Contents

Preface to First Edition xxiii
Preface to Second Edition xxv
Preface to Third Edition xxvi
Preface to Fourth Edition xxviii

CHAPTER 1
Introduction to Automotive Fuels and Their Specification 1
References 8
Further Reading 9

CHAPTER 2
A History of Gasoline and Diesel Fuel Development 11
2.1. Gasoline 11
  2.1.1. The Evolution of the Gasoline Engine 11
  2.1.2. Gasoline Development 12
2.2. Diesel Fuel 20
  2.2.1. The Evolution of the Diesel Engine 20
  2.2.2. Diesel Fuel Development 23
References 27
Further Reading 28
## CHAPTER 3

Manufacture of Gasoline and Diesel Fuel from Crude Oil

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1. Introduction</td>
<td>31</td>
</tr>
<tr>
<td>3.2. Crude Oil</td>
<td>32</td>
</tr>
<tr>
<td>3.3. Influence of Product Demand Pattern on Processing</td>
<td>32</td>
</tr>
<tr>
<td>3.4. Distillation</td>
<td>35</td>
</tr>
<tr>
<td>3.5. Cracking Processes</td>
<td>37</td>
</tr>
<tr>
<td>3.5.1. Thermal Cracking</td>
<td>38</td>
</tr>
<tr>
<td>3.5.2. Visbreaking</td>
<td>39</td>
</tr>
<tr>
<td>3.5.3. Coking</td>
<td>39</td>
</tr>
<tr>
<td>3.5.4. Catalytic Cracking</td>
<td>41</td>
</tr>
<tr>
<td>3.5.5. Hydrocracking</td>
<td>43</td>
</tr>
<tr>
<td>3.5.6. Steam Cracking</td>
<td>45</td>
</tr>
<tr>
<td>3.6. Catalytic Reforming</td>
<td>45</td>
</tr>
<tr>
<td>3.7. Alkylation, Isomerization, and Polymerization</td>
<td>47</td>
</tr>
<tr>
<td>3.7.1. Alkylation</td>
<td>47</td>
</tr>
<tr>
<td>3.7.2. Isomerization</td>
<td>48</td>
</tr>
<tr>
<td>3.7.3. Polymerization</td>
<td>49</td>
</tr>
<tr>
<td>3.8. Finishing Processes</td>
<td>49</td>
</tr>
<tr>
<td>3.8.1. Caustic Washing</td>
<td>50</td>
</tr>
<tr>
<td>3.8.2. Merox Treating</td>
<td>50</td>
</tr>
<tr>
<td>3.8.3. Hydrodesulfurization</td>
<td>50</td>
</tr>
<tr>
<td>3.9. Oxygenated Gasoline Components</td>
<td>51</td>
</tr>
<tr>
<td>3.9.1. Alcohols</td>
<td>52</td>
</tr>
<tr>
<td>3.9.2. Ethers</td>
<td>53</td>
</tr>
<tr>
<td>3.10. Gasoline Blending</td>
<td>53</td>
</tr>
<tr>
<td>3.10.1. Blending Operations</td>
<td>55</td>
</tr>
<tr>
<td>3.10.2. Blending Calculations</td>
<td>55</td>
</tr>
<tr>
<td>3.10.3. Octane Blending</td>
<td>56</td>
</tr>
<tr>
<td>3.10.4. Reid Vapor Pressure (RVP) Blending</td>
<td>57</td>
</tr>
<tr>
<td>3.10.5. ASTM Distillation Blending</td>
<td>57</td>
</tr>
<tr>
<td>3.11. Diesel Fuel Blending</td>
<td>58</td>
</tr>
<tr>
<td>3.11.1. Diesel Blending Operations</td>
<td>58</td>
</tr>
<tr>
<td>3.11.2. Diesel Blend Calculations</td>
<td>59</td>
</tr>
</tbody>
</table>

References   61

Further Reading   63
CHAPTER 4
Manufacture of Gasoline and Diesel Fuel from Non-Crude Oil Fossil Sources

4.1. Introduction
4.2. Coal to Liquids
   4.2.1. Direct Coal Liquefaction (DCL)
   4.2.2. Indirect Coal Liquefaction (ICL)
4.3. Gaseous Fuels
   4.3.1. Gaseous Fuel Supply
   4.3.2. Gaseous Fuel Composition and Properties
   4.3.3. Gaseous Fuels Dispensing and Storage
4.4. Gas-to-Liquids
4.5. Methanol to Fuel
4.6. Oil Sands Fuel
   4.6.1. Oil Sands Extraction and Processing
4.7. Oil Shale Fuel
   4.7.1. Oil Shale Mining and Processing
   4.7.2. In Situ Retorting

References
Further Reading

CHAPTER 5
Manufacture of Gasoline and Diesel Fuel from Renewable Sources

5.1. Introduction
5.2. Minimally Processed Vegetable Oil
5.3. Bio-Ethanol
   5.3.1. Ethanol from Sugar Crops
   5.3.2. Ethanol from Grain Crops
   5.3.3. Lignocellulosic Ethanol
5.4. Biodiesel Fuel
5.5. Co-Processing Feedstocks
   5.5.1. Oleochemical Route
   5.5.2. Thermochemical Route
   5.5.3. Biochemical Route
CHAPTER 6

Storage, Distribution, and Handling of Gasoline and Diesel Fuel

6.1. Introduction
6.2. Safety Considerations for Storage and Handling
6.2.1. Flash Point
6.2.2. Electrical Conductivity
6.3. Health and Environmental Effects of Gasoline
6.3.1. Health Aspects
6.3.2. Exposure Limits
6.3.3. Ecotoxicity
6.3.4. Disposal
6.4. Health and Environmental Effects of Diesel Fuel
6.4.1. Health Aspects
6.4.2. Exposure Limits
6.4.3. Ecotoxicity
6.4.4. Disposal
6.5. Influences on Product Quality during Distribution
6.5.1. Sea Transport
6.5.2. Pipeline
6.5.3. Road and Rail
6.6. Influences on Product Quality during Storage
6.6.1. Water Contamination in Tankage
6.6.2. Microbiological Contamination
6.6.3. Sludge in Tankage
6.6.4. Evaporative Losses
6.6.5. Oxidation
6.7. Considerations with Oxygenated Blends
6.7.1. Environmental Aspects of Fuels Containing MTBE
6.7.2. Water Sensitivity of Alcohol Blends
CHAPTER 7

Positive Ignition Engine Combustion Process

7.1. Normal Combustion
  7.1.1. Mixture Requirements
  7.1.2. The Combustion Process

7.2. Spark Knock
  7.2.1. How Spark Knock Occurs

7.3. Measurement of Gasoline Antiknock Quality
  7.3.1. Research and Motor Octane Number
  7.3.2. Road Octane Number
  7.3.3. Octane Index and Modern Engines
  7.3.4. Influence of Chemical Structure on Octane Quality

7.4. Antiknock Additives
  7.4.1. Lead Alkyls
  7.4.2. MMT—Methylcyclopentadienyl Manganese Tricarbonyl
  7.4.3. Other Metallic Antiknocks
  7.4.4. Organic Antiknocks
  7.4.5. Oxygenated Blending Components

7.5. Octane Blending

7.6. Octane Requirements of Vehicles and Engines
  7.6.1. Vehicles with Knock Sensor Systems
  7.6.2. Data Analysis
  7.6.3. Octane Rating of Fuels Using Vehicles or Engines
  7.6.4. Engine and Other Factors That Influence Octane Requirements

7.7. Octane Requirement Increase (ORI)

7.8. Other Abnormal Combustion Phenomena
  7.8.1. Preignition
  7.8.2. Misfire
  7.8.3. Run-On

References

Further Reading
## CHAPTER 8
Gasoline Engine Design and Influence of Fuel Characteristics

### 8.1. Introduction

### 8.2. The Gasoline Engine

8.2.1. Otto Cycle
8.2.2. The Atkinson Cycle
8.2.3. The Miller Cycle

### 8.3. Vehicle Fuel Systems

8.3.1. The Fuel Metering System
8.3.2. The Fuel Tank and Pump

### 8.4. Ignition Systems

### 8.5. Combustion and Exhaust Emission Control Systems

8.5.1. Combustion Chamber Configuration
8.5.2. The Effect of Air-to-Fuel Ratio
8.5.3. Exhaust Aftertreatment Systems

References

Further Reading

## CHAPTER 9
Gasoline Volatility

### 9.1. Measurement of Gasoline Volatility

9.1.1. Vapor Pressure
9.1.2. Reid Vapor Pressure
9.1.3. Dry Vapor Pressure and DVPE
9.1.4. Distillation by ASTM D86
9.1.5. Vapor–Liquid Ratio
9.1.6. Effect of Oxygenated Blending Components

### 9.2. Cold Starting

9.2.1. Different Fuel System Technologies
9.2.2. Relevant Specifications

### 9.3. Cold Weather Driveability

9.3.1. Cold Weather Driveability Test Procedures
9.3.2. Relevant Fuel Parameters
9.4. Hot Weather Driveability 244
  9.4.1. Hot Weather Driveability Testing 245
  9.4.2. Hot Weather Driveability Problems 245
  9.4.3. Hot Weather Fuel Parameter Specification 246
9.5. Evaporative Emissions from Vehicles 247
  9.5.1. Measuring Evaporative Emissions 248
  9.5.2. Reducing Evaporative Emissions 249
9.7. Intake System Icing 250
  9.7.1. Throttle Icing in Carbureted and Throttle Body Injected Engines 250
  9.7.2. Throttle Icing in Multipoint Fuel-Injected Engines 252
9.8. Oil Dilution and Combustion Chamber Deposits 252
9.9. Fuel Economy and Gasoline Volatility 252
References 253
Further Reading 259

CHAPTER 10
Influence of Gasoline Composition on Stability, Gum Formation, and Engine Deposits 261

10.1. The Influence of Gasoline Composition on Stability 261
  10.1.1. Measurement of Stability 262
10.2. Deposit Formation in Engines Due to Gasoline Oxidation 263
  10.2.1. Deposit Formation in the Fuel Tank and Fuel Lines 264
  10.2.2. Deposit Formation in Fuel Injectors and Carburetors 265
  10.2.3. Deposit Formation in the Inlet Manifold, Ports, and on Valves 268
  10.2.4. Combustion Chamber Deposits 274
References 277

CHAPTER 11
Gasoline Additives 285

11.1. Additives to Improve Oxidation Stability 286
  11.1.1. Antioxidants 286
  11.1.2. Metal Deactivators 288
11.2. Additives Used in Gasoline Distribution 289
   11.2.1. Dyes and Markers 289
   11.2.2. Corrosion Inhibitors 289
   11.2.3. Biocides 290
   11.2.4. Anti-Static Additives 290
   11.2.5. Drag Reducing Agents 291
   11.2.6. Demulsifiers and Dehazers 291

11.3. Additives Used to Protect Engines and Fuel Systems 292
   11.3.1. Corrosion Inhibitors 292
   11.3.2. Anti-Icing Additives 293
   11.3.3. Deposit Control Additives (DCAs) 293
   11.3.4. Factory Fill Additives 297

11.4. Additives That Influence Combustion 297
   11.4.1. Antiknock Additives 297
   11.4.2. Anti-ORI Additives 298
   11.4.3. Anti-Pre-Ignition and Anti-Misfire Additives 298
   11.4.4. Spark-Aider Additives 299
   11.4.5. Additives for Improving Fuel Distribution between Cylinders 299
   11.4.6. Anti-Valve-Seat Recession Additives 300

11.5. Additives That Improve Lubricant Performance 300
   11.5.1. Upper Cylinder Lubricants 300
   11.5.2. Anti-Wear Additives 301
   11.5.3. Friction Modifiers 301
   11.5.4. Anti-Sludge Additives 301

11.6. Multifunctional Additive Packages 302

References 303

CHAPTER 12

Other Gasoline Specification and Non-Specification Properties 311

12.1. Density 311
12.2. Heat of Combustion 312
12.3. Composition 313
   12.3.1. Hydrocarbon Composition 313
   12.3.2. Elemental Composition 315
   12.3.3. Oxygenates 316
   12.3.4. Water 316
12.4. Flash Point 317
12.5. Surface Tension 317
12.6. Viscosity 318
12.7. Conductivity 318
12.8. Corrosivity 318
12.9. Freezing Point 319
12.10. Appearance 319

References 319

---

**CHAPTER 13**

Influence of Gasoline Characteristics on Emissions 323

  13.1.1. Development in the US 324
  13.1.2. Development in Europe 327
  13.1.3. Development in Japan 328
  13.1.4. Development in the Rest of the World 329

13.2. The Introduction of Reformulated Gasolines 329
  13.2.1. The Adoption of RFG in the US 329
  13.2.2. RFG Specifications 330
  13.2.3. European Experience of RFGs 331
  13.2.4. The Fuel and Emission Relationship Going Forward 331

13.3. The Influence of Gasoline Sulfur Content on Emissions 332
  13.3.1. The Effect of Sulfur on Tailpipe Emissions 332
  13.3.2. The Effect of Sulfur on Durability of Aftertreatment Systems 335
  13.3.3. The Effect of Sulfur on Onboard Diagnostics 336

13.4. The Influence of Gasoline Hydrocarbon Composition on Emissions 338
  13.4.1. Aromatics 339
  13.4.2. Olefins 341
  13.4.3. Oxygenates 341
  13.4.4. Fuel Composition and Particulate Emissions 342

13.5. The Influence of Gasoline Distillation Characteristics on Emissions 342
  13.5.1. Front-End Volatility 343
  13.5.2. Mid-Range Volatility 343
  13.5.3. Back-End Volatility 344

References 344

Further Reading 351
CHAPTER 14

Racing Fuels

14.1. General Considerations
   14.1.1. Safety
   14.1.2. Volatility
   14.1.3. Resistance to Detonation and Pre-Ignition
   14.1.4. Flammability Limits
   14.1.5. Flame Speed
   14.1.6. Heat of Vaporization
   14.1.7. Density
   14.1.8. Heating Value
   14.1.9. Stoichiometry
   14.1.10. Specific Energy

14.2. Hydrocarbon Racing Fuels
   14.2.1. Historical Perspective
   14.2.2. Current Perspective

14.3. Alcohols as Racing Fuels

14.4. Antiknock Components

14.5. Nitro-Paraffins as Racing Fuels

14.6. Fuel Additives
   14.6.1. Hydrazine
   14.6.2. Antiknock Additives
   14.6.3. Stabilizers
   14.6.4. Deposit Control Additives
   14.6.5. Dyes and Markers
   14.6.6. Static Dissipaters

14.7. Nitrous Oxide as an Oxidant for Racing Fuels

References

CHAPTER 15

The Diesel Engine Combustion Process

15.1. The Diesel Combustion Process
   15.1.1. Ignition Delay Period
   15.1.2. Premixed Burning Period
   15.1.3. Diffusion Burning Period
   15.1.4. Tail-End Burning Period
## 15.2. Fuel Properties Influencing Combustion

15.2.1. Ignition Quality 377

## 15.3. Emissions Characteristics of Diesel Combustion

15.3.1. Smoke and Particulates 381
15.3.2. Oxides of Nitrogen 383

References 384

Further Reading 388

---

### CHAPTER 16

Diesel Engine Design and Influence of Fuel Characteristics 391

16.1. Introduction 391

16.2. The Diesel Compression Ignition Engine 392

16.2.1. Direct Injection 392
16.2.2. Indirect Injection 393
16.2.3. Other Considerations 394

16.3. Diesel Vehicle Fuel Systems 394

16.3.1. Strainers, Filters, and Separators 396
16.3.2. Transfer or Lift Pumps 397
16.3.3. Injection Systems 397

16.4. Exhaust Aftertreatment 405

16.4.1. Diesel Oxidation Catalysts 406
16.4.2. Diesel Particulate Filters 407
16.4.3. NO\textsubscript{X} Reduction Systems 410
16.4.4. Integrated Systems 413

16.5. Influence of Fuel Properties on Engine Systems Performance 415

16.5.1. Influence of Fuel Density 416
16.5.2. Influence of Diesel Fuel Volatility 416
16.5.3. Influence of Diesel Fuel Viscosity 418
16.5.4. Influence of Diesel Fuel Composition 418

References 419

Further Reading 426
# CHAPTER 17

**Diesel Fuel Low-Temperature Characteristics**

## 17.1. Diesel Fuel Low-Temperature Properties

17.1.1. Cloud Point
17.1.2. Wax Appearance Point
17.1.3. Pour Point
17.1.4. Significance of CP and PP
17.1.5. Cold Filter Plugging Point
17.1.6. Low-Temperature Flow Test
17.1.7. Simulated Filter Plugging Point (SFPP)
17.1.8. Cold Soak Filtration Test

## 17.2. Additives to Improve Cold Weather Performance

17.2.1. Wax Crystal Modifiers (WCM)
17.2.2. PP Depressants
17.2.3. Flow Improvers
17.2.4. CP Depressants
17.2.5. Wax Anti-Settling Additives (WASA)
17.2.6. Mechanism of Wax Crystal Modification
17.2.7. Factors Influencing Choice of Wax Modifier Additive
17.2.8. The Incorporation of Biodiesel

## 17.3. Measurement of Diesel Fuel Low-Temperature Performance

17.3.1. Selection of Field Test Site
17.3.2. Procedure for Low-Temperature Testing
17.3.3. Fuel Storage
17.3.4. Vehicle Instrumentation
17.3.5. Preparation of Test Vehicles
17.3.6. Operational Procedure
17.3.7. Climate Chamber Testing
17.3.8. Interpretation of Results
17.3.9. Low-Temperature Test Experience
17.3.10. Reducing Sensitivity to Waxing Problems by Vehicle Design
17.3.11. Experience with Modified Fuel Systems

## References

---

# CHAPTER 18

**Influence of Diesel Fuel Composition on Stability and Engine Deposits**

## 18.1. The Influence of Diesel Fuel Composition on Stability

18.1.1. Petroleum Fuel Composition Effects
20.4. Lubricity 525
   20.4.1. Evaluation of Different Test Methods 526
   20.4.2. Ball on Three Seats (BOTS) Method 528
   20.4.3. Ball-on-Cylinder Lubricity Evaluator (BOCLE) 528
   20.4.4. High-Frequency Reciprocating Rig (HFRR) 528

20.5. Water and Sediment Content 529

20.6. Ash Content 530

20.7. Carbon Residue 531

20.8. Density 531

20.9. Heating Value 532

20.10. Flash Point 532

20.11. Electrical Conductivity 533

20.12. Appearance and Color 533

References 534

CHAPTER 21
Influence of Diesel Fuel Characteristics on Emissions 539

   21.1.1. Development in the US 541
   21.1.2. Development in Europe 544
   21.1.3. Development in Japan 546
   21.1.4. Development in the Rest of the World 547

21.2. Diesel Fuel Cetane Number and Emissions 547
   21.2.1. Effect of CN under Fully Warm Operating Conditions 548
   21.2.2. Effect of CN under Cold Start Condition 552
   21.2.3. Natural and Improved CN 554

21.3. The Influence of Diesel Fuel Physical Characteristics on Emissions 556
   21.3.1. Diesel Fuel Density Effects 556
   21.3.2. The Influence of Viscosity 559
   21.3.3. Diesel Fuel Distillation Characteristics and Emissions 559

21.4. The Influence of Chemical Composition of Diesel Fuel on Emissions 560
   21.4.1. Diesel Fuel Sulfur Effects on Emissions 560
   21.4.2. The Influence of Aromatic Content on Emissions 562
   21.4.3. The Influence of Oxygenate Content on Emissions 564

References 566

Further Reading 574
CHAPTER 22
The Kinetically Controlled Compression Ignition Engine and Combustion Process

22.1. Brief History of Kinetically Controlled Combustion

22.2. The Low-Temperature Combustion Process

22.3. LTC Engines
   22.3.1. LTC Engines Using Gasoline-Type Fuels
   22.3.2. LTC Engines Using Diesel Type Fuels
   22.3.3. LTC Engines Using More Than One Fuel
   22.3.4. LTC Engines with a Fuel Reformer

22.4. Fuel Effects on Kinetically Controlled CI
   22.4.1. Fuel Effects on CAI Engine Performance
   22.4.2. Fuel Effects on PCCI Engine Performance
   22.4.3. Fuel Effects on RCCI Engine Performance

References
Further Reading

CHAPTER 23
Future Trends and Alternative Fuels

23.1. Environmental Considerations and Legislation

23.2. Fossil Fuel Price and Security of Supply
   23.2.1. Crude Oil
   23.2.2. Other Oil Sources
   23.2.3. Coal
   23.2.4. Natural Gas

23.3. Renewable Fuel Price and Availability
   23.3.1. Bio-Ethanol Feedstocks
   23.3.2. Biodiesel Feedstocks
   23.3.3. Other Renewable Feedstocks

23.4. Changes in Engine and Vehicle Technology
   23.4.1. Gasoline Engine Development
   23.4.2. Diesel Engine Development
   23.4.3. Hybrid Electric Vehicles
   23.4.4. Fuel Cell Vehicles
Contents

23.5. Alternative Fuels
  23.5.1. Hydrogen
  23.5.2. Ammonia
  23.5.3. Dimethyl Ether
  23.5.4. Polyoxymethylene Dimethyl Ethers (OMES)
  23.5.5. Furans

References

Further Reading

Appendix 1: Introduction to Fuel Chemistry
Appendix 2: Worldwide Fuel Charter Recommendations
Appendix 3: TOP TIER™ Fuel Standards
Appendix 4: Composition of Biodiesel from Different Feedstocks
Appendix 5: Material Safety Data Sheets
Appendix 6: Lead Alkyls
Appendix 7: Physical Properties of Hydrocarbons
Appendix 8: Abbreviations and Acronyms
Appendix 9: Glossary of Terms
Index
About the Authors