

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

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4.9 Thin Liquid Film on a Plate Withdrawn Vertically from a Pool Filled with Viscous Liquid (the Landau-Levich Problem of Dip Coating)	93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-Kompaneys 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

The Pi-Theorem

Applications to Fluid Mechanics and Heat and Mass
Transfer

Yarin, L.P.

2012, XXVI, 306 p., Hardcover

ISBN: 978-3-642-19564-8