

## CONTENTS

	Page
<b>I. THE TRANSFER OF ENERGY</b>	<b>1</b>
1.1 Heat Transfer—An Engineering Science	1
1.2 The Provisions for Energy Transfer in Nature	3
1.3 The Mechanism of Thermal Conduction	4
1.4 Thermal Conductivity	12
1.5 Energy Transfer Through the Junction Between Two Different Materials	15
1.6 Energy Transfer Through a Solid-Fluid Interface	17
1.7 Energy Transfer from a Heated Surface to a Fluid Stream	18
1.8 The Heat Transfer Coefficient	21
1.9 The Nature of Thermal Radiation	23
1.10 Radiant Energy Exchange	27
1.11 Separate Study of Conduction, Convection, and Radiation	29
<b>II. THE FOURIER CONDUCTION EQUATION</b>	<b>32</b>
2.1 Derivation of the Fourier Equation	32
2.2 Thermal Diffusivity	34
2.3 The Potential Field Equation	35
2.4 The Presence of a Heat Source	35
2.5 Variable Thermal Conductivity	36
2.6 Cylindrical and Spherical Coordinates	36
<b>III. ONE-DIMENSIONAL STEADY-STATE CONDUCTION</b>	<b>38</b>
3.1 Linear Heat Flow	38
3.2 Radial Heat Flow Through a Cylinder	39
3.3 The Logarithmic-Mean Area	40
3.4 Radial Heat Flow Through a Sphere	41
3.5 Thermal Conductivity Measurements	41
3.6 Unidirectional Flow with Losses to the Surroundings—Fins	44
3.7 The Electrical Analogy and Overall Heat Transfer	50
3.8 Thermal Conductance	53
<b>IV. TWO-DIMENSIONAL STEADY-STATE CONDUCTION</b>	<b>56</b>
4.1 The Temperature Distribution in a Thin Semi-infinite Rectangular Plate	56
4.2 The Flux Plot	59
4.3 Shape Factors from Voltage of Resistance Measurements	64
4.4 The Relaxation Method—One Dimension	65
4.5 The Relaxation Method—Two Dimensions	68
<b>V. IDEAL FLUID FLOW</b>	<b>74</b>
5.1 Flow Without Friction—The Ideal Fluid	74
5.2 The Stream Function	75
5.3 The Velocity Potential	76
5.4 The Differential Equation for Ideal fluid Flow	77
5.5 The Fundamental Equations for One - Dimensional Flow	79
5.6 One - Dimensional Flow Through Ducts of Varying Cross Section—The Venturi	82
5.7 Compressible Flow Through a Nozzle	84
<b>VI. VISCOUS FLUID FLOW</b>	<b>93</b>
6.1 Dynamic Viscosity	93
6.2 Kinematic Viscosity	95
6.3 Viscosities of Gases and Liquids	95

6.4	Viscosity Measurements	98
6.5	Laminar and Turbulent Flow in Pipes—The Reynolds Number	100
6.6	Application of Dimensional Analysis to Pressure Drop along a Pipe	102
6.7	Pressure Drop along Pipes with Incompressible Fluid Flow	105
6.8	Hydraulic Diameter	109
6.9	Flow Through Valves and Fittings	109
6.10	The Pitot Tube	109
6.11	The Venturi Meter	113
6.12	Flow about Submerged Bodies—Lift and Drag	114
6.13	Drag Coefficient Curves	118
6.14	Lift and Drag Coefficients of an Airfoil	119
6.15	The Boundary Layer—Skin Friction Drag	123
6.16	Drag at Supersonic Velocities	125
6.17	Drag at Supersonic Velocities	127
<b>VII.</b>	<b>LAMINAR FLOW CONVECTIVE HEAT TRANSFER</b>	<b>134</b>
7.1	The Hydrodynamic and Thermal Boundary Layers	135
7.2	Equation of Motion for Hydrodynamic Boundary Layer	136
7.3	Energy Equation of the Thermal Boundary Layer	137
7.4	Velocity Distribution in the boundary Layer	139
7.5	The Prandtl Number	143
7.6	Temperature Distribution in the Boundary Layer	144
7.7	The Local Heat Transfer Coefficient	144
7.8	A Dimensionless Heat Transfer Coefficient—The Nusselt Number	147
7.9	Velocity Distribution in the Entrance Region of a Tube	148
7.10	Forced Convection in Laminar Flow Through a Tube or Duct	150
7.11	Local and Average Heat Transfer Coefficients for Laminar Flow in a Tube	152
7.12	The Asymptotic Value of $hx$ in Tubes	157
<b>VIII.</b>	<b>TURBULENT FLOW CONVECTIVE HEAT TRANSFER</b>	<b>161</b>
8.1	Similarity Relations in Convection	161
8.2	The Stanton Number	164
8.3	A General Equation for Forced Convection from Dimensional Analysis	164
8.4	Heat Transfer and Skin Friction—The Reynolds Analogy	166
8.5	The General Form of Reynolds Analogy	167
8.6	Heat Transfer in Turbulent Flow in Tube	168
8.7	Heat Transfer in Turbulent Flow Parallel to a Plate	170
8.8	Heat Transfer from the Laminar and Turbulent Flow Regions along a Flat Plate	170
8.9	The Theory of Turbulent Flow	173
8.10	Eddy Viscosity	174
8.11	Turbulent Flow Velocity Distribution in Tubes	176
8.12	Turbulent Flow Velocity Distribution in Tubes	176
8.13	Eddy Diffusivity for Heat	178
8.14	Analysis of Heat Transfer during Turbulent Flow in a Tube	178
8.15	Heat Transfer to Liquid Metals	183
<b>IX.</b>	<b>HEAT TRANSFER OUTSIDE TUBES AND IN HIGH-VELOCITY FLOW</b>	<b>191</b>
9.1	The Cylinder in Crossflow	191
9.2	Boundary Layer Separation Revealed by Interference Photograph	192
9.3	Distribution of Heat Transfer around a Cylinder	194
9.4	Frictional Dissipation in High-Velocity Gas Flow	198
9.5	The Stagnation Temperature and Recover Factor	199
9.6	An Adiabatic Wall	199
9.7	The Adiabatic Flat Plate	200
9.8	Recovery Factors of Laminar and Turbulent Boundary Layers	202
9.9	The Heated or Cooled Plate with Frictional Heating	203
9.10	Heat Transfer at High Supersonic Velocities	206

<b>X.</b>	<b>NATURAL CONVECTION HEAT TRANSFER</b>	<b>208</b>
10.1	Free Convection Flow	208
10.2	Temperature and Velocity Distributions in a Free Convection Boundary Layer	211
10.3	Heat Transfer from a Vertical Plate Using the Integral Method	212
10.4	Integral forms of the Boundary Layer Equations	213
10.5	The Local Heat Transfer Coefficient	214
10.6	The Grashof Number	216
10.7	The Average Heat Transfer Coefficient	216
10.8	Free-Convection Calculations	217
<b>XI.</b>	<b>CONDENSATION AND BOILING HEAT TRANSFER</b>	<b>221</b>
11.1	Condensation	221
11.2	Film wise Condensation on Vertical Surface	221
11.3	Condensation Heat Transfer Coefficients	223
11.4	A Film Reynolds Number and Equations for Condensation on Vertical Surfaces	224
11.5	Boiling Liquids	226
<b>XII.</b>	<b>THERMAL RADIATION</b>	<b>231</b>
12.1	Monochromatic and Total Emissive Power	231
12.2	Absorptivity, Reflectivity, and Transmissivity	232
12.3	Kirchhoff's Law	233
12.4	Black and Gray Bodies Defined	234
12.5	Regular and Diffuse Surfaces; Radiation Intensity	235
12.6	Radiation Density	236
12.7	Isothermal Enclosure	237
12.8	Radiation Pressure	238
12.9	Derivation of the Stefan-Boltzmann Law	239
12.10	Spectral distribution of Radiation	241
12.11	The Wien Displacement Law	242
12.12	Formulas for the Spectral Distribution of Radiation Planck's Law	245
12.13	Emission and Reflection Characteristics of Bodies	245
<b>XIII.</b>	<b>RADIATION HEAT TRANSFER</b>	<b>252</b>
13.1	Radiation Exchange between Surfaces Separated by a Non-Absorbing Medium	252
13.2	The Geometrical Factor	254
13.3	The Reciprocity Theorem	255
13.4	Determination of Geometrical Factors	255
13.5	Refractory Surfaces	258
13.6	General Case of Radiant Heat Exchange	258
13.7	Network Method of Analysis	260
13.8	Radiation from Flames and Gases	262
13.9	The Radiation Heat Transfer Coefficient	268
13.10	Measurement of Total Normal Emissivity	269
<b>XIV.</b>	<b>TRANSIENT AND PERIODIC HEAT TRANSFER</b>	<b>275</b>
14.1	Systems in Which the Thermal Conductivity Can Be Considered Infinite	275
14.2	Response of Thermocouples	278
14.3	Transient Temperature Measurements and Determination of the Heat Transfer Coefficient	279
14.4	The Analogous Electrical System—The R-C Circuit	283
14.5	Periodic Heat Flow in the Single Capacity System	286
14.6	Solution from the Analogous Electrical Network	288
<b>XV.</b>	<b>TRANSIENT TEMPERATURE VARIATION IN SOLIDS</b>	<b>293</b>
15.1	The Infinite Flat Plate or Slab	293
15.2	Calculations of the Temperature and Heat Flow in an Infinite Plate	297

15.3	Heisler Charts for the Plate	300
15.4	The Cylinder and Sphere	304
15.5	Heisler Charts for the Cylinder and Sphere	306
15.6	The Semi-infinite Solid	306
15.7	Heating and Cooling of Finite Bodies	311
15.8	The Finite-Difference Method of Schmidt	315
15.9	Closure	319
<b>XVI.</b>	<b>HEAT EXCHANGERS</b>	<b>321</b>
16.1	The Overall Heat Transfer Coefficient	322
16.2	Fouling Factors	323
16.3	The Logarithmic-Mean Temperature Difference	324
16.4	Parallelflow , Counterflow and Crossflow Ecchangers	327
16.5	Heat Exchanger Designs	330
16.6	Heat Transfer and Pressure Drop in a Tube Bank	334
16.7	Logarithmic-Mean Temperature Correction Design Approach	339
16.8	Effectiveness-Number of Transfer Units Design Approach	346
<b>INDEX</b>		<b>367</b>