

Contents

| | | |
|----------|---|-----------|
| 1 | Introduction to Heat Transfer | 1 |
| 1.1 | General Considerations | 1 |
| 1.2 | Modes of Heat Transfer | 2 |
| 1.2.1 | Conduction | 2 |
| 1.2.2 | Convection | 2 |
| 1.2.3 | Radiation | 2 |
| 1.3 | Laws of Heat Transfer | 3 |
| 1.3.1 | Conduction | 3 |
| 1.3.2 | Convection | 4 |
| 1.3.3 | Radiation | 5 |
| 1.4 | Overall Heat Transfer Coefficient | 6 |
| 2 | Steady Conduction | 13 |
| 2.1 | Introduction | 13 |
| 2.2 | Conduction through a Plane Wall | 13 |
| 2.3 | Conduction through a Plane Multiwall | 16 |
| 2.4 | Conduction through a Cylindrical Wall | 19 |
| 2.5 | Conduction through a Cylindrical Multiwall | 21 |
| 2.6 | Conduction through a Spherical Wall | 23 |
| 2.7 | Conduction through Liquids and Gases | 25 |
| 3 | Transient Conduction | 29 |
| 3.1 | Introduction | 29 |
| 3.2 | General Law of Thermal Conduction | 30 |
| 3.3 | Surface Temperature Variation in Infinite Thickness Walls | 34 |
| 3.4 | Surface Temperature Variation in Finite Thickness Walls | 38 |
| 3.5 | Immersed Plane Wall in Fluid at Different Temperature | 44 |
| 3.6 | Transient Conduction in Tubes | 46 |
| 3.7 | Fourier's Number | 48 |
| 4 | Dimensional Analysis | 49 |
| 4.1 | Introduction | 49 |
| 4.2 | Three Methods to Find Dimensionless Groups | 51 |
| 4.2.1 | Algebraic Method | 51 |

| | | |
|----------|--|------------|
| 4.2.2 | Use of Differential Equations | 53 |
| 4.2.3 | Geometric, Kinematical and Dynamical Similitude | 58 |
| 4.3 | Theory of Models | 60 |
| 5 | Convection | 63 |
| 5.1 | Types of Motion | 63 |
| 5.2 | Physical Characteristics of Fluids | 64 |
| 5.2.1 | Water | 65 |
| 5.2.2 | Air | 66 |
| 5.2.3 | Flue Gas | 68 |
| 5.3 | Natural Convection | 72 |
| 5.3.1 | Plane Vertical Wall and Vertical Tubes | 74 |
| 5.3.2 | Horizontal Cylinders | 76 |
| 5.3.3 | Horizontal Plane Plates | 79 |
| 5.3.4 | Interspace Between two Plane Walls | 80 |
| 5.4 | Forced Convection Inside the Tubes | 81 |
| 5.4.1 | Water | 84 |
| 5.4.2 | Superheated Steam | 88 |
| 5.4.3 | Mineral Oils | 92 |
| 5.4.4 | Air | 93 |
| 5.4.5 | Different Kinds of Gas | 95 |
| 5.5 | Heat Transfer in the Initial Section | 97 |
| 5.6 | Special Instances | 102 |
| 5.6.1 | Annular Interspace | 102 |
| 5.6.2 | Plane Wall | 103 |
| 5.7 | Laminar Motion in the Tubes | 105 |
| 5.8 | Forced Convection Outside a Tube Bank | 107 |
| 5.8.1 | Introduction | 107 |
| 5.8.2 | Air | 113 |
| 5.8.3 | Various Types of Gas and Superheated Steam | 113 |
| 5.9 | Comparison Between In-Line and Staggered Arrangement | 115 |
| 5.10 | Heat Transfer to a Single Tube | 118 |
| 5.11 | Heat Transfer to Finned Tubes | 119 |
| 5.12 | Boiling Liquids | 127 |
| 5.12.1 | Boiling Liquids Outside the Tubes | 127 |
| 5.12.2 | Boiling Liquids Inside the Tubes | 132 |
| 5.13 | Condensing Vapors | 135 |
| 6 | Radiation | 139 |
| 6.1 | Introduction | 139 |
| 6.2 | The Laws of Radiation | 140 |
| 6.2.1 | Planck's Law | 140 |
| 6.2.2 | Wien's Law | 142 |
| 6.2.3 | Stefan-Boltzmann's Law | 143 |
| 6.2.4 | Kirchhoff's Law | 145 |

| | | |
|----------|--|------------|
| 6.2.5 | Lambert' Law – Black Bodies Arranged in any Which Way | 146 |
| 6.3 | Plane Surfaces Facing Each Other | 150 |
| 6.4 | Body Completely Contained in Another Body | 154 |
| 6.5 | Solar Radiation | 155 |
| 6.6 | Flame Radiation | 157 |
| 6.7 | Flame Radiation and Convection | 173 |
| 6.8 | Radiation of CO ₂ and Steam | 181 |
| 7 | Heat Exchangers and Tube Banks | 191 |
| 7.1 | Introduction | 191 |
| 7.2 | Mean Logarithmic Temperature Difference | 192 |
| 7.3 | Mean Specific Heat | 196 |
| 7.3.1 | Water and Superheated Steam | 197 |
| 7.3.2 | Air and Other Gases | 197 |
| 7.4 | Design Calculation | 198 |
| 7.5 | The Mean Difference in Temperature in Reality | 199 |
| 7.5.1 | Fluids with Cross Flow | 201 |
| 7.5.2 | Heat Exchangers | 202 |
| 7.5.3 | Coils | 205 |
| 7.5.4 | Tube Bank with Various Passages of the External Fluid | 206 |
| 7.6 | Verification Calculation | 209 |
| 7.6.1 | General Considerations | 209 |
| 7.6.2 | Fluids in Parallel Flow or in Counter flow | 209 |
| 7.6.3 | Factor Ψ in Real Cases | 218 |
| 8 | Pressure Drops | 225 |
| 8.1 | Introduction | 225 |
| 8.2 | Distributed Pressure Drops | 225 |
| 8.2.1 | Turbulent Motion | 225 |
| 8.2.2 | Laminar Motion | 239 |
| 8.3 | Concentrated Pressure Drops | 242 |
| 8.4 | Pressure Drops through Tube Banks | 250 |
| 8.5 | Pressure Drop in Finned Tubes | 253 |
| A | Thermal Characteristics of Materials | 257 |
| B | Corrective Factors for the Design Computation in Real Cases | 275 |
| C | Corrective Factors for the Verification Computation in Real Cases | 299 |
| | Bibliography | 321 |
| | Index | 325 |