

Contents

Dedication	Page	V
Foreword	VII	
Preface	XIII	
List of Symbols	XV	
1	Fundamentals of Mathematical Modeling of One-Dimensional Flows of Fluid and Gas in Pipelines	1
1.1	Mathematical Models and Mathematical Modeling	1
1.1.1	Governing Factors	3
1.1.2	Schematization of One-Dimensional Flows of Fluids and Gases in Pipelines	4
1.2	Integral Characteristics of Fluid Volume	5
1.3	The Law of Conservation of Transported Medium Mass. The Continuity Equation	7
1.4	The Law of Change in Momentum. The Equation of Fluid Motion	9
1.5	The Equation of Mechanical Energy Balance	11
1.5.1	Bernoulli Equation	15
1.5.2	Input of External Energy	16
1.6	Equation of Change in Internal Motion Kinetic Energy	17
1.6.1	Hydraulic Losses (of Mechanical Energy)	18
1.6.2	Formulas for Calculation of the Factor $\lambda(Re, \varepsilon)$	20
1.7	Total Energy Balance Equation	22
1.8	Complete System of Equations for Mathematical Modeling of One-Dimensional Flows in Pipelines	29
2	Models of Transported Media	31
2.1	Model of a Fluid	31
2.2	Models of Ideal and Viscous Fluids	32
2.3	Model of an Incompressible Fluid	34
2.4	Model of Elastic (Slightly Compressible) Fluid	34

2.5	Model of a Fluid with Heat Expansion	34
2.6	Models of Non-Newtonian Fluids	36
2.7	Models of a Gaseous Continuum	38
2.7.1	Model of a Perfect Gas	39
2.7.2	Model of a Real Gas	39
2.8	Model of an Elastic Deformable Pipeline	42
3	Structure of Laminar and Turbulent Flows in a Circular Pipe	45
3.1	Laminar Flow of a Viscous Fluid in a Circular Pipe	45
3.2	Laminar Flow of a Non-Newtonian Power Fluid in a Circular Pipe	47
3.3	Laminar Flow of a Viscous-Plastic Fluid in a Circular Pipe	49
3.4	Transition of Laminar Flow of a Viscous Fluid to Turbulent Flow	51
3.5	Turbulent Fluid Flow in a Circular Pipe	52
3.6	A Method to Control Hydraulic Resistance by Injection of Anti-Turbulent Additive into the Flow	62
3.7	Gravity Fluid Flow in a Pipe	65
4	Modeling and Calculation of Stationary Operating Regimes of Oil and Gas Pipelines	73
4.1	A System of Basic Equations for Stationary Flow of an Incompressible Fluid in a Pipeline	73
4.2	Boundary Conditions. Modeling of the Operation of Pumps and Oil-Pumping Stations	75
4.2.1	Pumps	75
4.2.2	Oil-Pumping Station	78
4.3	Combined Operation of Linear Pipeline Section and Pumping Station	81
4.4	Calculations on the Operation of a Pipeline with Intermediate Oil-Pumping Stations	84
4.5	Calculations on Pipeline Stationary Operating Regimes in Fluid Pumping with Heating	87
4.6	Modeling of Stationary Operating Regimes of Gas-Pipeline Sections	92
4.6.1	Distribution of Pressure in Stationary Gas Flow in a Gas-Pipeline	94
4.6.2	Pressure Distribution in a Gas-Pipeline with Great Difference in Elevations	96
4.6.3	Calculation of Stationary Operating Regimes of a Gas-Pipeline (General Case)	97
4.6.4	Investigation of Thermal Regimes of a Gas-Pipeline Section	98
4.7	Modeling of Blower Operation	100
5	Closed Mathematical Models of One-Dimensional Non-Stationary Flows of Fluid and Gas in a Pipeline	109
5.1	A Model of Non-Stationary Isothermal Flow of a Slightly Compressible Fluid in a Pipeline	109
5.2	A Model of Non-Stationary Gas Flow in a Pipeline	112

- 5.3 Non-Stationary Flow of a Slightly Compressible Fluid in a Pipeline 113
 - 5.3.1 Wave Equation 113
 - 5.3.2 Propagation of Waves in an Infinite Pipeline 115
 - 5.3.3 Propagation of Waves in a Semi-Infinite Pipeline 117
 - 5.3.4 Propagation of Waves in a Bounded Pipeline Section 119
 - 5.3.5 Method of Characteristics 121
 - 5.3.6 Initial, Boundary and Conjugation Conditions 124
 - 5.3.7 Hydraulic Shock in Pipes 127
 - 5.3.8 Accounting for Virtual Mass 134
 - 5.3.9 Hydraulic Shock in an Industrial Pipeline Caused by Instantaneous Closing of the Gate Valve 135
- 5.4 Non-Isothermal Gas Flow in Gas-Pipelines 138
- 5.5 Gas Outflow from a Pipeline in the Case of a Complete Break of the Pipeline 146
- 5.6 Mathematical Model of Non-Stationary Gravity Fluid Flow 149
- 5.7 Non-Stationary Fluid Flow with Flow Discontinuities in a Pipeline 152

- 6 Dimensional Theory 157**
 - 6.1 Dimensional and Dimensionless Quantities 157
 - 6.2 Primary (Basic) and Secondary (Derived) Measurement Units 158
 - 6.3 Dimensionality of Quantities. Dimensional Formula 159
 - 6.4 Proof of Dimensional Formula 161
 - 6.5 Central Theorem of Dimensional Theory 163
 - 6.6 Dimensionally-Dependent and Dimensionally-Independent Quantities 164
 - 6.7 Buckingham Π -Theorem 168

- 7 Physical Modeling of Phenomena 173**
 - 7.1 Similarity of Phenomena and the Principle of Modeling 173
 - 7.2 Similarity Criteria 174
 - 7.3 Modeling of Viscous Fluid Flow in a Pipe 175
 - 7.4 Modeling Gravity Fluid Flow 176
 - 7.5 Modeling the Fluid Outflow from a Tank 178
 - 7.6 Similarity Criteria for the Operation of Centrifugal Pumps 179

- 8 Dimensionality and Similarity in Mathematical Modeling of Processes 183**
 - 8.1 Origination of Similarity Criteria in the Equations of a Mathematical Model 183
 - 8.2 One-Dimensional Non-Stationary Flow of a Slightly Compressible Fluid in a Pipeline 184
 - 8.3 Gravity Fluid Flow in a Pipeline 186
 - 8.4 Pipeline Transportation of Oil Products. Batching 187

8.4.1 Principle of Oil Product Batching by Direct Contact 188
8.4.2 Modeling of Mixture Formation in Oil Product Batching 189
8.4.3 Equation of Longitudinal Mixing 192
8.4.4 Self-Similar Solutions 194

References 199

Appendices 201

Author Index 205

Subject Index 207