

Contents

Preface v

1. Introduction to Internal Combustion Engines 1

- 1.1 Introduction 1
- 1.2 Engine Cycles 2
- 1.3 Operational Parameters 6
- 1.4 Engine Configurations 12
- 1.5 Engine Examples 19
- 1.6 Alternative Power Plants 24
- 1.7 Sources of Additional Information 26
- 1.8 References 27
- 1.9 Homework 27

2. Gas Cycles 29

- 2.1 Introduction 29
- 2.2 Constant Volume Heat Addition 29
- 2.3 Constant Pressure Heat Addition 32
- 2.4 Dual Cycle 35
- 2.5 Miller Cycle 37
- 2.6 Finite Heat Release 39
- 2.7 Ideal Four-Stroke Process and Residual Fraction 45
- 2.8 Discussion of Gas Cycle Models 53
- 2.9 References 54
- 2.10 Homework 55

3. Fuel, Air, and Combustion Thermodynamics 57

- 3.1 Introduction 57
- 3.2 Ideal Gas Equations of State 57
- 3.3 Liquids and Liquid-Vapor-Gas Mixtures 61
- 3.4 Stoichiometry and Low Temperature Combustion Modeling 63
- 3.5 General Chemical Equilibrium 67
- 3.6 Chemical Equilibrium Using Equilibrium Constants 72
- 3.7 Combustion and the First Law 75
- 3.8 Isentropic Processes 78
- 3.9 References 79
- 3.10 Homework 80

4. Fuel-Air Cycles 82

- 4.1 Introduction 82
- 4.2 Comparison of First and Second Law Efficiency 82
- 4.3 Otto Cycle 85

4.4	Four-Stroke Otto Cycle	90
4.5	Fuel-Injected Limited-Pressure Cycle	93
4.6	Comparison of Fuel-Air Cycle with Actual Spark Ignition Cycles	96
4.7	Comparison of Fuel-Air Cycle with Actual Compression Ignition Cycles	101
4.8	References	103
4.9	Homework	103

5. Engine Testing and Control 105

5.1	Introduction	105
5.2	Dynamometers	105
5.3	Fuel and Air Flow Measurement	108
5.4	Exhaust Gas Analysis	110
5.5	Residual Fraction	118
5.6	Pressure-Volume Measurement and Combustion Analysis	119
5.7	Vehicle Emissions Testing	123
5.8	Engine Sensors and Actuators in Vehicles	125
5.9	Engine Control Systems	128
5.10	Effect of Ambient Pressure and Temperature	131
5.11	References	132
5.12	Homework	133

6. Friction 134

6.1	Introduction	134
6.2	Friction Mean Effective Pressure	134
6.3	Measurements of the Friction Mean Effective Pressure	135
6.4	Friction Coefficient	138
6.5	Journal Bearings	139
6.6	Piston and Ring Friction	143
6.7	Valve Train Friction	152
6.8	Pumping Mean Effective Pressure	156
6.9	Accessory Friction	157
6.10	Overall Engine Friction Mean Effective Pressure	158
6.11	References	161
6.12	Homework	161

7. Air, Fuel, and Exhaust Flow 163

7.1	Introduction	163
7.2	Valve Flow	163
7.3	Intake and Exhaust Flow	176
7.4	Fluid Flow in the Cylinder	183
7.5	Turbulent Flow	189
7.6	Air Flow in Two-Stroke Engines	194
7.7	Superchargers and Turbochargers	201
7.8	Fuel Injectors	206
7.9	Carburetion	212
7.10	References	214
7.11	Homework	216

8. Heat and Mass Transfer 221

- 8.1 Introduction 221
- 8.2 Engine Cooling Systems 221
- 8.3 Engine Energy Balance 223
- 8.4 Cylinder Heat Transfer Measurements 227
- 8.5 Heat Transfer Modeling 230
- 8.6 Heat Transfer Correlations 237
- 8.7 Radiation Heat Transfer 244
- 8.8 Mass Loss or Blowby 246
- 8.9 References 250
- 8.10 Homework 251

9. Combustion and Emissions 253

- 9.1 Introduction 253
- 9.2 Combustion in Spark Ignition Engines 253
- 9.3 Abnormal Combustion (Knock) in Spark Ignition Engines 259
- 9.4 Combustion in Compression Ignition Engines 264
- 9.5 Thermodynamic Analysis 271
- 9.6 Nitrogen Oxides 279
- 9.7 Carbon Monoxide 285
- 9.8 Hydrocarbons 287
- 9.9 Particulates 292
- 9.10 Emission Control 296
- 9.11 References 301
- 9.12 Homework 303

10. Fuels and Lubricants 307

- 10.1 Introduction 307
- 10.2 Hydrocarbon Chemistry 307
- 10.3 Refining 314
- 10.4 Gasoline Fuels 316
- 10.5 Diesel Fuels 319
- 10.6 Alternative Fuels 321
- 10.7 Engine Oils 329
- 10.8 References 332
- 10.9 Homework 333

11. Overall Engine Performance 334

- 11.1 Introduction 334
- 11.2 Engine Size 334
- 11.3 Ignition and Injection Timing 336
- 11.4 Engine and Piston Speed 339
- 11.5 Compression Ratio 340
- 11.6 Part-Load Performance 341
- 11.7 Engine Performance Maps 343
- 11.8 Vehicle Performance Simulation 349
- 11.9 References 350
- 11.10 Homework 350

Appendices 353

- A Physical Properties of Air 353**
- B Thermodynamic Property Tables for Various Ideal Gases 355**
- C Curve Fit Coefficients for Thermodynamic Properties of Various Ideal Gases and Fuels 362**
- D Conversion Factors and Physical Constants 365**

Index 367
