Contents

1 The Overview and Scope of the Book 1

2 Basics of the Dimensional Analysis 3
2.1 Preliminary Remarks 3
2.2 Basic Definitions 3
2.2.1 Dimensional and Dimensionless Parameters 3
2.2.2 The Principle of Dimensional Homogeneity 7
2.3 Non-Dimensionalization of the Governing Equations 11
2.4 Dimensionless Groups 18
2.4.1 Characteristics of Dimensionless Groups 18
2.4.2 Similarity 21
2.5 The Pi-Theorem 23
2.5.1 General Remarks 23
2.5.2 Choice of the Governing Parameters 26
Problems 30
References 37

3 Application of the Pi-Theorem to Establish Self-Similarity and Reduce Partial Differential Equations to the Ordinary Ones 39
3.1 General Remarks 39
3.2 Flow over a Plane Wall Which Has Instantaneously Started Moving from Rest (the Stokes Problem) 44
3.3 Laminar Boundary Layer over a Flat Plate (the Blasius Problem) ... 47
3.4 Laminar Submerged Jet Issuing from a Thin Pipe (the Landau Problem) 51
3.5 Vorticity Diffusion in Viscous Fluid 54
3.6 Laminar Flow near a Rotating Disk (the Von Karman Problem) 55
3.7 Capillary Waves after a Weak Impact of a Tiny Object onto a Thin Liquid Film (the Yarin-Weiss Problem) 58
3.8 Propagation of Viscous-Gravity Currents over a Solid Horizontal Surface (the Huppert Problem) 60
3.9 Thermal Boundary Layer over a Flat Wall (the Pohlhausen Problem) 63

Bibliografische Informationen
http://d-nb.info/1009990624

digitalisiert durch DEUTSCHE NATIONAL BIBLIOTHEK

3.10 Diffusion Boundary Layer over a Flat Reactive Plate (the Levich Problem) 65
Problems 67
References 69

4 Drag Force Acting on a Body Moving in Viscous Fluid 71
4.1 Introductory Remarks 71
4.2 Drag Action on a Flat Plate 73
4.2.1 Motion with Constant Speed 73
4.2.2 Oscillatory Motion of a Plate Parallel to Itself 75
4.3 Drag Force Acting on Solid Particles 76
4.3.1 Drag Experienced by a Spherical Particle at Low, Moderate and High Reynolds Numbers 76
4.3.2 The Effect of Rotation 79
4.3.3 The Effect of Acceleration 80
4.3.4 The Effect of the Free Stream Turbulence 81
4.3.5 The Influence of the Particle-Fluid Temperature Difference 82
4.4 Drag of Irregular Particles 82
4.5 Drag of Deformable Particles 84
4.6 Drag of Bodies Partially Submerged in Liquid 86
4.7 Terminal Velocity of Small Spherical Particles Settling in Viscous Liquid (the Stokes Problem for a Sphere) 87
4.8 Sedimentation 90
4.8.1 Dimensionless Groups 90
4.8.2 Terminal Velocity of Heavy Grains 91
4.8.3 The Critical State of a Fluidized Bed 92
4.9 Thin Liquid Film on a Plate Withdrawn Vertically from a Pool Filled with Viscous Liquid (the Landau-Levich Problem of Dip Coating) 93
Problems 96
References 101

5 Laminar Flows in Channels and Pipes 103
5.1 Introductory Remarks 103
5.2 Flows in Straight Pipes of Circular Cross-Section 106
5.2.1 The Entrance Flow Region 106
5.2.2 Fully Developed Region of Laminar Flows in Smooth Pipes 109
5.2.3 Fully Developed Laminar and Turbulent Flows in Rough Pipe 109
5.3 Flows in Irregular Pipes and Ducts 111
5.4 Microchannel Flows 112
5.5 Non-Newtonian Flows 113

5.6 Flows in Curved Pipes 116
5.7 Unsteady Flows in Straight Pipes 120
Problems 123
References 129

6 Jet Flows 131
6.1 Introductory Remarks 131
6.2 The Far Field of Submerged Jets 136
6.3 The Dimensionless Groups of Jet Flows 139
6.4 Plane Laminar Submerged Jet 141
6.5 Laminar Wake of a Blunt Solid Body 143
6.6 Wall Jets over Plane and Curved Surfaces 146
6.7 Buoyant Jets (Plumes) 149
Problems 154
References 156

7 Heat and Mass Transfer 159
7.1 Introductory Remarks 159
7.2 Conductive Heat and Mass Transfer 160
7.2.1 Temperature Field Induced by Plane Instantaneous Thermal Source 160
7.2.2 Temperature Field Induced by a Pointwise Instantaneous Thermal Source 161
7.2.3 Evolution of Temperature Field in Medium with Temperature-Dependent Thermal Diffusivity (The Zel'dovich-Kompaneyets Problem) 162
7.3 Heat and Mass Transfer Under Conditions of Forced Convection .. 165
7.3.1 Heat Transfer from a Hot Body Immersed in Fluid Flow 165
7.3.2 The Effect of Particle Rotation 169
7.3.3 The Effect of the Free Stream Turbulence 171
7.3.4 The Effect of Energy Dissipation 173
7.3.5 The Effect of Velocity Gradient 174
7.3.6 Mass Transfer to Solid Particles and Drops Immersed in Fluid Flow 176
7.4 Heat and Mass Transfer in Channel and Pipe Flows 178
7.4.1 Couette Flow 178
7.4.2 The Entrance Region of a Pipe 180
7.4.3 Fully Developed Flow 181
7.5 Thermal Characteristics of Laminar Jets 183
7.6 Heat and Mass Transfer in Natural Convection 186
7.6.1 Heat Transfer from a Spherical Particle Under the Conditions of Natural Convection 186
7.6.2 Heat Transfer from Spinning Particle Under the Condition of Mixed Convection 187

7.6.3 Mass Transfer from a Spherical Particle Under the Conditions of Natural and Mixed Convection 189
7.6.4 Heat Transfer From a Vertical Heated Wall 190
7.6.5 Mass Transfer to a Vertical Reactive Plate Under the Conditions of Natural Convection 193
7.7 Heat Transfer From a Flat Plate in a Uniform Stream of Viscous, High Speed Gas 195
7.8 Heat Transfer Related to Phase Change 199
7.8.1 Heat Transfer Due to Condensation of Saturated Vapor on a Vertical Wall 199
7.8.2 Freezing of a Pure Liquid (The Stefan Problem) 202
Problems 205
References 209

8 Turbulence 211
8.1 Introductory Remarks 211
8.2 Decay of Isotropic Turbulence 215
8.3 Turbulent Near-Wall Flows 217
8.3.1 Plane-Parallel Flows 217
8.3.2 Pipe Flows 220
8.3.3 Turbulent Boundary Layer 221
8.4 Friction in Pipes and Ducts 222
8.4.1 Friction in Smooth Pipes 222
8.4.2 Friction in Rough Pipes 223
8.5 Turbulent Jets 224
8.5.1 Eddy Viscosity and Thermal Conductivity 224
8.5.2 Plane and Axisymmetric Turbulent Jets 229
8.5.3 Inhomogeneous Turbulent Jets 232
8.5.4 Co-flowing Jets 238
8.5.5 Turbulent Jets in Crossflow 245
8.5.6 Turbulent Wall Jets 248
8.5.7 Impinging Turbulent Jet 252
Problems 254
References 258

9 Combustion Processes 261
9.1 Introductory Remarks 261
9.2 Thermal Explosion 265
9.3 Combustion Waves 268
9.4 Combustion of Non-premixed Gases 271
9.5 Diffusion Flame in the Mixing Layer of Parallel Streams of Gaseous Fuel and Oxidizer 274

9.6 Gas Torches 280
9.7 Immersed Flames 288
Problems 294
References 296

Author Index 297

Subject Index 303