Contents

Preface xiii

Nomenclature xvii

1 Introduction to Fire 1
  1.1 Fire in History 1
  1.2 Fire and Science 2
  1.3 Fire Safety and Research in the Twentieth Century 8
  1.4 Outlook for the Future 10
  1.5 Introduction to This Book 11
    1.5.1 Thermodynamics 13
    1.5.2 Fluid mechanics 14
    1.5.3 Heat and mass transfer 15
    1.5.4 Supportive references 16

References 17
Problems 17

2 Thermochemistry 19
  2.1 Introduction 19
  2.2 Chemical Reactions 20
  2.3 Gas Mixture 23
  2.4 Conservation Laws for Systems 25
    2.4.1 Constant pressure reaction 27
    2.4.2 Heat of combustion 28
    2.4.3 Adiabatic flame temperature 29
  2.5 Heat of Formation 30
  2.6 Application of Mass and Energy Conservation in Chemical Reactions 31
  2.7 Combustion Products in Fire 35

References 41
Problems 41

3 Conservation Laws for Control Volumes 49
  3.1 Introduction 49
  3.2 The Reynolds Transport Theorem 50
7.2 Estimate of Ignition Time Components
  7.2.1 Chemical time 161
  7.2.2 Mixing time 162
  7.2.3 Pyrolysis 163
7.3 Pure Conduction Model for Ignition 164
7.4 Heat Flux in Fire 166
  7.4.1 Typical heat flux levels 166
  7.4.2 Radiation properties of surfaces in fire 167
  7.4.3 Convective heating in fire 167
  7.4.4 Flame radiation 169
  7.4.5 Heat flux measurements 170
  7.4.6 Heat flux boundary conditions 170
7.5 Ignition in Thermally Thin Solids 171
  7.5.1 Criterion for thermally thin 171
  7.5.2 Thin theory 172
  7.5.3 Measurements for thin materials 174
7.6 Ignition of a Thermally Thick Solid 176
  7.6.1 Thick theory 176
  7.6.2 Measurements for thick materials 180
  7.6.3 Autoignition and surface ignition 182
7.7 Ignition Properties of Common Materials 184

References 188
Problems 188

8 Fire Spread on Surfaces and Through Solid Media 191
  8.1 Introduction 191
  8.2 Surface Flame Spread – The Thermally Thin Case 194
  8.3 Transient Effects 198
  8.4 Surface Flame Spread for a Thermally Thick Solid 200
  8.5 Experimental Considerations for Solid Surface Spread 202
    8.5.1 Opposed flow 202
    8.5.2 Wind-aided 207
  8.6 Some Fundamental Results for Surface Spread 210
  8.7 Examples of Other Flame Spread Conditions 213
    8.7.1 Orientation effects 213
    8.7.2 Porous media 215
    8.7.3 Liquid flame spread 216
    8.7.4 Fire spread through a dwelling 217
References 219
Problems 220

9 Burning Rate 227
  9.1 Introduction 227
  9.2 Diffusive Burning of Liquid Fuels 233
    9.2.1 Stagnant layer 233
    9.2.2 Stagnant layer solution 237
    9.2.3 Burning rate – an eigenvalue 241
11.3 Heat Transfer
11.3.1 Convection 348
11.3.2 Conduction 348
11.3.3 Radiation 349
11.3.4 Overall wall heat transfer 351
11.3.5 Radiation loss from the vent 351

11.4 Fuel Behavior
11.4.1 Thermal effects 352
11.4.2 Ventilation effects 353
11.4.3 Energy release rate (firepower) 354

11.5 Zone Modeling and Conservation Equations
11.5.1 Conservation relationships 356
11.5.2 Dimensionless factors in a solution 357

11.6 Correlations
11.6.1 Developing $\dot{r}_{\text{repower}}$ 358
11.6.2 Fully developed fires 360

11.7 Semenov Diagrams, Flashover and Instabilities
11.7.1 Fixed area fire 366
11.7.2 Second item ignition 366
11.7.3 Spreading fires 368

References 369
Problems 370

12 Scaling and Dimensionless Groups
12.1 Introduction 377

12.2 Approaches for Establishing Dimensionless Groups
12.2.1 Buckingham pi method 378
12.2.2 Partial differential equation (PDE) method 379
12.2.3 Dimensional analysis 380

12.3 Dimensionless Groups from the Conservation Equations
12.3.1 Conservation of mass 381
12.3.2 Conservation of momentum 381
12.3.3 Energy equation 382
12.3.4 Heat losses 384
12.3.5 Mass flows 385
12.3.6 Liquid droplets 386
12.3.7 Chemical species 388
12.3.8 Heat flux and inconsistencies 389
12.3.9 Summary 392

12.4 Examples of Specific Correlations
12.4.1 Plume interactions with a ceiling 395
12.4.2 Smoke filling in a leaky compartment 396
12.4.3 Burning rate 397
12.4.4 Compartment fire temperature 398
12.4.5 Effect of water sprays on fire 400