

Table of Contents

Preface	ix
Abbreviation	xiii
Nomenclature	xvii

CHAPTER 1

Introduction	1
1.1 Recent Progress and Outlook of Automotive Engines	2
1.1.1 Achievement in Engine Performance and Emissions	2
1.1.2 Future Development of IC Engines	5
1.2 Roles of Multidimensional Engine Simulation	9
References	14

CHAPTER 2

Combustion Basis of Internal Combustion Engines	19
2.1 Thermodynamic Analysis	19
2.2 Mixture Formation and Combustion in Spark-Ignition Gasoline Engines	28
2.3 Combustion in Diesel Engines	37
2.4 Advanced Concepts of Low-Temperature Combustion	41
References	49

CHAPTER 3

Mathematical Description of Reactive Flow with Sprays	53
3.1 Governing and Spray Equations	53
3.1.1 Governing Equations of Gas Phase	53
3.1.2 Spray Equation	56

3.2 Numerical Methods	58
3.2.1 The KIVA Code	58
3.2.2 The CONVERGE Code	60
3.3 Boundary Conditions	61
3.3.1 General Description	61
3.3.2 Velocity Law-of-the-Wall Function	63
3.3.3 Temperature Wall Function and Wall Heat Transfer	65
References	72

CHAPTER 4

In-Cylinder Turbulence 75

4.1 Turbulence Features in Reciprocating Engines	75
4.1.1 In-Cylinder Flows	75
4.1.2 Turbulence Scales	82
4.2 RANS Methodology and Classical k-ϵ Models	86
4.2.1 RANS Methodology	86
4.2.2 The Classical k- ϵ Model	89
4.3 RNG k-ϵ Models	90
4.3.1 RNG Methodology	91
4.3.2 The RNG k- ϵ Model for Variable-Density Flows	94
4.3.3 Other RNG k- ϵ Model Variants	98
4.4 Large-Eddy Simulation	99
4.4.1 LES Methodology and Sub-Grid Models	100
4.4.1.1 Smagorinsky Model	101
4.4.1.2 Dynamic Smagorinsky Model	102
4.4.1.3 k-Equation Model	103
4.4.1.4 Dynamic Structure Model	103
4.4.2 Engine Simulation Examples	105
4.4.2.1 Intake and In-Cylinder Flows	105
4.4.2.2 Cycle-to-Cycle Combustion Variation	107
4.4.2.3 Low-Temperature Spray Combustion	109
4.4.2.4 Ignition Effects on DI Gasoline Combustion	110
4.4.2.5 Stratified-Charge DI Gasoline Combustion	111
References	113

CHAPTER 5

Fuel Sprays 119

5.1 General Description	120
5.1.1 Multidimensional Spray Modeling	120
5.1.2 Structure Parameters of Sprays	123

5.2 Spray Atomization	126
5.2.1 Numerical Treatment of Fuel Injection	126
5.2.2 Jet Atomization	127
5.2.3 Sheet Atomization	133
5.3 Drop Dynamics	140
5.3.1 Secondary Breakup	140
5.3.2 Collision and Coalescence	142
5.3.3 Drag, Deformation, and Turbulent Dispersion	145
5.4 Evaporation	147
5.4.1 Single-Component Evaporation	148
5.4.2 Multi-Component Evaporation	152
5.5 Spray Wall Impingement	156
5.5.1 Spray Impingement Regimes	158
5.5.2 Post Impingement Outcomes	163
5.5.3 Wall Film Hydrodynamics and Heat Transfer	174
References	185

CHAPTER 6

Combustion and Pollutant Emissions	193
6.1 Overview	193
6.2 Characteristic-Time Combustion Model	196
6.2.1 Model Formulation	196
6.2.2 Diesel Engine Combustion Simulation	198
6.3 Flamelet Methods	203
6.3.1 Level Set G-Equation Model	203
6.3.2 SI Engine Combustion Simulation	206
6.4 Sub-Grid Direct Chemistry Approach	209
6.4.1 Description of the Method	209
6.4.2 HCCI Combustion Simulation	213
6.5 Chemical Reaction Mechanism and Its Reduction	216
6.6 Ignition Models	221
6.6.1 Spark Ignition	221
6.6.2 Compression Ignition	222
6.7 Models of NO_x and Soot Emissions	223
6.7.1 NO _x Emission Models	224
6.7.2 Soot Emission Models	225
6.7.3 Model Predictions	227
References	230

CHAPTER 7

Optimization of Direct-Injection Gasoline Engines	237
7.1 Advanced Combustion Development Methodology	238
7.1.1 Modeling-Driven Approach	238
7.1.2 Overview of Optimization Algorithms	242
7.2 CFD Codes and Software for IC Engines	246
7.3 Direct-Injection Spray Characterization	247
7.4 Mixing in Wall-Guided DI Systems	257
7.4.1 Homogeneous Mixture Formation	257
7.4.1.1 In-Cylinder Mixing Phenomena	257
7.4.1.2 Mixture Homogeneity and Improvement	260
7.4.2 Stratified-Charge Formation	265
7.5 Soot and Hydrocarbon Emissions by Wall-Wettings	271
7.6 Mixing in Spray-Guided and Turbocharged DI Systems	281
References	292

CHAPTER 8

Optimization of Diesel and Alternative Fuel Engines	297
8.1 Direct-Injection Diesel Engines	297
8.1.1 Emissions Reduction by Multiple Injections	298
8.1.1.1 NO Reduction Mechanism	301
8.1.1.2 Soot Reduction Mechanism	303
8.1.2 Geometry of Helical Port and Combustion Chamber	308
8.1.3 Emissions at Cold Start	312
8.2 Alternative Fuel Engines	317
8.2.1 Spark-Ignition Natural Gas Engines	318
8.2.2 RCCI in Diesel-Natural Gas Dual-Fuel Combustion	324
8.2.3 Combustion and NO_x Emissions of Biodiesel Fuels	332
References	336
Index	339
About the Author	347