

3G E-LEARNING

Fluid Mechanics

FLUID MECHANICS

2ND EDITION



FLUID MECHANICS

2nd Edition



© 2022 3G E-learning LLC 90 Church Street FL 1 #3514 New York, NY 10008 United States of America www.3ge-learning.com email: info@3ge-learning.com

Authored and Edited by 3G E-learning LLC, USA

ISBN: 978-1-98465-932-3

This book contains information obtained from highly regarded resources. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the authors, editors, and the publisher cannot assume responsibility for the legality of all materials or the consequences of their use. The authors, editors, and the publisher have attempted to trace the copyright holders of all material in this publication and express regret to copyright holders if permission to publish has not been obtained. If any copyright material has not been acknowledged, let us know so we may rectify in any future reprint. Registered trademark of products or corporate names are used only for explanation and identification without intent to infringe.

Notice: Registered trademark of products or corporate names are used only for explanation and identification without intent of infringement. Case Studies and/or Images presented in the book are the proprietary information of the respective organizations, and have been used here specifically and only for educational purposes. Although care has been taken to check accuracy of formulas and procedures, the detailed methods should be tested further on a small scale before being adopted commercially.

For more information about 3G E-Learning LLC and its products, visit www.3ge-learning.com

TABLE OF CONTENTS

	Preface	xv
Chapter 1	Introduction to Fluid Mechanics	1
	Introduction	1
0	Basic Concept of Fluid mechanics	3
Els_	Brief History	4
	Fluid Classification: Fluid Properties	7
2	Newtonian Fluids	7
	Non- Newtonian Fluids	12
553	Other Types of Fluid	14
	Basic Properties of Fluids	16
	Units and Scales of Pressure Measurement	19
	Scalar Nature	24
	International System of Units (SI system) I Metric	25
	Summary	32
	Multiple Choice Questions	33
	Review Questions	33
	References	35
Chapter 2	Pressure	37
	Introduction	37
	Pressure-Measuring Device and Pressure at a Point	38
	Pressure at a Point	39
	What is fluid Pressure?	40



ntroduction Pressure-Measuring Device and Pressure at a Point	37 38
Pressure at a Point	39
What is fluid Pressure?	40
Type's Fluid pressure	47
Surface Pressure and Surface Tension	50
Direction of Liquid Pressure	53
Absolute, Gauge and Differential Pressures	54
Pressure Variation in a Static Fluid	56
Variation of Pressure with Depth	57



	59
Other Pressure Measurement Devices	67
Mechanics of Manometers	72
How to Perform a Manometer Test	74
Summary	76
Multiple Choice Questions	77
Review Questions	79
References	80

Chapter 3 Hydrostatic Forces and Buoyind 81

Hydrostatic Forces on Plane Surfaces	82
Hydrostatic Forces on Curved Surfaces	86
Hydrostatic Forces in Layered Fluids	88
Buoyancy and Stability	89
Archimedes' Principle	90
Forces and Equilibrium	95
Static Stability	99
Compressible Objects	· 100
Hydroelectric Power Stations	1 01
Elements of Hydroelectric Power StallPO	102
Main Components of a Hydroelectric	104
Balance chimneys	106
Operation of a Hydroelectric Power Static	107
Pumped Storage Plants-Storage Require	108
Power Developed From a Given Cat	110
Heads and Efficiencies	113
Turbulent flow	116
Use of Hydraulic Turbines	117
Classification of Turbines	118
Reaction Turbines	124
Summary	127
Multiple Choice Questions	129
Review Questions	130
Keierences	131

%

Chapter 4 Relative Equilibrium



Relative Equilibrium: Rotation Astronomy Rotation Plane Summary Multiple Choice Questions Review Questions References



Introduction	133
Relative Equilibrium: Rectilinear Acceleration	134
Acceleration	136
Definition and Properties	139
Relative Equilibrium: Rotation	141
Astronomy	141
Rotation Plane	142

Introduction **Classification of Fluid Flow Reynolds' Transport Theorem** Conservation of Mass and Linear Momentum Formulation and Examples Linear Momentum **Conservation of Angular Momentum** Angular Momentum Example and Implications **Conservation of Energy** Flow in Pipes Laminar and Turbulent Flows Uniform Flow and Steady Flow Compressible or Incompressible Flow Three-dimensional Flow Stream lines and Stream tubes Flow Rate Pipe Flow Equations and Friction Losses Simple Pipe Problems and Minor Losses Multiple Pipe Systems **Open-Channel Flow and Uniform Flow** Classifications of Flow **Geometric Elements of an Open Channel Multiple Reservoir Problems Fluid Flow Measurement** Types of Flow Measurement Devices

133



Fluids in Motion Bernoulli's Theorem _{Example of} th ^e Use of the Bernoulli E Head, Velocity Head, Poten	quation tial Head	194 196 197
and Total Hea		198
venturi Meter		201
Measurement flow of Venturi Meter		205
Summany		210
Multiple Choice Questions		212
Review Questions		213
References		214
		215
Fluid Statics		
		215
Fluid Statics Introduction Dimensions and Units		215 216
Fluid Statics Introduction Dimensions and Units Physical Properties of Fluids		215 216 218
Fluid Statics Introduction Dimensions and Units Physical Properties of Fluids Vapor Pressure and Their Influence on	<mark>គ្រើប្រ</mark> ថៃ Motion	215 216 218 1 229
Fluid Statics Introduction Dimensions and Units Physical Properties of Fluids Vapor Pressure and Their Influence on Vapor Pressure Plots and Boiling Poj	ı Fjy ici Mottor Als	215 216 218 229 231
Fluid Statics Introduction Dimensions and Units Physical Properties of Fluids Vapor Pressure and Their Influence on Vapor Pressure Plots and Boiling Poi	ıFlyid Motfor Als	215 216 218 229 231 238
Fluid Statics Introduction Dimensions and Units Physical Properties of Fluids Vapor Pressure and Their Influence on Vapor Pressure Plots and Boiling Poi Summary Multiple Choice Questions	ıFjyjd Mottor Als	215 216 218 229 231 238 239



Chapter 7 Fluid Kinematics and Fluid; Dynamics

Review Questions

References

243

241



Introduction	243
Fluid Kinematics	244
Stream line, path line, streak lines and stream tube	244
Difference between Streak Line and Path Lire	248
Classification of Flows-Steady and Unsteady	249
Uniform and non-uniform	251
Laminar and turbulent flow	252
One, Two and Three Dimensional Flows	256
Fluid Dynamics	257
Euler and Bernoulli Equations	258
Substantial Derivative	260
Summary	278
Multiple Choice Questions	279
Review Questions	279
References	28 1

Chapter 8 Transportation of Fluids



Introduction
Fluids Transportation
Pump Classifications
Suction, Discharge, Net Pressure Heads. Specific Speed and Power Calculations
Characteristics and Constructional Details of Centrifugal Pumps
Cavitation
Positive Displacement Pumps
Principle of Operation
Pump Characteristics
Different types of Positive Displacement Pumps
Airlift Pump
Selection of Pumps
Fans, Blowers, and Compressors
Summary
Multiple Choice Questions
Review Questions
References

283

283 284 285

285

289

327

327

328 328

328

332

334

335

336

Chapter 9 Prandtl Boundary Layer Equations



INTRODUCTION **Concept and Assumptions** Assumptions The Displacement Thickness Continuity Navier-Stokes Equation Qualitative Idea of Boundary Layer and Separation Separation - Traditional Approach Triple-deck theory **Dynamical Aspects** Structure of Flow in Separation Region Streamlined and Bluff Bodies Streamlined Body Bluff body **Drag and Lift Forces** Drag Lift Lift and Drag Coefficients Numerical Calculation of Total Force Flow Measurements



Orifice and Venturi Flow Meters	336
Rotameter	337
Ultrasonic Flow Meters	339
Turbine Flow Meter	341
Target Flow Meter	342
Rotary Vane Flow Meter	342
Electro Magnetic Flow Meter	343
ummary	353
ultiple Choice Questions	354
eview Questions	355
eferences	356

Chapter 10 Differential Analysis



Introduction	357
Differential Equations of Mass Transfer]	358
Importance of the Component Differentia	361
Navier Stokes Equations	365
Different Flavors of the Navier-Stokes Eq	368
About the Experiment	369
High Reynolds Number/Turbulent Flow	370
Flow Compressibility	371
Flow Regimes: Solve by the Navier-Sto e	373
Fluid-Structure Interaction	373
Mass Conservation	376
Conditions under which incompressibl~ flo_ valid:	377
Incompressible fluid flow example- Vertical flove in the ocean	- 79
Governing Equations of Fluid Motion	380
Concepts of System and Control Volum	382
Reynolds Transport Theorem (RTT)	385
Corollary of Reynolds Transport Theorem	386
Conservation of Mass	387
Summary	390
Multiple Choice Questions	391
Review Questions	393
References	394

Chapter 11 Inviscid Analysis

Introduction	
Inviscid Flows	
Prandtl Hypothesis	
Superfluids	
Applications	
Reynolds Number	
Bernoulli's Equation	
Bernoulli's Equation Derivation	
Bernoulli's Principle	
Incompressible Flow Equation	
Applications	
Potential Function	
Elementary Plane Flows	
Two Dimensional Uniform Flow	
Two Dimensional Line Source	
Two Dimensional Line Sink	
Two Dimensional Doublet or Dipole	
Two Dimensional Vortex Line	
Generic Two Dimensional Potential	
Summary	
Multiple Choice Questions	
Review Questions	
References	

395

Index

REFERENCES

- 1. Anderson, J.D. (2016), "Some reflections on the history of fluid dynamics", in Johnson, R.W. (ed.), Handbook of fluid dynamics (2nd ed.), CRC Press
- 2. Batchelor, G.K. (2000). An Introduction to Fluid Dynamics. Cambridge: Cambridge University Press.
- 3. Chanson, H. (2009), Applied Hydrodynamics: An Introduction to Ideal and Real Fluid Flows, CRC Press,
- 4. Clarke, Cathie; Carswell, Bob (2007). Principles of Astrophysical Fluid Dynamics. Cambridge University Press.
- 5. E., Stewart, Warren; N., Lightfoot, Edwin (2007-01-01). Transport phenomena. Wiley.
- Ison, David (1 July 2006). "Bernoulli Or Newton: Who's Right About Lift?". Plane & Pilot Magazine. Retrieved 2018-07-27.
- 7. L., Bergman, Theodore; S., Lavine, Adrienne; P., Incropera, Frank; P., Dewitt, David (2011-01-01). Fundamentals of heat and mass transfer. Wiley.
- 8. Oertel, Herbert; Prandtl, Ludwig; Bihle, M.; Mayes, Katherine (2004). Prandtl's Essentials of Fluid Mechanics. Springer. pp. 70-71
- 9. Rott, N (2003-11-28). "Note on the History of the Reynolds Number". Annual Review of Fluid Mechanics. 22 (1): 1–12.
- 10. Runstedtler, Allan (2013). "Inviscid Flow Arrangements in Fluid Dynamics". International Journal of Fluid Mechanics Research. 40 (2): 148–158.

INDEX

Α

Abrade delicate materials 303 Absolute measurement method 68 Absolute pressure 21, 29, 40, 41, 43, 54, 55, 56, 60, 68, 70, 234, 236, 237 Absolute temperature 416 Acceleration 134, 135, 136, 139, 140, 144 Adiabatic process 18 Airlift pump 302,303 Alternate configuration 192 Assumptions 48 Atmosphere 39, 48, 52, 59, 60, 67, 68, 71, 72, 73,74,232,233,234,235 Atmospheric circulation 233 Atmospheric pressure 19, 20, 21, 26, 27, 39, 40, 41, 42, 43, 49, 51, 52, 54, 55, 56, 58, 68, 72, 73, 75, 180, 197, 229, 231, 233, 234, 235, 236, 237

Axial flow machine 306

В

Best efficiency point (BEP) 293 boundary layer (BL) 318, 353 Buoyancy 81, 89, 91, 97, 100, 127 Buoyancy force 90, 91, 94, 96, 97, 99, 101

С

Carbon dioxide 156

Cavitation 287, 289, 292, 293, 294 Centrifugal blower 305 Centrifugal pump 286, 289, 290, 291, 295, 304, 305,307 circular cross section 160 Circular cylinder 250 Circumstance 18 Commonest method 304 Complete thermodynamic cycle 416 Complex potential 401, 402, 403 Compressive force 39, 76 compressors 304, 305, 306 Computational fluid dynamics (CFD) 7 Conservation 154, 155, 156, 157, 158, 159, 160, 162, 174, 196, 207, 210 Constant density 51, 58, 168, 197, 211 Continuum hypothesis 260 Coulomb friction 89

D

Derivative of velocity 140 Differential analysis 390 displacement 314, 319, 321, 341, 353, 354 Domestic water system 175 drag 311, 312, 313, 327, 328, 329, 330, 331, 332, 333,334,335,336,342,349,350,351,353,355 Dynamic system 41, 43, 44, 45

Ε

Elastic membrane 19 Electromagnetic Flow Meters 343, 345 Elementary flow 424 Energy destructors 105

F

flow measurement 182, 188, 192, 193, 205 Flow pressure force 193, 194 Flow separation 318,353 Flow velocity 156, 164, 167, 181, 190, 202 Fluid density 21, 22 fluid distribution networks 160, 211 Fluid dynamics 250, 258 Fluid flow 182, 183, 258, 266 Fluidic force 191 Fluid mechanic 1, 3, 4, 5, 6, 7, 12, 16, 19, 30, 32.258 Fluid medium 17 Fluid motion 244, 250, 257, 258, 278 Fluid particles 412 Fluid quantities 289, 307 fluid stream 328, 341, 353 Fluid system 41 Force vectors perpendicular 54 Frequency 192,193

G

Gas density 416 Geometry 244,267,278 Gravitational field 90, 94, 127

Η

Heat capacity 407 Heat transfer 161, 162, 416 high kinetic energy 285, 291 Homogeneous flow 402, 403, 405 Horizontal plane 83 Hydraulic 38, 56 Hydraulic energy 118 Hydraulic motor 82 hydraulic power stations 102, 106 Hydraulic system 38 Hydraulic Turbines 118, 119 Hydroelectric micro power stations 102 Hydroelectric power 101, 102, 103, 104, 107, 128 Hydroelectric power plants 102 Hydrostatic circuit 82 Hydrostatic pressure 48, 101 Hyperbolic 401

I

Instantaneous acceleration 137, 139 internal flow 164, 165 International Standard (SI) 226 Isothermal process 18

Κ

Kinematic pressure 54 kinematics 244 kinematic viscosity 164 Kinetic energy 118, 120, 121, 124, 125, 126, 397, 410, 411, 412, 419, 422, 433, 435

L

Law of conservation 390 Lift 328,332,334,335,353 Linear momentum 156, 210 Liquid 160,190,211 Liquid changes 118, 119 Liquid drop 17, 19 Liquid layer 89 Liquid pressure 47,51,52,53 59 76 Liquid surface 251

М

Magnetic fields 192 Magnitude 19,39,40,45 Manometer 47, 59, 61, 62, 64, 65, 79 Mass-energy conservation 155 Mathematical operation 55 Measurement methods 69 Measure pressure 59, 62, 67 Mechanical energy 106, 107, 110, 112 Medium velocity 191 Mercury barometer 235 Moderate temperature 302 Moderate vacuum pressure 55 Modern natural science 155 Momentum 154, 156, 157, 158, 159, 163, 164, 210, 257, 258, 261, 263, 266, 270 271 272 274 284, 285, 307 Motion 396, 397, 398, 400, 401 406 411 412 415, 417, 419, 420, 422, 431, 433, 434, 43 5

Ν

Net positive suction head (NPSH) 288 Newtoman mechanics 90 non-equilibrium processes 284 Non-Newtonian fluid 12, 32

0

Operational requirement 118

p

Partial vaporization 288 Particle physics 155 Phenomena 117 Phenomenon 68 Physical layout 184 Piezoelectric material 70 Polymerization 88, 127 Power fluid 302 Practical application 58 Preliminary assumption 4 pressure energy 285, 291 Pressure measurement 45, 46, 47, 54, 69, 76 Pressure measurement system 47 Pressure sensor 46, 47, 67, 70 Pressure system 191 Pressure transducer 47, 67, 68, 70, 71 Pumped storage 108 pumping equipment 285, 307

Q

Quantum mechanic 408

R

rapid fluctuations 163, 164 Reaction turbine 106 Recirculation cavitation 293 Rectangle 135, 144 Resistance change 68, 70 Reversible process 416 Reynolds Number 164, 185, 187 Right angle 135, 144 Rotameter 337, 338 rotary gear pump 285 Rotary pump 297, 300, 301 Rotational Flow 255

S

Scalar quantity 39 sensible thermal energy 161 Shear stress 8, 9, 10, 11, 12, 13, 14, 15 17 Simplistic approach 86 Single cylinder 306 Single molecule 58, 59 Sliding-vane design 298 Social costs 108 Specific Gravity of liquids 221 Specificspeed 285,286,287,289,307 Spherical shape 19 Stable equilibrium 90 Stable operation 287 Static fluid 37, 42, 56, 57 Static liquid 43 Static system 41, 43, 76 Steady flow 167, 170, 174, 179, 212, 249, 278 Streak line 247, 278 Streamline 245, 278 streamlined body 327, 353, 355 Sufficient fluid pressure 303 Suitable arrangement 125 Superfluid helium 407, 408 Surface area 19 Surface force 397 Surface integrated 98 Surface tension 89, 91, 225, 226, 227, 228, 238



Т

Target Flow Meter 342 Temperature 6, 16, 18, 28 Temperature volume 218, 220 Thermal conductivity 18 Thermodynamic equilibrium 51 Thermodynamics 252, 397 Transient system 46, 76 Translational momentum 156, 210 Transmitting energy 83 Transport processes 284, 285 transport properties 284 turbine flow meter 341 Turbulent flow 251, 252, 253, 255

u

ultrasonic flow meters 339 Uniform flow 251, 257 Urine Specific gravity (USG) 221

V

Vacuum 19, 20, 21, 32, 40, 41, 54, 55, 56, 235, 236.237 Vacuum pressures 55 Vacuum pressure transducer 237 Velocity 38, 39, 44, 46, 48, 50, 53, 76, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 410, 411, 413, 416, 419, 420, 421, 424, 428, 430, 431, 433.436 Velocity gradient 8, 11, 13, 15 Velocity head 200, 201, 202 Ventilation system 62, 63 Venturi effect 337 Venturi meters 201, 203, 205 Verticalline 425,426,427 Viscosity 222, 223, 224, 225, 238, 251, 253, 254, 255

W

Water pressure energy 106

