

# LIST OF TABLES

Table	Title	Page
2-1	Commercial Solutions for FCC Gasoline Reformulation	2-26
2-2	Patent and Research Developments for FCC Gasoline Reformulation	2-26
2-3	Commercial Solutions for Increasing FCC Gasoline Yield	2-28
2-4	Patent and Research Developments for Increasing FCC Gasoline Yield	2-30
2-5	Commercial Solutions for Increasing FCC LCO Yield	2-33
2-6	Patents and Research Developments for Increasing FCC LCO Yield	2-34
2-7	Commercial Solutions for Increasing FCC Propylene Yield	2-37
2-8	Patents and Research Developments for Increasing FCC Propylene Yield	2-39
2-9	Commercial Solutions for FCC NO <sub>x</sub> , SO <sub>x</sub> , CO, and PM Reduction	2-45
2-10	Patent and Research Developments for FCC NO <sub>x</sub> , SO <sub>x</sub> , CO, and PM Reduction	2-45
2-11	Commercial Solutions for Resid Fluid Catalytic Cracking	2-49
2-12	Patent and Research Developments for Resid Fluid Catalytic Cracking	2-50
2-13	Methods to Reduce FCCU CO <sub>2</sub> Emissions	2-53
2-14	Summary of BioFeeds Useful in Fluid Catalytic Cracking	2-56
2-15	Improving FCCU Productivity and Increasing Energy Efficiency	2-60
2-16	Commercial Hydrotreating Solutions for Production of Ultra-Clean Gasoline and Diesel	2-63
2-17	Patent and Research Developments for Ultra-Clean Gasoline and Diesel Production	2-68
2-18	Commercial Solutions for Resid Hydrotreating	2-71
2-19	Patent and Research Developments for Resid Hydrotreating	2-71
2-20	Commercial Solutions for Hydrotreating Renewables	2-72
2-21	Patent and Research Developments for Hydrotreating Renewables	2-73
2-22	Commercial Solutions for Increasing Productivity and Improving Energy Efficiency for Hydrotreating	2-73
2-23	Patent and Research Developments for IMproving Productivity and Increasing Energy Efficiency of Hydrotreating	2-74
2-24	Commercial Hydrocracking Solutions for Production of ULSD	2-75
2-25	Patent and Research Developments for Hydrocracker ULSD Production	2-77
2-26	Comercial Solutions for Hydrocracking Resids	2-79
2-27	Patent and Research Developments for Resid Hydrocracking	2-81
2-28	Commercial Solutions for Hydrocracking Renewables	2-82
2-29	Patent and Research Developments for Hydrocracking Renewables	2-83
2-30	Commercial Solutions for Increasing Productivity and Improving Energy Efficiency for Hydrocracking	2-83
2-31	Patent and Research Developments for Increasing Productivity and Improving Energy Efficiency for Hydrocracking	2-84
3-1	Worldwide Fuel Objectives by 2010	3-4
3-2	Current and Future Motor Gasoline Specifications	3-4
3-3	Current and Future Middle Distillate Specifications	3-8
3-4	Current and Future Residual Fuel Oil Specifications	3-13
3-5	CONCAWE's Categorization of Refinery Emissions Sources	3-15
3-6	Diesel Specs Related to Performance, Safety, and Handling Issues	3-31
3-7	US Phase II RFG Gasoline Specifications	3-38
3-8	Changes in Gasoline Components for Ethanol Blending	3-39
3-9	Gasoline Sulfur and NO <sub>x</sub> Specifications	3-39
3-10	State Legislation Involving MTBE	3-43
3-11	New York Harbor Oil Product Specs	3-44
3-12	Specifications for CARB Reformulated Gasoline	3-44
3-13	US EPA's 2006 Specifications for Diesel Fuel	3-45
3-14	Upcoming US Reductions in Allowable Diesel Sulfur	3-46
3-15	Texas Low-Emission Diesel Specifications	3-49
3-16	NSPS Standards for FCCU Regenerator Emissions of PM, CO, and SO <sub>x</sub>	3-54

Table	Title	Page
3-17	RCRA Requirements that Apply to the Refining Industry	3-64
3-18	EPA Hazardous Listing Status for Refining Wastes	3-66
3-19	Percentage of Pollution from Transportation Fuels	3-66
3-20	Canada's Typical Diesel Specifications	3-69
3-21	Canada's Typical Jet A-1 Fuel Specifications	3-70
3-22	Motor Gasoline Specifications in Latin American Countries	3-73
3-23	Diesel Specifications in Latin American Countries	3-74
3-24	EU27 Sulfur Specifications	3-78
3-25	EU Diesel Specifications	3-81
3-26	European City and Swedish Diesel Specifications	3-81
3-27	Past and Forecast Sulfur Specs for European and US Fuel Oil	3-83
3-28	EU Legislation Governing Environmental Emissions	3-86
3-29	European National Standards for Air Emissions of Pollutants from FCCUs	3-87
3-30	EU Directives and Decisions on Regulation of Wastes	3-95
3-31	Targets and Deadlines for Asian Sulfur and other Specifications	3-106
3-32	Japanese Diesel Specifications	3-115
4-1	Mid-year 2008 review and forecast	4-11
4-2	Demand and Production of Various Products in the EU	4-27
4-3	Projected Differences between European Production and European Demand for Gasoline and Gas Oil/Diesel	4-29
4-4	Major Sources of Propylene and Percentages of Global Supply Growth from 2004-2010	4-75
4-5	Projections for Global Chemical- and Polymer-Grade Propylene Market Demand Met by Specific Processes	4-79
4-6	Middle Eastern Propylene Capacity Increase, 2005-2010	4-81
5-1	Regional Crude Refining Capacities	5-2
5-2	Top 25 Worldwide Refiners	5-4
5-3	Top 18 US Refiners	5-8
5-4	Top Five Canadian Refiners	5-21
5-5	Top 10 Latin American Refiners	5-24
5-6	Refining Capacities of Other Latin American/Caribbean Countries	5-32
5-7	Top 20 West European Refiners	5-33
5-8	Top 10 CIS and Central/East European Refiners	5-45
5-9	Refining Capacities of Other CIS and Central/East European Nations	5-55
5-10	Top 10 Middle Eastern Refiners	5-56
5-11	Top 10 African Refiners	5-62
5-12	Refining Capacities of Other African Nations	5-68
5-13	Top 20 Asian-Pacific Refiners	5-69
5-14	Refining Capacities of Other Asian-Pacific Nations	5-84
6-1	Status and Outlook for Major FCC Catalyst Producers	6-2
6-2	Status and Outlook for Major FCC Process Licensers	6-4
6-3	Status and Outlook for Major HP Catalyst Producers and Process Licensers	6-7
6-4	Competition in Commercially Available HT Reactor Internals	6-10
6-5	Competition in Available HC Technology for Retrofit	6-11
6-6	Competition in Available HC Reactor Internals	6-12
6-7	Summary of Leading Technology Providers	6-13
6-8	Worldwide Fluid Catalytic Cracking Capacity	6-17
6-9	Average Annualized change for FCC Capacity	6-18
6-10	Worldwide Hydrotreating Capacity	6-19
6-11	Hydrotreating Capacity by Application	6-21
6-12	Average Annualized Change for Hydrotreating Capacity	6-22
6-13	Worldwide Hydrocracking Capacity	6-23
6-14	Hydrocracking Capacity by Application	6-24

Table	Title	Page
6-15	Average Annualized Change for Hydrocracking Capacity	6-24
6-16	FCC Recent and Planned Construction Activity	6-26
6-17	Hydrotreating Recent and Planned Construction Activity	6-31
6-18	Hydrocracking Recent and Planned Construction Activity	6-44
7-1	Benzene Removal Options	7-3
7-2	Variation in Sulfur Levels of Gasoline Pool Components	7-6
7-3	Typical Product Sulfur Levels (wt% Sulfur on Feed Basis)	7-8
7-4	Product Sulfur Content for Various FCCU Feeds	7-8
7-5	Effect of FCC Process Parameters on Gasoline Sulfur Content	7-17
7-6	FCC Naphtha Desulfurization Processes	7-19
7-7	Ozone Reactivities and Blending RVPs for C <sub>4</sub> -C <sub>5</sub> components	7-24
7-8	Effect on FCC Yields of Revamp for Maximum Light Olefins	7-27
7-9	Commercial Performance of Albemarle's RESOLVE 700	7-31
7-10	ACE Test Results: NaphthaMax-LSG vs. Three Commercial FCC Catalysts	7-35
7-11	Olefins Reduction with Albemarle's TOM Catalysts	7-40
7-12	Gasoline Sulfur-reducing Catalysts and Additives	7-42
7-13	Gasoline Olefins-reducing Catalysts and Additives	7-44
7-14	Thiophene/Oxide Reactivity	7-57
7-15	Comparison of Sulfur Reduction Techniques	7-70
7-16	Comparison of Olefin Reduction Techniques	7-72
7-17	Comparison of RVP Reduction Options	7-73
7-18	Effect of FCCU Modifications on Key Gasoline Reformulation Targets	7-74
7-19	Recent Crude and Product Price Volatility	7-75
7-20	Regional Consumption: Light Distillate vs. Middle Distillate	7-75
7-21	Yield Slate and Economic Comparison of LCO Recycle Options	7-80
7-22	Commercial USY Catalysts/Additives	7-84
7-23	Commercial ZSM-5 Additives	7-85
7-24	Increased Gasoline Catalysts/Additives	7-85
7-25	Commercial Hardware Offerings	7-86
7-26	FCC Gasoline Patent and R&D Activity Distribution	7-93
7-27	Various Cracking Selectivities	7-98
7-28	Relative Cracking Rates of Single Rings	7-99
7-29	FCC versus MILOS FCC	7-103
7-30	LCO Maximization by ZSM-5 Additive	7-104
7-31	Yield Comparison at Commercial Conditions	7-105
7-32	Product Yields from Albemarle FCC Catalyst Families	7-105
7-33	Upgrader MD Commercial Trial Results	7-106
7-34	Petromax-MD versus High and Low Z/M Catalysts	7-106
7-35	Maximize Product Value with MIDAS-300	7-109
7-36	Commercial Process and Hardware Offerings	7-110
7-37	Commercial Catalysts/Additives	7-111
7-38	FCC Diesel Patent and R&D Activity Distribution	7-118
7-39	Conversion of Minas Gas Oil in MAXOFIN Operating Modes	7-123
7-40	Superflex Product Yields from Various Feeds	7-125
7-41	Steam Cracking plus Superflex versus Steam Cracking with Recycle	7-126
7-42	Operating Conditions of Downer and Riser Pilot Plants	7-128
7-43	Effect of Feed Oil Type on Product Yields	7-128
7-44	Comparative Economics for FCCU and DCCU	7-129
7-45	Commercial Performance of DCC	7-130
7-46	FDCC Commercial Trials	7-131
7-47	MIP-CGP Commercial Trial	7-132
7-48	Product Distributions from Conventional FCC and PetroFCC	7-133

Table	Title	Page
7-49	ATOMAX-2 Commercial Trial $\Delta$ Yields Compared to ATOMAX	7-134
7-50	Optimix Feed Distributor Benefits	7-135
7-51	FCC versus MILOS FCC	7-137
7-52	Comparative Operating Conditions for FCC, DCC, CPP, and SC	7-143
7-53	DCC Product Slate and Olefins Yields	7-144
7-54	Relative Performance of ZSM-5 and Albemarle AFX-2	7-145
7-55	BASF's MPA Catalyst Additive versus ZSM-5	7-146
7-56	BASF's Maximum Olefins Additives versus ZSM-5	7-147
7-57	Grace Davison's PMC versus Conventional Catalyst Plus ZSM-5	7-149
7-58	Grace Davison's OlefinsMax versus Competitive Additive	7-150
7-59	INTERCAT's PENTA-CAT versus GrAce Davison's OlefinsPlus	7-151
7-60	INTERCAT's ZMX versus ZSM-5	7-152
7-61	Commercial Process and Hardware Offerings	7-153
7-62	Commercial Additives	7-155
7-63	Process and Hardware R&D Activity	7-166
7-64	FCC Propylene: Catalyst and Additive R&D Activity	7-168
7-65	FCCU Regenerator Emission Targets	7-169
7-66	Flue Gas Particulate Concentrations Corresponding to US EPA Limit	7-170
7-67	Typical Design Criteria for Dupont Belco EDV Wet scrubber Systems	7-193
7-68	EDV Economic Analysis for Valero Refining	7-195
7-69	LABSORB Scrubber Inlet/Outlet Conditions	7-196
7-70	Comparison of DynaWave Options for Reducing SO <sub>x</sub> Emissions	7-200
7-71	Cyclofines TSS Test Data from Altona Refinery	7-202
7-72	Recent TSS Performance Data	7-205
7-73	Particulate Emissions after Installation of UOP TSS (Flying J Refinery)	7-206
7-74	Reaction Rate Constants for Ozone and Flue Gas Pollutants	7-207
7-75	Commercial Results for Grace Davison DENOX	7-211
7-76	Commercial Results for Grace Davison XNOX	7-212
7-77	Commercial Test of Albemarle Resolve 800 FCC Catalyst Additive	7-214
7-78	Cost Comparison of Scrubber vs. SO <sub>x</sub> Down Additive	7-214
7-79	Composition and Relative Activities: SO <sub>x</sub> Getter and DESOX Additives	7-216
7-80	Commercial Comparison: SO <sub>x</sub> Getter, DESOX, and Super SO <sub>x</sub> Getter	7-216
7-81	Commercial Tests of SO <sub>x</sub> Getter Additives	7-217
7-82	Back-to-back Commercial Trial of Three SO <sub>x</sub> -reduction Additives	7-218
7-83	Commercial Performance of Three SO <sub>x</sub> Reduction Additives in a UD Partial-burn FCCU	7-218
7-84	Catalytic Performance Comparing NaphthaMax and NaphthaMax LMF	7-220
7-85	Summary Commercial Process Options for Reducing Pollutants in FCC Flue Gas	7-221
7-86	Commercial Catalysts and Additives for Reducing Flue Gas Pollutants	7-222
7-87	Effect of Promoters on SO <sub>2</sub> Reduction	7-232
7-88	Coke Combustion Tests on CO Promoters	7-236
7-89	Effects of Ruthenium and Support Material on NO and CO Conversions	7-239
7-90	Effect of Cerium Promoter on NO and CO Conversions	7-239
7-91	Effect of Palladium in Addition to Ruthenium on NO and CO Conversions	7-239
7-92	Effect of Level of Ruthenium Addition on NO and CO Conversions	7-239
7-93	Effects of Silver and Cerium on NO and CO Conversions	7-240
7-94	Effects of Iridium and Cerium on NO and CO Conversions	7-241
7-95	Regenerator Emissions Mitigation Methods	7-248
7-96	A Comparison of Current and Future Solutions	7-249
7-97	Properties of Kuwait VGO, Atmospheric Resid, and Vacuum Resid	7-252
7-98	Study of Resid Composition and Cracked Product Slate	7-253
7-99	Relative Reducion of H <sub>2</sub> Production of Various Elements	7-257
7-100	Definitions of Feed Properties for Correlations with Cracked Product Yields	7-259

Table	Title	Page
7-101	RFCC Regenerator Configuration Options	7-264
7-102	Typical Operating Conditions and Product Yields for a Flexicracking IIR Unit Processing Resid	7-269
7-103	Commercial Results from Petrobras PAC Refineries	7-272
7-104	Commercial Tests of CPP in Various Operating Modes	7-273
7-105	Performance Data from Shell's Long Resid Stanlow FCCU	7-277
7-106	Comparison of RFCC Gasoline Products with MIP-CGP	7-279
7-107	Performance of SK RFCC Unit	7-280
7-108	Atomax-2 Revamp Improvements	7-281
7-109	Effect of Quenching on FCC Yield	7-286
7-110	Catalyst Regeneration with and without Regenmax	7-290
7-111	General Features of ADM Materials	7-294
7-112	AFX RFCCU Performance Data	7-297
7-113	Centurion MAX Applies ADM Synergy to Improve Bottoms Conversion	7-298
7-114	RFCC Product Yield: Coral SMR vs. Alumina Sol Catalyst	7-300
7-115	Opal Allows for Processing Greater Amounts of Resid in Feed	7-301
7-116	Petrobras High Accessibility Catalyst Performance	7-302
7-117	Effects of Flushing Catalyst Component	7-302
7-118	Performance Benefits of ReVolution Catalyst	7-303
7-119	Upgrader Catalyst Evaluation	7-304
7-120	Commercial Performance of Albemarle BCMT-100 Bottoms Cracking Additive	7-305
7-121	Commercial Performance of Albemarle BCMT-500 Bottoms Cracking Additive	7-305
7-122	Albemarle Families of Resid FCC Catalysts and Additives	7-306
7-123	Impacts of Changeover to Flex-Tec on MAP RCC Unit	7-309
7-124	Commercial Example of Engelhard Converter Additive	7-309
7-125	BASF RFCC Catalysts and Additives	7-310
7-126	Grace Davison RFCC Catalyst Components	7-311
7-127	Performance of Grace Davison AURORA at Pertamina Refinery	7-312
7-128	Performance of Grace Davison IMPACT at Gulf Coast Refinery	7-314
7-129	Replacement of KRISTAL with NEKTOR—Yields from Commercial Trial	7-316
7-130	Commercial Replacement of NEKTOR with NEKTOR-ULCC	7-316
7-131	Effects of Conversion from KRISTAL to ResidMax at BP Coryton	7-318
7-132	Grace Davison RFCC Catalysts	7-319
7-133	Commercial Applications of INTERCAT BCA-105	7-321
7-134	Commercial Results of Hi-Y Addition	7-322
7-135	Synergistic Effects of Super-Z and BCA-110 Additives	7-323
7-136	Commercial Trial Results for INTERCAT CAT-AID Additive	7-324
7-137	INTERCAT RFCC Catalysts and Additives	7-325
7-138	MAT Results for Initial Commercial Test of MVP	7-326
7-139	RIPP Tailored Gradient Catalysts for Cracking Vacuum Resid Feeds	7-327
7-140	RIPP MLC-500 Diesel Selective AR Cracking Catalyst	7-330
7-141	Impact of MagnaCat on Kyokuto RFCCU	7-334
7-142	DCR Performance of Catalyst Rejuvenated by Demet IV Process	7-335
7-143	Performance of Catalyst Rejuvenated by Sinopec RECAS Process	7-336
7-144	Commercial Resid FCC Process Technologies	7-337
7-145	Commercial RFCC Catalyst/Additive Solutions	7-339
7-146	HVGO and DAO Feed Characteristics	7-340
7-147	High-resolution NMR Performance Data for a Resid Feed	7-342
7-148	Performance of Various Metals Trapping RFCC Additives	7-357
7-149	Challenges in Catalytically Cracking Resid Feeds	7-368
7-150	Comparison of Current and Future Resid Cracking Solutions	7-368
7-151	Operating Data Showing Increased LCO Yield and Decreased Coke Make	7-376
7-152	Effect of Preheating Process on FCCU CO <sub>2</sub> Emissions	7-378

Table	Title	Page
7-153	FCCU Pre-combustion Challenges	7-382
7-154	FCCU Regenerator CO <sub>2</sub> Reforming Model Results	7-385
7-155	Effect of Novel Process on Regenerator CO <sub>2</sub> Emissions	7-389
7-156	FCCU Pre-combustion Summary	7-395
7-157	FCCU Oxyfiring Challenges	7-397
7-158	CLC Possibilities for FCCU Regenerators	7-399
7-159	FCCU Oxyfiring Summary	7-401
7-160	Typical Flue Gas Conditions	7-402
7-161	FCCU Post-combustion Challenges	7-403
7-162	Refinery Post Combustion Capture Utility Requirements	7-404
7-163	Refinery Post Combustion Capture Emissions	7-404
7-164	Refinery Post Combustion Capture Capital Costs	7-405
7-165	Reformer Flue Gas	7-409
7-166	Flue Gas Composition	7-409
7-167	Adsorption vs. Absorption Cost Comparison	7-416
7-168	Capture Costs	7-417
7-169	Influence of Pressure Drop on Cost	7-417
7-170	Carbozyme Process Cost Comparisons	7-422
7-171	FCCU Post-combustion Summary	7-427
7-172	Comparison of CO <sub>2</sub> Sorbent Capacities	7-428
7-173	Frontier Concepts for FCC Regenerator CO <sub>2</sub> Capture	7-428
7-174	FCCU Carbon Capture Technology Summary	7-432
7-175	Methods to Reduce FCCU CO <sub>2</sub> Emissions	7-433
7-176	LignoCellulosic Sources of Biomass	7-437
7-177	Comparison of FCCU BioFeed Properties	7-439
7-178	Challenges and Benefits for the Fluid Catalytic Cracking of Biomass-Derived Feeds	7-440
7-179	FCC Product Yields for VGO/Pyrolysis Oil and VGO/Lignin Feeds	7-443
7-180	Lignin Cracking over ZSM-5	7-446
7-181	Catalyst Performance for a Wood-derived Bio-oil at 370°C	7-448
7-182	BTL Wax Feed Properties	7-449
7-183	Catalyst Properties for BTL Wax Upgrading	7-449
7-184	Product Yields for BTL Wax and VGO Feeds	7-450
7-185	Product Yields on BTL Wax at 80 wt% Conversion	7-451
7-186	F-T wax and VGO Feed Properties	7-452
7-187	FCC Pilot Plant Results for BTL Wax and VGO at 80 wt% Conversion	7-453
7-188	Effect of Increasing Temperature on F-T Wax Conversion	7-453
7-189	Comparative Product Distributions from Conventional Catalytic Cracking of VGO and of Oil/Greases to Gasoline and to Olefins	7-455
7-190	FCC Yields for Castor Oil and VGO Feeds	7-459
7-191	Performance of FCC Catalysts in the Cracking of Palm Oil	7-461
7-192	Performance of Beta-zeolite Blends for Cracking Palm Oil	7-462
7-193	Performance of USY Blends for Cracking Palm Oil	7-462
7-194	Pilot Plant FCC Yields for Soybean oil Feed	7-464
7-195	Yield Changes Upon Triglyceride Feed Blending	7-467
7-196	Summary of BioFeeds Useful in Fluid Catalytic Cracking	7-468
7-197	FCCU Energy-saving Opportunities	7-475
7-198	FCCU Heat Source/Heat Sinks	7-476
7-199	FCCU Gasoline Splitter Comparison	7-477
7-200	Summary of Commercially Available Advanced Control Systems	7-483
7-201	Commercially Available Process Models and Simulation Software	7-486
7-202	Energy Efficiency and Unit Productivity Summary	7-489
7-203	Comparison of Haldor Topsøe Aroshift Process with Conventional FCC Pretreating	7-495

Table	Title	Page
7-204	Performance of VGO Unionfining Units	7-497
7-205	ApART versus NiMo or CoMo Catalyst for Pretreating FCC Feed Containing CGO	7-498
7-206	Case Study Summary of ApART Catalyst Systems	7-499
7-207	Relative Performance of Albemarle Catalysts in FCC Pretreating	7-500
7-208	Relative Capacities for Metals of Albemarle Catalysts	7-500
7-209	Comparative Performances of Criterion CENTINEL Catalysts for FCCU Feed Pretreatment	7-501
7-210	Comparative Performances of ASCENT Catalysts for FCC Pretreating	7-502
7-211	Relative Economics of ASCENT DN-3551	7-503
7-212	Improved FCCU Performance Using Stacked ASCENT Catalysts	7-503
7-213	Commercial Application of Prime-G+ 1st Step	7-508
7-214	Comparative Economics of CDHydro/CDHDS and CDHDS+	7-516
7-215	HDS of Full-Range FCC Gasoline Using ExxonMobil OCT-220 Catalyst	7-517
7-216	FRIPP OTA Process Performance	7-519
7-217	Comparative Economics for Processing Reformate by CDHydro and Conventional Hydrotreating	7-521
7-218	Relative Economics of UOP H-8 and H-18 BenSat Catalysts	7-523
7-219	Performance of Catalyst for Reducing Olefins in FCC Naphtha	7-542
7-220	HDAR Operating Conditions and Performance	7-546
7-221	Performance of Prime-D Options for ULSD	7-548
7-222	Diesel Quality from FRIPP FHI Process	7-549
7-223	Diesel Upgrading with RIPP's SSHT Process	7-552
7-224	Guide for Choosing SynTechnology and Suitable Reactor System	7-553
7-225	Comparative Product Qualities for SynShift and Conventional HDS	7-556
7-226	Albemarle Guide to Selecting Hydrotreating Catalysts	7-562
7-227	Product Qualities Obtained by Hydrotreating Different Feeds with KF 848	7-564
7-228	Comparative Economics for use of NEBULA versus a New Reactor with STARS Catalyst	7-566
7-229	Relative Performance of NEBULA-1 and KF 848 for Hydrotreating SR LGO	7-567
7-230	Comparative Performances of NEBULA-20, STARS KF 848, and a Conventional NiMo Catalyst for Hydrocracker Pretreating	7-568
7-231	Comparative Performances of NEBULA-20, KF 757, and KF 848 for FCC Pretreating	7-568
7-232	Comparative RVAs and H <sub>2</sub> Consumption for NEBULA, STARS NiMo, and STARS CoMo Catalysts	7-568
7-233	Economics of Desulfurizing SR Diesel with and without Added LCGO	7-570
7-234	Criterion CENTINEL, CENTINEL GOLD, AND ASCENT CATALYSTS	7-574
7-235	Activity of DN-3330 Relative to DN-3110 for ULSD Production from Different Feeds	7-576
7-236	Sulfur in Hydrotreated SR Diesel at Very High Gas-to-Oil Rates	7-581
7-237	Effect of TiO <sub>2</sub> Content in Alumina Catalyst Support on Diesel HDS Activity	7-593
7-238	Comparison of Bulk and Supported NiMoW Catalysts	7-601
7-239	REDAR Upgrade of LCO to Ultralow-Sulfur Diesel Product	7-606
7-240	Equipment Requirements for Revamping with IsoTherming and with Conventional Means	7-613
7-241	Process Technologies for Revamping Hydrotreaters	7-618
7-242	Comparative Performance of Axens EquiFlow Trays	7-621
7-243	Comparison of Haldor Topsøe DPF Tray and a Conventional Tray in a Diesel Hydrotreater	7-622
7-244	Comparison of Element Configuration between VLT and a Bubble Cap Tray	7-623
7-245	Revamp of Preemraff SynSat Unit with CENTINEL GOLD Catalyst and Shell Reactor Internals	7-625
7-246	PRS Impact on RDS Resid Quality	7-629
7-247	FCC Yields as a Function of Feed Hydrogen Content	7-630
7-248	ART Catalysts for Chevron RDS/VRDS, OCR, and UFR Units	7-631
7-249	Property Comparison of VRDS VR with Original VR	7-633
7-250	Comparison of Resid Conversion Processes	7-634
7-251	Performance of Shengli RDS/UFR Unit	7-637
7-252	Performance of Shell Residual Oil Hydrodesulfurization Process	7-638
7-253	SUPERCETANE Properties for Various Feedstocks	7-658
7-254	Neste Patents on Conversion of Biofeeds to Hydrocarbons	7-660

Table	Title	Page
7-255	NExBTL versus US Diesel Standards	7-661
7-256	NExBTL versus EN590 and Other Diesels	7-662
7-257	Emissions Reductions from Euro 4 Truck Engines for NExBTL	7-662
7-258	Nippon Oil Hydrotreated Palm Oil Diesel	7-664
7-259	Comparison of Conventional and Bio-Synfining Diesel and Jet Fuels	7-665
7-260	Comparison of Syntroleum Bio-Synfining Staged BTL and Standalone BTL	7-666
7-261	Typical Ecofining Process Results using 100% Vegetable Oil	7-668
7-262	Properties of Petrodiesel, Green Diesel, and Biodiesel	7-669
7-263	Diesel Blend with Green Diesel and LCO	7-669
7-264	Example Graded Catalyst Bed	7-673
7-265	Graded Catalyst Beds Used at Murphy Oil Meraux Refinery	7-673
7-266	Appropriate Use of Regenerated Catalysts	7-675
7-267	Comparison of TRICAT Regeneration Process and Other Methods	7-677
7-268	Energy Use in Hydrotreating	7-678
7-269	Utility Consumption of a Naphtha Hydrotreater	7-679
7-270	Utility Consumption of a Middle Distillate Hydrotreater	7-679
7-271	Utility Consumption of a Resid Hydrotreater	7-680
7-272	Relative Activities of Molybdenum, Tungsten, and Rhenium Catalysts	7-700
7-273	Commercial Process, Hardware, Catalyst, and Additive solutions for Hydrotreating	7-708
7-274	Characteristics of Hydrocracking Units	7-717
7-275	Properties of VGO/HCGO Feed for HyK-HC processing	7-721
7-276	Performance of Three HyK-HC Schemes for Processing VGO/HCGO	7-721
7-277	Properties of Hamaca HCGO/HVGO Feed	7-724
7-278	TSR ISOCRACKING of HCGO	7-726
7-279	Utility Requirements for SSOT and TSR ISOCRACKING	7-726
7-280	Split-Feed Injection versus Coprocessing	7-729
7-281	Performance of CLG MHC with ISOFLEX	7-730
7-282	Product Yields and Properties for Cat Feed Hydrotreating and MPHC	7-732
7-283	MPHC-LCO Operating Conditions and Product Yields and Qualities	7-734
7-284	ExxonMobil MPHC-MIDW Operation	7-735
7-285	Product Yields and Qualities for MPHC-MIDW	7-736
7-286	Economics of Shell Hydrocracking Processes	7-737
7-287	MHUG Progressive Upgrading	7-739
7-288	Economics of MHUG Processing Options	7-740
7-289	FDC Operating Conditions for Different Feeds	7-741
7-290	FDC Product Yields for Different Feeds	7-741
7-291	Change in Product Yields for Upgrading Hydroskimming Refinery with Unicracking and SDA	7-743
7-292	Economics for Upgrading Hydroskimming Refinery with Unicracking and SDA	7-743
7-293	Comparison of Partial-Conversion Unicracking with Mild Hydrocracking	7-745
7-294	Comparison of Product Yield and Quality in a European Refinery from LCO Hydrotreating and LCO Unicracking	7-746
7-295	Comparison of Product Yield and Quality in a US Coker/FCC Refinery from LCO Hydrotreating and LCO Unicracking	7-747
7-296	Comparison of Economics in a US Coker/FCC Refinery from LCO Hydrotreating and LCO Unicracking	7-747
7-297	Comparison of Once-through Unicracking and APCU	7-750
7-298	Product Yields and Qualities with Chevron Zeolite Catalysts	7-752
7-299	Distillate-Selective Hydrocracking Catalyst from Criterion	7-753
7-300	UOP Hydrocracking Catalysts Introduced in the Last Decade	7-755
7-301	Equipment Changes for Converting VGO Hydrotreater to MHC Unit	7-760
7-302	Properties of LVGO Feed and Mild Hydrocracked Products	7-761
7-303	Impacts on LCO Yield and Quality from Different FCC Feed Pretreatments	7-763
7-304	Feed Conversion and Diesel Selectivity for Each Catalyst	7-785

Table	Title	Page
7-305	Comparison of MPHC-PTU with MPHC and HPHC	7-792
7-306	Hamaca HCGO/HVGO Blend	7-793
7-307	Product Properties from Hydrocracking Hamaca HCGO/HCGO Blend	7-793
7-308	Shell HYCON Treatment of Arabian Heavy VR: Product Yields and Properties	7-798
7-309	H-Oil Commercial Installations	7-801
7-310	Properties of Middle Distillate Pool for Three Processing Options	7-803
7-311	Products from LC-Fining Unit with Integrated Hydrotreater	7-806
7-312	LC-FINING Process Performance	7-806
7-313	Commercial Experience of LC-FINING Process	7-807
7-314	Product Yields and Qualities for MICROCAT-RC Hydrotreating of 524:C+ Cold Lake VR	7-810
7-315	EMRE O-T MSHP Conversion of ALVR	7-811
7-316	(HC)3 Yields, Utilities, and Economics	7-813
7-317	Atmospheric Resid from Athabasca Bitumen	7-817
7-318	Sequential Hydrocracking and Hydrotreating of Athabasca Bitumen Atmospheric Resid	7-818
7-319	Canmet Process Product Yields at Two Conversion Levels	7-819
7-320	Product Qualities of VCC Process with/without Integrated Hydrotreating	7-823
7-321	Gudao VR Feedstock Conversions	7-825
7-322	HDS, HDN, and HDM of Gudao VR Feedstocks	7-825
7-323	Experimental Results of Ni-Co Bimetallic Catalyst	7-836
7-324	Results of Hydrocracking AR with Mono/Bimetallic Catalysts	7-837
7-325	Properties of Wood Pyrolysis Oil and a Heavy Fuel Oil	7-842
7-326	Composition and Properties of Bio-Oil and Its Fractions	7-842
7-327	Product Yields from Hydrocracking Pyrolytic Lignin	7-844
7-328	Physical Properties of F-T Diesel, Conventional Diesel, and Diesel Blends	7-845
7-329	Product Yields from Hydrocracking of F-T Wax over Unsulfided and Sulfided Catalysts	7-846
7-330	Process Operations Effect on Conversion and Selectivity	7-849
7-331	Comparison of Albemarle KF-1014 and KF-1022 Catalysts	7-860
7-332	Commercially Available APC Systems for Hydrocracking	7-862
7-333	Comparative Advantages and Disadvantages of Methods for Mitigating Fouling	7-867
7-334	Comparison of Product Qualities from Partial-Conversion Unicracking and Dieselmax	7-870
7-335	Performance of Sinopec FC-28 at Different H <sub>2</sub> /Oil Ratios	7-871
7-336	Commercial Process, Hardware, Catalyst, and Additive Solutions for Hydrocracking	7-884
8-1	FCC Process Economics Provided by Licensers	8-2
8-2	FCC Catalyst Economics Provided by Licensers	8-3
8-3	Survey Economic Data for FCC Revamps	8-4
8-4	Survey Economic Data for FCC New Unit/Expansion Projects	8-4
8-5	Yield Slate and Economic Comparison of LCO Recycle Options	8-5
8-6	Comparative Economics for FCCU and DCCU	8-5
8-7	SO <sub>x</sub> and PM Mitigation Economic Data	8-6
8-8	Post-combustion CCS Economics	8-8
8-9	Refinery Post-combustion Capture Capital Costs	8-9
8-10	Adsorption vs. Absorption Cost Comparison	8-9
8-11	Carbon Capture Operating Costs Per Ton of CO <sub>2</sub> Avoided	8-10
8-12	Influence of Pressure Drop on Cost	8-10
8-13	Carbozyme Process Cost Comparisons	8-10
8-14	FCC Process Control and Simulation Economic Data	8-12
8-15	Hydrotreating Economic Data Provided by Licensers	8-13
8-16	Survey Economic Data for Hydrotreater Revamps	8-15
8-17	Survey Economic Data for HT New Unit/Expansion Projects	8-15
8-18	Hydrocracking Economic Data Provided by Licensers	8-16
8-19	Survey Economic Data for HC New Unit/Expansion Projects	8-18
9-1	Global Environmental and Fuel Specifications	9-1

Table	Title	Page
9-2	Future Roles of FCC, Hydrotreating, and Hydrocracking	9-3
9-3	A Comparison of Current and Potential Process and Hardware Solutions to Reformulate FCC Gasoline	9-7
9-4	A Comparison of Current and Potential Catalyst and Additive Solutions to Reformulate FCC Gasoline	9-7
9-5	Effect of FCCU Modifications on Key Gasoline Reformulation Targets	9-8
9-6	A Comparison of Current and Potential Process and Hardware Solutions to Produce Gasoline	9-9
9-7	A Comparison of Current and Potential Catalyst and Additive Solutions to Produce Gasoline	9-10
9-8	A Comparison of Current and Potential Process and Hardware Solutions to Produce LCO	9-11
9-9	A Comparison of Current and Potential Catalyst and Additive Solutions to Produce LCO	9-12
9-10	A Comparison of Current and Potential Process and Hardware Solutions to Produce Propylene	9-13
9-11	A Comparison of Current and Potential Catalyst and Additive Solutions to Produce Propylene	9-14
9-12	A Comparison of Current and Potential Process and Hardware Solutions to Reduce Emissions	9-16
9-13	A Comparison of Current and Potential Catalyst and Additive Solutions to Reduce Emissions	9-17
9-14	Challenges in Catalytically Cracking Resid Feeds	9-19
9-15	A Comparison of Current and Potential Process and Hardware Solutions to Crack Resid	9-20
9-16	A Comparison of Current and Potential Catalyst and Additive Solutions to Crack Resid	9-22
9-17	Potential Methods to Reduce FCCU CO <sub>2</sub> Emissions	9-23
9-18	Summary of BioFeeds Potentially Useful for FCC	9-26
9-19	Improvements In FCC productivity and Energy Efficiency	9-28
9-20	A Comparison of Current and Potential Process and Hardware Solutions to Produce Ultra-Clean Gasoline and Diesel	9-30
9-21	A Comparison of Current and Potential Catalyst and Additive Solutions for Hydrotreating to Produce Ultra-clean Gasoline and Diesel	9-31
9-22	A Comparison of Current and Potential Solutions for Hydrotreating Resids	9-33
9-23	A Comparison of Current and Potential Solutions for Hydrotreating Fats and Oils	9-34
9-24	A Comparison of Current and Potential Solutions for Hydrotreating to Increase Productivity and Improve Energy Efficiency	9-35
9-25	A Comparison of Current and Potential Process and Hardware Solutions for Production of ULSD	9-38
9-26	A Comparison of Current and Potential Catalyst and Additive Solutions for Production of ULSD	9-39
9-27	A Comparison of Current and Potential Solutions for Hydrocracking Resid Feeds	9-40
9-28	A Comparison of Current and Potential Solutions for Hydrocracking Renewable Feeds	9-41
9-29	A Comparison of Current and Potential Solutions for Hydrocracking to Increase Productivity and Improve Energy Efficiency	9-42
9-30	Urgent Energy and Environmental Issues Facing Regions Throughout the World	9-45