# Contents

## Part I  Selective Catalytic Reduction Technology

1  **Review of Selective Catalytic Reduction (SCR) and Related Technologies for Mobile Applications**  
   Timothy V. Johnson  
   1.1 Introduction ........................................ 3  
   1.2 Regulatory Overview ................................. 4  
   1.2.1 Heavy-Duty Truck Regulations ................... 4  
   1.2.2 Light-Duty Regulations ............................ 5  
   1.3 Engine Developments ................................. 6  
   1.3.1 Heavy-Duty Engines ............................... 6  
   1.3.2 Light-Duty Diesel Engines ....................... 8  
   1.4 SCR Technologies ................................. 10  
   1.4.1 SCR System Introduction ......................... 10  
   1.4.2 Urea Delivery System ............................ 12  
   1.4.3 Alternative Sources for Ammonia and Systems ... 13  
   1.4.4 DOC Overview ................................ 14  
   1.4.5 SCR Catalysts ................................ 15  
   1.4.6 Ammonia Slip Catalysts ......................... 19  
   1.5 SCR System Design ................................ 20  
   1.6 Onboard Generation of Ammonia Using Lean NOx Traps 23  
   1.7 Outlook ............................................ 25  
   1.8 Conclusions ....................................... 26  
   1.8.1 Regulations and Engine Technologies ............... 26  
   1.8.2 Onboard Ammonia Delivery Systems  
   and SCR Catalyst Systems ............................. 26  
   1.8.3 Outlook ........................................ 27  
   References .......................................... 27  

2  **SCR Technology for Off-highway (Large Diesel Engine) Applications**  
   Daniel Chatterjee and Klaus Rusch  
   2.1 Introduction ....................................... 33  
   2.2 Off-highway Emission Legislation .................... 36
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>SCR Systems for High-Speed Engines</td>
<td>38</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Small Ship Applications</td>
<td>39</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Rail Applications</td>
<td>39</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Gensets</td>
<td>40</td>
</tr>
<tr>
<td>2.4</td>
<td>Medium and Low-Speed Engines</td>
<td>42</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Fuels and Sulfur</td>
<td>42</td>
</tr>
<tr>
<td>2.4.2</td>
<td>SCR Technology for Marine Applications</td>
<td>45</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Low-Speed Engine Genset</td>
<td>45</td>
</tr>
<tr>
<td>2.5</td>
<td>Combined Systems</td>
<td>47</td>
</tr>
<tr>
<td>2.5.1</td>
<td>DPF + SCR</td>
<td>47</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Combination of DeNoxation and DeSulfurization</td>
<td>51</td>
</tr>
<tr>
<td>2.6</td>
<td>System Integration</td>
<td>51</td>
</tr>
<tr>
<td>2.6.1</td>
<td>Reductant Supply</td>
<td>51</td>
</tr>
<tr>
<td>2.6.2</td>
<td>Canning Concepts</td>
<td>55</td>
</tr>
<tr>
<td>2.7</td>
<td>Control Strategies</td>
<td>56</td>
</tr>
<tr>
<td>2.8</td>
<td>Outlook</td>
<td>58</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>59</td>
</tr>
</tbody>
</table>

### Part II Catalysts

#### 3 Vanadia-Based Catalysts for Mobile SCR | 65
---

Jonas Jansson

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Introduction</td>
<td>65</td>
</tr>
<tr>
<td>3.2</td>
<td>Legislation</td>
<td>66</td>
</tr>
<tr>
<td>3.3</td>
<td>Main SCR Reactions</td>
<td>67</td>
</tr>
<tr>
<td>3.4</td>
<td>Urea Injection</td>
<td>68</td>
</tr>
<tr>
<td>3.5</td>
<td>Properties of Vanadia SCR Catalyst</td>
<td>68</td>
</tr>
<tr>
<td>3.6</td>
<td>Reaction Mechanism</td>
<td>71</td>
</tr>
<tr>
<td>3.7</td>
<td>Function/Principle Design</td>
<td>73</td>
</tr>
<tr>
<td>3.8</td>
<td>Dimensioning of SCR System</td>
<td>76</td>
</tr>
<tr>
<td>3.9</td>
<td>Effect of NO₂</td>
<td>81</td>
</tr>
<tr>
<td>3.10</td>
<td>Aging of Vanadia SCR Catalysts</td>
<td>83</td>
</tr>
<tr>
<td>3.10.1</td>
<td>Thermal Aging</td>
<td>83</td>
</tr>
<tr>
<td>3.10.2</td>
<td>Impact of Sulfur</td>
<td>85</td>
</tr>
<tr>
<td>3.10.3</td>
<td>Alkali Metals and Alkaline Earth Metals</td>
<td>87</td>
</tr>
<tr>
<td>3.10.4</td>
<td>Oil Poisons</td>
<td>88</td>
</tr>
<tr>
<td>3.10.5</td>
<td>Hydrocarbons</td>
<td>90</td>
</tr>
<tr>
<td>3.10.6</td>
<td>Arsenic and Lead</td>
<td>91</td>
</tr>
<tr>
<td>3.10.7</td>
<td>Biofuel</td>
<td>91</td>
</tr>
<tr>
<td>3.10.8</td>
<td>In-use Aging Evaluation</td>
<td>92</td>
</tr>
<tr>
<td>3.11</td>
<td>Summary and Conclusions</td>
<td>92</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>93</td>
</tr>
</tbody>
</table>
4  Fe-Zeolite Functionality, Durability, and Deactivation 
   Mechanisms in the Selective Catalytic Reduction (SCR) 
   of NO\textsubscript{x} with Ammonia ................................. 97
   Todd J. Toops, Josh A. Pihl and William P. Partridge
   4.1  Introduction .................................................. 97
   4.2  Experimental Considerations in Evaluating 
       and Aging Catalysts ........................................... 99
   4.3  Fe-Zeolite NO\textsubscript{x} Reduction Characteristics ............. 104
   4.4  Durability, Aging Techniques, and Deactivation Mechanism 
       Affecting Performance ....................................... 111
   4.5  Summary ..................................................... 118
   References ...................................................... 119

5  Cu/Zeolite SCR Catalysts for Automotive Diesel NO\textsubscript{x} 
   Emission Control .................................................. 123
   Hai-Ying Chen
   5.1  Introduction .................................................. 123
   5.2  Chemistry and Functionality of Cu/Zeolite SCR Catalysts ....... 124
   5.3  Deactivation Mechanisms of Cu/Zeolite SCR Catalysts .......... 126
       5.3.1  Hydrothermal Deactivation ............................... 126
       5.3.2  Hydrocarbon Storage, Inhibition, and Poisoning .......... 132
       5.3.3  Sulfur Poisoning ......................................... 133
       5.3.4  Urea and Urea Deposit Related Catalyst 
              Deactivation ........................................... 133
       5.3.5  Chemical Poisoning .................................... 134
   5.4  Development of Small-Pore Zeolite Supported 
       Cu SCR Catalysts .............................................. 135
   5.5  Investigation on the Superior Hydrothermal Stability 
       of Small-Pore Zeolite Supported Cu SCR Catalyst ........... 140
   5.6  Investigation on the Active Cu Sites in Small-Pore 
       Zeolite Supported Cu SCR Catalysts ........................ 142
   5.7  Summary ..................................................... 143
   References ...................................................... 144

6  Low-Temperature Selective Catalytic Reduction (SCR) of NO\textsubscript{x} 
   with NH\textsubscript{3} Over Zeolites and Metal Oxide-Based Catalysts 
   and Recent Developments of H\textsubscript{2}-SCR ...................... 149
   Gongshin Qi, Lifeng Wang and Ralph T. Yang
   6.1  Ammonia-SCR .................................................. 149
       6.1.1  Introduction .............................................. 149
       6.1.2  Catalysts and Mechanistic Aspects 
              of the Low-Temperature Ammonia-SCR ................. 151
6.2 H2-SCR ........................................... 163
  6.2.1 Introduction ................................... 163
  6.2.2 Catalysts and Mechanistic Aspects of H2-SCR ....... 165
6.3 Challenges and Prospective ............................. 171
References ............................................. 172

Part III Mechanistic Aspects

7 Active Sites for Selective Catalytic Reduction .......... 181
Wolfgang Grüner

  7.1 Introduction ....................................... 181
  7.2 Strategies and Methods for the Identification of Active Sites ... 182
  7.3 Supported Vanadia Catalysts .......................... 193
  7.4 Zeolite-Based Catalysts ............................... 198
    7.4.1 Fe Zeolites .................................... 198
    7.4.2 Cu Zeolites .................................... 206
  7.5 Recent Catalyst Development ............................ 208
  7.6 Concluding Remarks .................................. 210
References ............................................. 211

8 Mechanistic Aspect of NO–NH3–O2 Reacting System ...... 221
Masaoki Iwasaki

  8.1 Introduction ........................................ 221
  8.2 Steady-State Reaction Analysis ........................ 221
    8.2.1 NH3/NO/O2, NH3/O2, and NO/O2 Reactions ............ 221
    8.2.2 Apparent Activation Energy ......................... 223
    8.2.3 Apparent Reaction Orders ........................... 224
    8.2.4 Relationship with NO Oxidation Activity .............. 227
    8.2.5 Effect of Coexisting Gases and Poisoning .......... 230
  8.3 Transient Reaction Analysis ............................ 233
    8.3.1 Periodic NH3 Supply ................................ 233
    8.3.2 NO Pulse Reaction ................................. 237
    8.3.3 In Situ FT-IR Analysis ............................. 238
  8.4 Reaction Mechanisms ................................... 240
    8.4.1 Vanadium-Based Catalysts .......................... 240
    8.4.2 Fe- or Cu-Exchanged Zeolite Catalysts .............. 242
  8.5 Conclusions ......................................... 244
References ............................................. 244

9 The Role of NO2 in the NH3–SCR Catalytic Chemistry .... 247
Enrico Tronconi and Isabella Nova

  9.1 Introduction ........................................ 247
  9.2 Experimental ....................................... 248
9.3 Surface Storage of NOx ........................................... 249
  9.3.1 NO₂ Adsorption/Desorption ................................. 249
  9.3.2 FTIR in Situ Study of NO₂ Adsorption ................... 250
  9.3.3 Effect of the Catalyst Redox State
        on NO₂ Adsorption ........................................ 251
9.4 The Role of Surface Nitrates in the Fast SCR Mechanism .... 253
  9.4.1 NH₃ + NOₓ Temperature Programmed Reaction
        (TPR) Runs .............................................. 253
  9.4.2 Role of Nitrates in the NO/NO₂–NH₃
        SCR Mechanism ........................................... 255
9.5 Mechanistic Studies by Transient Response Methods .......... 255
  9.5.1 Reactivity of Surface Nitrates with NO
        and with NH₃ ............................................. 256
  9.5.2 The Role of Nitrites ......................................... 257
  9.5.3 Overall Mechanistic Scheme ................................. 258
  9.5.4 Ammonia Blocking of Nitrates Reduction ................. 259
  9.5.5 Considerations on the Red-ox Nature of the
        NH₃–SCR Mechanisms ...................................... 260
  9.5.6 Higher Temperatures: The NO₂–SCR Reaction .......... 261
  9.5.7 Selectivity Issues: The Formation
        of NH₄NO₃, N₂O ........................................... 262
9.6 Feeding Nitrates: The Enhanced SCR Reaction ................. 263
  9.6.1 The Boosting Action of Ammonium Nitrate .......... 263
  9.6.2 Analysis of the Enhanced SCR Chemistry ............. 267
9.7 Summary and Conclusions ......................................... 268
References .......................................................... 269

Part IV Reaction Kinetics

10 Kinetics of NH₃-SCR Reactions Over
    V₂O₅–WO₃/TiO₂ Catalyst ..................................... 273
    Isabella Nova and Enrico Tronconi
  10.1 Introduction .................................................. 273
  10.2 Methods ..................................................... 274
     10.2.1 Experimental Rig and Procedures ..................... 274
     10.2.2 Mathematical Model of the Microreactor
            for Kinetic Tests .................................... 275
  10.3 NH₃/O₂ Reacting System ..................................... 276
  10.4 NH₃–NO/O₂ Reacting System ................................ 282
  10.5 NH₃–NO/NO₂ Reacting System ............................... 294
  10.6 Conclusions ................................................ 308
References .......................................................... 308
11 Lean NOx Reduction by NH3 on Fe-Exchanged Zeolite
and Layered Fe/Cu Zeolite Catalysts: Mechanisms,
Kinetics, and Transport Effects. ......................... 311
Michael P. Harold and Pranit Metkar
11.1 Introduction ........................................... 311
11.2 Reaction System Performance Features ............ 312
   11.2.1 NO Oxidation and NO₂ Decomposition ........ 315
   11.2.2 NH₃ Oxidation .................................. 316
   11.2.3 Selective Catalytic Reduction of NOx ........ 317
11.3 Kinetics and Mechanistic Considerations .......... 324
   11.3.1 NO Oxidation .................................. 325
   11.3.2 Standard SCR Reaction ........................ 331
   11.3.3 Ammonia Inhibition ............................ 333
   11.3.4 Selective Catalytic Reaction with NO and NO₂ . 334
11.4 Reaction and Transport Interactions ............... 343
11.5 Reactor Modeling Developments .................... 348
11.6 Concluding Remarks ................................ 353
References ................................................. 354

12 Kinetic Modeling of Ammonia SCR for Cu-Zeolite Catalysts ... 357
Louise Olsson
12.1 Introduction ........................................... 357
12.2 Kinetic Models for Ammonia and Water Storage
   Over Cu-Zeolites ...................................... 358
   12.2.1 Global Kinetic Model for Ammonia Storage
         and Desorption .................................. 361
   12.2.2 Detailed Kinetic Model for Ammonia
         and Water Storage ............................... 362
12.3 Kinetic Models for Ammonia Oxidation Over Cu-Zeolites ...364
   12.3.1 Global Kinetic Model for Ammonia Oxidation . 364
   12.3.2 Detailed Kinetic Model for Ammonia Oxidation . 364
12.4 Kinetic Models for NOₓ Storage and NO Oxidation
   Over Cu-Zeolites .................................... 365
   12.4.1 Detailed Kinetic Model for NO Oxidation ....... 365
   12.4.2 Global Kinetic Model for NO Oxidation ....... 369
12.5 Kinetic Models for SCR Reactions Over Cu-Zeolites .....371
   12.5.1 Global Kinetic Models for SCR Over Cu-Zeolites . 371
   12.5.2 Detailed Kinetic Models for SCR
         Over Cu-Zeolites ............................... 376
12.6 Conclusions .......................................... 381
References ................................................. 381
Part V Modeling and Control

13 **SCR Reactor Models for Flow-Through and Wall-Flow Converters**

Dimitrios Karamitros and Grigorios Koltsakis

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1</td>
<td>Introduction</td>
<td>385</td>
</tr>
<tr>
<td>13.2</td>
<td>Fundamentals of Flow-Through Catalyst Modeling</td>
<td>386</td>
</tr>
<tr>
<td>13.2.1</td>
<td>Balance Equations</td>
<td>387</td>
</tr>
<tr>
<td>13.2.2</td>
<td>Washcoat Internal Diffusion Modeling</td>
<td>389</td>
</tr>
<tr>
<td>13.2.3</td>
<td>Multidimensional Model Extension</td>
<td>391</td>
</tr>
<tr>
<td>13.3</td>
<td>Reaction Modeling</td>
<td>392</td>
</tr>
<tr>
<td>13.3.1</td>
<td>Adsorption Model</td>
<td>392</td>
</tr>
<tr>
<td>13.3.2</td>
<td>de-NO_x Reactions</td>
<td>394</td>
</tr>
<tr>
<td>13.3.3</td>
<td>Parameter Calibration</td>
<td>397</td>
</tr>
<tr>
<td>13.4</td>
<td>Importance of Washcoat Diffusion Modeling</td>
<td>397</td>
</tr>
<tr>
<td>13.4.1</td>
<td>Experimental Results</td>
<td>398</td>
</tr>
<tr>
<td>13.4.2</td>
<td>Simulation Study and Effective Diffusivity Investigation</td>
<td>398</td>
</tr>
<tr>
<td>13.5</td>
<td>From Lab Reactor Tests to Real-World System Modeling</td>
<td>400</td>
</tr>
<tr>
<td>13.5.1</td>
<td>Overview of Model Parameterization Approaches</td>
<td>400</td>
</tr>
<tr>
<td>13.5.2</td>
<td>Microreactor and Monolith Reactor Tests</td>
<td>400</td>
</tr>
<tr>
<td>13.5.3</td>
<td>Real-World Full-Scale Applications</td>
<td>402</td>
</tr>
<tr>
<td>13.6</td>
<td>Fundamentals of SCR on DPF Modeling</td>
<td>403</td>
</tr>
<tr>
<td>13.6.1</td>
<td>Wall-Flow Filter Model</td>
<td>403</td>
</tr>
<tr>
<td>13.6.2</td>
<td>SCR Kinetic Model and Soot Oxidation Kinetics</td>
<td>406</td>
</tr>
<tr>
<td>13.6.3</td>
<td>Wall-Flow Versus Flow-Through Monoliths</td>
<td>407</td>
</tr>
<tr>
<td>13.6.4</td>
<td>Interactions Between Soot and de-NO_x Activity</td>
<td>408</td>
</tr>
<tr>
<td>13.7</td>
<td>Integrated Exhaust System Modeling</td>
<td>412</td>
</tr>
<tr>
<td>13.7.1</td>
<td>Model-Based DPF + SCR System Optimization</td>
<td>413</td>
</tr>
<tr>
<td>13.7.2</td>
<td>Combined LNT-SCR Concepts</td>
<td>416</td>
</tr>
<tr>
<td>13.7.3</td>
<td>Combined SCR-ASC Concept</td>
<td>418</td>
</tr>
<tr>
<td>13.8</td>
<td>Conclusion: Perspectives</td>
<td>419</td>
</tr>
</tbody>
</table>

14 **Diesel Engine SCR Systems: Modeling, Measurements, and Control**

Ming-Feng Hsieh and Junmin Wang

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.1</td>
<td>Introduction</td>
<td>425</td>
</tr>
<tr>
<td>14.2</td>
<td>SCR Control-Oriented Modeling</td>
<td>426</td>
</tr>
<tr>
<td>14.2.1</td>
<td>Introduction</td>
<td>426</td>
</tr>
<tr>
<td>14.2.2</td>
<td>Main SCR Reactions</td>
<td>426</td>
</tr>
<tr>
<td>14.2.3</td>
<td>Control-Oriented SCR Model</td>
<td>427</td>
</tr>
<tr>
<td>14.3</td>
<td>SCR Sensing and Estimation Systems</td>
<td>430</td>
</tr>
<tr>
<td>14.3.1</td>
<td>NO_x Sensor NH3 Cross-Sensitivity</td>
<td>431</td>
</tr>
</tbody>
</table>
14.3.2 SCR Catalyst Ammonia Coverage
   Ratio Estimation ........................................ 437
14.4 SCR Control .............................................. 441
  14.4.1 Control-Oriented SCR Model ......................... 442
  14.4.2 Controller Design and Architecture ................. 443
  14.4.3 Experimental Setup ................................ 444
  14.4.4 Experimental Results of US06 Test Cycle .......... 446
14.5 Conclusions .............................................. 448
References .................................................. 449

Part VI Ammonia Supply

15 DEF Systems and Aftertreatment Architecture Considerations .... 455
   Ryan Floyd, Levin Michael and Zafar Shaikh
   15.1 Role of Engine and Dosing Calibration .................. 459
   15.2 Overview of Injection Technology and Spray Quality ...... 461
   15.3 Overview of SCR System Mixing Devices ................. 467
   15.4 SCR System Mixing Devices: Ford Practical Example ...... 471
   15.5 Aftertreatment Architecture ............................. 474
   15.6 Deposit Mitigation: Practical Example ................... 479
   15.7 Concluding Remarks .................................... 483
References .................................................. 483

16 Ammonia Storage and Release in SCR Systems
   for Mobile Applications ................................. 485
   Daniel Peitz, Andreas Bernhard and Oliver Kröcher
   16.1 Introduction ............................................ 485
   16.2 Urea as Ammonia Precursor Compound ................... 486
      16.2.1 Solid Urea ........................................ 486
      16.2.2 Urea Solution ..................................... 487
      16.2.3 Urea Thermolysis and Evaporation .................. 487
      16.2.4 Urea Decomposition Byproducts and Catalyst Deactivation .... 489
      16.2.5 Catalytic Urea Decomposition ....................... 491
   16.3 Alternative Ammonia Precursor Compounds ............... 493
      16.3.1 Cyanuric Acid ..................................... 493
      16.3.2 Ammonium Formate ................................ 494
      16.3.3 Ammonium Carbamate ................................ 495
      16.3.4 Metal Ammine Chlorides ............................ 496
      16.3.5 Methanamide ........................................ 498
      16.3.6 Guanidinium Salts ................................ 499
      16.3.7 Catalytic Decomposition of Alternative NH₃ Precursor Compounds .... 499
References .................................................. 501
17 Modeling the Gas Flow Process Inside Exhaust Systems:
One Dimensional and Multidimensional Approaches .......................... 507
Gianluca Montenegro and Angelo Onorati
17.1 Introduction .................................................................................. 507
17.2 1D Models for the Prediction of Gas Flows .................. 508
17.2.1 Modeling the Thermal Aspects ............................................ 510
17.2.2 Thermal and Hydrolytic Decomposition of Urea ... 516
17.2.3 Kinetic Model ................................................................. 517
17.3 Multidimensional Models ............................................................. 521
17.3.1 Governing Equations .......................................................... 521
17.3.2 Modeling the UWS Injection ............................................. 526
17.3.3 Modeling the Formation of Liquid Film ...................... 532
17.3.4 Discretization of Source Terms and Equations ........ 535
17.3.5 Examples of CFD Application ........................................... 538
References ....................................................................................... 547

Part VII Integrated Systems

18 Dual-Layer Ammonia Slip Catalysts for Automotive SCR
Exhaust Gas Aftertreatment: An Experimental
and Modeling Study ........................................................................ 553
Isabella Nova, Massimo Colombo, Enrico Tronconi,
Volker Schmeißer, Brigitte Bandl-Konrad and Lisa Zimmermann
18.1 Introduction .................................................................................. 554
18.2 Methods ...................................................................................... 556
18.2.1 Experimental ................................................................. 557
18.2.2 Modeling ....................................................................... 558
18.3 Derivation and Validation of the SCR Model .................. 561
18.3.1 Reaction Network and Kinetic Scheme
Over the SCR Component ......................................................... 561
18.3.2 Kinetic Fit ........................................................................... 566
18.3.3 Model Validation ............................................................. 567
18.4 Derivation and Validation of the PGM Catalyst Model ..... 567
18.4.1 Reaction Network and Kinetic Scheme
Over the PGM Component .......................................................... 567
18.4.2 Model Fit ........................................................................... 573
18.4.3 Model Validation ............................................................. 573
18.5 Analysis and Modeling of SCR/PGM Interactions .......... 575
18.5.1 Experimental Study of SCR/PGM Interactions ............ 575
18.5.2 Predictive Simulations of the SCR/PGM
Combined Systems ................................................................. 577
18.6 Modeling of Dual-Layer Monolith ASC .......................... 579
18.6.1 Development of a Dual-Layer Monolith Model ............ 579
18.6.2 Validation of the Dual-Layer Monolith ASC Model ... 581
18.7 Conclusions ..................................................... 583
References ........................................................... 584

19 NSR–SCR Combined Systems: Production and Use of Ammonia ................................. 587
Fabien Can, Xavier Courtois and Daniel Duprez
19.1 Introduction ...................................................... 587
19.2 NH3 Emission from NSR Catalysts ......................... 588
19.2.1 The NSR Process ........................................... 588
19.2.2 Ammonia Formation Pathways ............................ 589
19.2.3 Influencing Parameters/Ammonia Reactivity ............ 591
19.2.4 Conclusion .................................................. 596
19.3 Coupling of NOx Trap and NH3–SCR Catalysts .......... 596
19.3.1 Emergence and Development of the NSR–SCR Coupling Concept .......................................... 596
19.3.2 Coupling of Pt Catalysts with Zeolites .................. 598
19.3.3 Coupling of Pt(RhPd)/BaO/Al2O3 with Cu–Zeolite Catalysts ........................................... 598
19.3.4 Coupling of Pt(RhPd)/BaO/Al2O3 with Fe–Zeolite Catalysts ........................................... 603
19.3.5 Other Systems Including Tungsten-Based Catalysts .................................................. 606
19.4 Selective Catalytic Reduction of NOx by Ammonia (NH3–SCR) ........................................... 608
19.4.1 Mechanistic Aspects of the SCR Reaction ............... 608
19.4.2 Effect of Zeolite Framework ................................ 610
19.4.3 Role of Acidic Sites ......................................... 611
19.4.4 Active Sites and Performances of Cu–Zeolite, Fe–Zeolite, and Other Systems in NH3–SCR .... 612
19.5 Conclusion and Perspective .................................... 614
References ........................................................... 615

20 Integration of SCR Functionality into Diesel Particulate Filters ........................................ 623
Thorsten Boger
20.1 Introduction ...................................................... 624
20.2 Diesel Particulate Filter Technologies ....................... 626
20.2.1 Diesel Particulate Filter Designs and Materials ....... 626
20.2.2 Catalyst Coatings for Diesel Particulate Filters ....... 629
20.3 Performance Considerations for SCR Integrated Diesel Particulate Filters

20.3.1 Pressure Drop and Permeability
20.3.2 Filtration
20.3.3 Filter Regeneration, Thermal Management, and Durability
20.3.4 DeNOx Efficiency

20.4 Modeling of SCR Integrated Particulate Filters

20.5 Application Examples

20.5.1 Light Duty
20.5.2 Heavy Duty

20.6 Summary

References

Part VIII Case Histories

21 Development of the 2010 Ford Diesel Truck Catalyst System

Christine Lambert and Giovanni Cavataio

21.1 Introduction

21.2 Early Research at Ford on Lean NOx Control for Diesel Vehicles

21.3 Ford’s Research Program on a Prototype Light-Duty Diesel Truck

21.3.1 SCR System Design
21.3.2 DOC Development for SCR Systems
21.3.3 SCR Catalyst Formulations
21.3.4 Vehicle System Results

21.4 Migration of Research into a Production Vehicle Program

21.4.1 Vehicle Program Needs for Lean NOx Control
21.4.2 Catalyst and System Design Options

21.5 Development Challenges Associated with SCR Catalyst Systems

21.5.1 Thermal Stability of the DOC
21.5.2 Thermal Stability of the SCR Catalyst
21.5.3 Ammonia Storage Management
21.5.4 HC Poisoning/Coking of Zeolitic SCR Catalysts
21.5.5 Precious Metal Poisoning
21.5.6 Sulfur Effects on Catalysts
21.5.7 Urea Injection/Mixing
21.5.8 Urea Specifications and Refill
### 21.6 Environmental Impact of Medium-Duty Diesels:

- **Current and Future**: 683
- **NOx Emissions**: 683
- **Greenhouse Gas Footprint (CO₂, CH₄, N₂O)**: 684
- **Use of Base Metals, Pd Rich Catalysts**: 684

### 21.7 Conclusion: 686

References: 687

### 22 Model-Based Approaches to Exhaust Aftertreatment System Development

Michel Weibel, Volker Schmeißer and Frank Hofmann

- **Introduction**: 692
- **Modeling of the Exhaust Gas Aftertreatment System**: 693
  - **Total System Simulation**: 693
  - **Model Structure**: 694
  - **Kinetics and Parameterization**: 695
- **Simulation Methods in the Development Process**: 696
  - **Demands of the Development Process**: 696
  - **The Virtual Testbench Concept**: 697
  - **Development of an AdBlue® Dosing Control Strategy**: 697
- **Outlook: On-board Model-Based SCR Control**: 704
- **Summary**: 705

References: 706

About the Editors: 709

Index: 711
Urea-SCR Technology for deNOx After Treatment of Diesel Exhausts
Nova, L.; Tronconi, E. (Eds.)
2014, XX, 716 p. 411 illus., 292 illus. in color., Hardcover
ISBN: 978-1-4899-8070-0