
9.10	Heat transfer when both particle and gas convective components are important	251

9.11 General features of the dependence of heat transfer on gas velocity in bubbling fluidized beds 254
9.12 Heat transfer with type A and type C powders 256
9.13 Heat transfer with type B-powders 259
9.14 Gas convective heat transfer 262
9.15 Heat transfer in circulating fluidized beds 263
Symbols 265
References 267

10 Types of gas fluidization 268
10.1 Introduction 268
10.2 Types of powder with gas–solid systems 268
10.3 Powder classification diagram 270
10.4 Experimental results 277
Symbols 278
References 279

11 Local structure of gas-fluidized beds 280
11.1 Introduction 280
11.2 Bubble features 280
11.3 Principal layout of the experimental set-up 282
11.4 Bubble flow pattern 283
Symbols 291
References 291

Index 293