
WORLDWIDE REFINERY PROCESSING REVIEW

Monitoring Technology Development and Competition in One Single Source

Second Quarter 2020

Hydrocracking



HYDROCARBON PUBLISHING COMPANY

Translating Knowledge into Profitability®

P.O. Box 815, Paoli, PA 19301-0815 (U.S.A.)

Phone: (610) 408-0117

Review@Hydrocarbonpublishing.com

WORLDWIDE REFINERY PROCESSING REVIEW

Monitoring Technology Development and Competition in a Single Source

Second Quarter 2020

Hydrocracking

<http://www.hydrocarbonpublishing.com>

WORLDWIDE REFINERY PROCESSING REVIEW is published by Hydrocarbon Publishing Co. every quarter. Copyright 2007-2020. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or translated into any language or by any means—electronic, mechanical, photocopying, recording or otherwise—without prior written permission of Hydrocarbon Publishing Company. P.O. Box 815, Paoli, PA 19301-0815 (USA). Tel: (610) 408-0117. E-mail: review@hydrocarbonpublishing.com

1Q, 2Q, 3Q, 4Q...(the) first, second, third, and fourth quarters, respectively	K	thousand
AAA American Automobile Association (US)	kL.....	kiloliter
ANS Alaskan North Slope crude	lb.....	pound(s)
API..... American Petroleum Institute (US)	METI	Ministry of Economy, Trade and Industry (Japan)
ARA..... Antwerp, Rotterdam, Amsterdam	MM	million
ASTM American Society for Testing & Materials	MOU.....	memorandum of understanding
b or bbl..... barrel(s)	mpg.....	miles per gallon
B billion	mt.....	metric ton
boe barrel(s) of oil equivalent	MW.....	megawatt
CA California	N.A.	not applicable or not available
CAA..... Clean Air Act (US)	NAAQS	national ambient air quality standards
CARB California Air Resources Board	NESCAUM.....	Northeast States for Coordinated Air Use Management
cf..... cubic foot, cubic feet	NG	natural gas
cfr..... cost and freight	NGL.....	natural gas liquid
cif..... cost, insurance, and freight	NPRA	National Petrochemical & Refiners Association (US)
Concawe Conservation of Clean Air and Water Europe	NWE.....	Northwest Europe
CIS..... Commonwealth of Independent States	NYMEX	New York Mercantile Exchange (US)
CNG..... compressed natural gas	OECD	Organization for Economic Cooperation & Development
cst..... centistoke	OPEC.....	Organization of the Petroleum Exporting Countries
d..... day	OSHA	Occupational, Safety and Health Administration (US)
DOE..... Department of Energy	PC	petrochemical(s)
EEC European Economic Community	PM	particulate matter
EIA..... US Energy Information Administration	RBOB	RFG before oxygenate blending
EPA US Environmental Protection Agency	RFG	reformulated gasoline
EPC(M)..... engineering, procurement, and construction (management)	RMT.....	refining, marketing, and transportation
EU15..... 15 original EU members	RVP	Reid vapor pressure
EU25..... EU15 and the 10 new members admitted in May 2004	SCAQMD	South Coast Air Quality Management District (California)
EUROPIA..... European Petroleum Industry Association (Brussels)	VLCC	very large crude carrier
FCV fuel cell vehicle	WTI	West Texas Intermediate
fd..... free delivered	y	year
FEED front-end engineering design	¢.....	US cent(s)
fob..... free on board	€.....	EU euro(s)
gal..... gallon	£.....	UK pound(s)
GTL gas to liquid(s)	\$.....	US dollar(s)
h..... hour	¥.....	Japanese yen
H1 or H2 first or second half of the year		
ICE..... Int'l Commodity Exchange (UK—formerly Int'l Petroleum Exchange)		
IEA Int'l Energy Agency (Paris-based)		
IPAA..... Independent Petr. Assoc. of America		
IPO..... initial public offering		
j.v..... joint venture		
LPG liquefied petroleum gas		

2Q 2020 Review

Hydrocracking

1. INTRODUCTION.....	1
2. HYDROCRACKING.....	5
2.1 Market/Technology Trends & Opportunities	5
2.1.1 Introduction	5
2.1.2 Market Conditions and Outlook	6
2.1.2.1 Global Transportation Fuels Specifications.....	6
2.1.2.1.1 Motor Gasoline.....	7
2.1.2.1.2 Middle Distillates.....	9
2.1.2.2 Global Refined Products Demand.....	11
2.1.2.2.1 Oil Demand Suffers due to COVID-19 Pandemic.....	13
2.1.2.2.1.1 Diesel Growth Opportunities Still Exist	14
2.1.2.2.1.2 Jet Fuel Demand Sinking around the Globe	15
2.1.2.3 Shifting Crude Slate.....	16
2.1.2.3.1 Opportunity Crudes.....	16
2.1.2.3.2 Tight Oil	19
2.1.2.4 Hydrogen Supply and Demand	19
2.1.2.5 Capacity Expansion	20
2.1.2.6 Construction Projects and Unit Revamps	20
2.1.2.7 Hydrocracking Catalyst Market.....	21
2.1.3 Technology Competition, Direction, and Future Prospects.....	22
2.1.3.1 Market Layout and Strategic Alliances	22
2.1.3.2 Recent Technology Developments	28
2.1.3.2.1 Catalyst Developments.....	28
2.1.3.2.1.1 Middle Distillates.....	30
2.1.3.2.1.2 Heavy Naphtha.....	31
2.1.3.2.2 Process and Hardware Developments	32
2.1.3.2.2.1 Aromatics Production.....	33
2.1.3.2.2.2 Two-phase Hydrocracking.....	35
2.1.3.2.2.3 Reactor Internals	36
2.1.3.2.2.4 HPNAs Removal.....	36
2.1.3.2.3 Conventional and Mild Hydrocracking	37
2.1.3.2.4 Resid Hydrocracking	38
2.1.3.2.5 Alternative Feed Hydrocracking	42
2.1.3.2.6 Integration Options	43
2.1.3.2.7 Process Modeling and Control	44
2.1.3.3 Latest R&D Trends	45
2.1.4 Conclusion.....	46
2.2 State-of-the-Art Technology	48
2.2.1 Introduction	48
2.2.2 Commercial Process Technology	49
2.2.2.1 Axens.....	50
2.2.2.1.1 Mild Hydrocracking	51
2.2.2.1.1.1 Mild-HCK.....	51
2.2.2.1.1.2 HyC-10/HyC-10+	52
2.2.2.1.2 H-Oil _{DC}	56
2.2.2.1.3 Medium-pressure Hydrocracking.....	57

2.2.2.1.4	Conventional (High-pressure) Hydrocracking	57
2.2.2.1.5	HPNA Removal.....	63
2.2.2.1.6	Reactor Internals	63
2.2.2.2	Chevron Lummus Global	66
2.2.2.2.1	ISOCRACKING	66
2.2.2.2.1.1	Single-stage Once Through and Single-stage Recycle.....	69
2.2.2.2.1.2	Two-stage Recycle	72
2.2.2.2.1.3	Optimized Partial Conversion	76
2.2.2.2.1.4	Selective Staging.....	78
2.2.2.2.1.5	Split-feed Injection.....	81
2.2.2.2.1.6	Single-stage Reverse Sequencing.....	81
2.2.2.2.2	ISOFLEX	83
2.2.2.2.3	Reactor Internals	85
2.2.2.3	DuPont Clean Technologies.....	88
2.2.2.4	ExxonMobil.....	91
2.2.2.4.1	Single-stage MPHC.....	92
2.2.2.4.2	MPHC-PTU	97
2.2.2.4.3	MPHC-LCO	98
2.2.2.4.4	Two-stage MPHC	100
2.2.2.4.5	MIDW.....	102
2.2.2.4.6	Spider-Vortex Reactor Internals	104
2.2.2.5	Haldor Topsoe	104
2.2.2.5.1	Mild Hydrocracking.....	105
2.2.2.5.1.1	Staged Partial Conversion Hydrocracking	107
2.2.2.5.1.2	Back-End Shift (BES) Process.....	108
2.2.2.5.2	Conventional (High-pressure) Hydrocracking	109
2.2.2.5.3	HPNA Trim	109
2.2.2.5.4	Reactor Internals	111
2.2.2.6	Honeywell UOP	114
2.2.2.6.1	MHC Unicracking	115
2.2.2.6.2	Unicracking	116
2.2.2.6.2.1	Single-stage Once Through or with Recycle	118
2.2.2.6.2.2	Two-stage	122
2.2.2.6.2.3	Enhanced Two-Stage	124
2.2.2.6.3	Partial-conversion Unicracking	126
2.2.2.6.4	Dieselmax.....	130
2.2.2.6.5	HyCycle Unicracking.....	132
2.2.2.6.6	Advanced Partial Conversion Unicracking	133
2.2.2.6.7	HPNA Removal Systems.....	135
2.2.2.6.8	Reactor Internals	135
2.2.2.7	Shell Catalysts & Technologies	138
2.2.2.7.1	Mild Hydrocracking.....	139
2.2.2.7.2	Conventional Hydrocracking.....	141
2.2.2.7.3	Reactor Internals	145
2.2.2.8	Sinopec	152
2.2.2.8.1	Flexible Hydrotreating/Mild Hydrocracking	152
2.2.2.8.2	Medium-pressure Hydro-Upgrading.....	154
2.2.2.8.3	Moderate-pressure Hydrocracking.....	156
2.2.2.8.4	High-pressure Hydrocracking.....	157
2.2.2.8.4.1	Single-stage Hydrocracking.....	157
2.2.2.8.4.2	Single-stage in Series Hydrocracking	158

2.2.2.8.4.3	Single-stage, Double-catalyst Hydrocracking	159
2.2.2.8.4.4	Two-stage Hydrocracking	160
2.2.2.8.4.5	Flexible Hydrocracking	161
2.2.2.9	Summary of Hydrocracking Process Technologies	162
2.2.3	Commercial Catalysts.....	167
2.2.3.1	Albemarle.....	168
2.2.3.2	Axens.....	169
2.2.3.3	Clariant Catalysts	173
2.2.3.4	Chevron Lummus Global.....	174
2.2.3.5	Haldor Topsoe.....	184
2.2.3.6	Honeywell UOP	192
2.2.3.7	JGC Catalysts & Chemicals	197
2.2.3.8	Shell Catalysts & Technologies.....	198
2.2.3.9	Sinopec Catalyst Co.....	216
2.2.3.10	Summary of Commercially Available Hydrocracking Catalysts.....	219
2.2.4	Auxiliary Catalyst Technology	222
2.2.4.1	Axens.....	222
2.2.4.2	Crystaphase Products	222
2.2.4.3	Eurecat.....	223
2.2.4.4	Reactor Resources	224
2.2.4.5	TRICAT.....	225
2.2.5	Control and Optimization Systems	225
2.2.6	Resid Hydrocracking	231
2.2.7	Renewable Hydrocracking	243
2.3	<i>Plant Operations and Practices</i>	247
2.3.1	General Hydrocracking Operations.....	247
2.3.1.1	Feed Considerations, Operational Variables, Process Configurations, and Hardware	248
2.3.1.1.1	Feedstock Characterization	248
2.3.1.1.2	Contaminants	249
2.3.1.1.3	Upgrading Tight Oil.....	250
2.3.1.1.4	Increasing Conversion for Heavier Feedstocks.....	251
2.3.1.1.5	Upgrading LCO and/or HCO in Hydrocrackers.....	252
2.3.1.1.6	Undercutting LVGO to Increase Hydrocracker Utilization.....	255
2.3.1.1.7	Optimizing Operational Variables	255
2.3.1.1.7.1	Recycle Rate in Two-stage Units	256
2.3.1.1.7.2	Setting Operational Pressure	256
2.3.1.1.7.3	Flow Control on Feeds from Coking Unit	257
2.3.1.1.8	Reactor Configuration	258
2.3.1.1.9	Optimized Hydrocracker Reactor Internals.....	258
2.3.1.1.10	Removing Welded Attachments from Reactor Internals	261
2.3.1.1.11	Changing Unit Configuration to Boost Yields and Process Alternative Feeds	262
2.3.1.1.12	Large Single Process Train vs. Smaller Parallel Trains in Hydrocrackers	263
2.3.1.1.13	Reactor Fabrication and Metallurgy.....	263
2.3.1.1.14	Comparison of Quench Systems	266
2.3.1.1.15	Revamping the Overhead Condenser of a Hydrocracker	267
2.3.1.1.16	Hydrocracker Stripper Revamp	267
2.3.1.1.17	Designing Hydrocracker Charge Heater	269
2.3.1.1.18	Hydrocracker Pump Selection	270
2.3.1.1.19	Membranes for H ₂ Recovery from Hydrocrackers	270
2.3.1.1.20	Parameters Impacting Hydrogen Purity in Recycle Gas	271

2.3.1.2	Fouling, Particulate Deposition, and Corrosion.....	271
2.3.1.2.1	Causes of Hydroprocesser Fouling and Possible Treatments	271
2.3.1.2.2	Chlorides Fouling in Effluent Exchangers.....	277
2.3.1.2.3	Elimination of Polynuclear Aromatics (PNA) Buildup	279
2.3.1.2.4	Preventing Sedimentation in Ebullated-bed Hydrocrackers.....	281
2.3.1.2.5	Iron Sulfide Buildup in VGO Hydrocrackers	281
2.3.1.2.6	Feed Filter Operation.....	285
2.3.1.2.7	Mitigating High Temperature Hydrogen Attack	285
2.3.1.2.8	Fouling in Furnace Tubes	286
2.3.1.2.9	Corrosion in Overhead System	287
2.3.1.2.10	Corrosion in Auxiliary Equipment	288
2.3.1.2.11	Reducing Foaming in an Amine Scrubber	289
2.3.1.3	Operational Problems	289
2.3.1.3.1	Increased Yield Using Multivariable Predictive Control (MPC).....	289
2.3.1.3.2	Improving Hydrocracker Temperature Control	292
2.3.1.3.3	Detecting Radial Temperature Spread and Preventing Reactor Runaway	295
2.3.1.3.4	Hydrocracker Furnace Operations.....	297
2.3.1.3.5	Causes of Overcracking	298
2.3.1.3.6	Improving the Performance of a Debutanizer	299
2.3.1.3.7	Preventing Off-color Naphtha Product.....	301
2.3.1.3.8	Reducing the Level of Sulfur in Naphtha at EOR Conditions.....	302
2.3.1.3.9	Limiting Ammonia Concentration in the Cold High-pressure Separator Overhead.....	302
2.3.1.3.10	Inline Hydrocracker Cleaning System	303
2.3.1.3.11	Improving Recycle Gas Compressor Operation	303
2.3.1.4	Catalyst Management	305
2.3.1.4.1	Selection Process for Hydrocracking Catalysts	305
2.3.1.4.2	Catalyst Testing on Different Scales	306
2.3.1.4.3	Catalyst Loading Precautions.....	306
2.3.1.4.4	Measuring Hydrocracking Catalyst Activity	307
2.3.1.4.5	Catalysts for Processing Tight Oil.....	308
2.3.1.4.6	Catalysts for Processing Various Feeds.....	308
2.3.1.4.7	Replacing a Noble Metal Catalyst with a Base Metal Catalyst.....	310
2.3.1.4.8	Catalyst Structure: Homogeneous vs. Stacked	311
2.3.1.4.9	Ex-Situ Sulfiding (Presulfiding) of Hydrocracking Catalysts	312
2.3.1.4.10	Hydrocracking Catalyst Passivation	315
2.3.1.4.11	Disproportionate Catalyst Deactivation in the First Bed of a Hydrocracker.....	318
2.3.1.4.12	Designing a Posttreat Bed for Hydrocracking Reactors	318
2.3.1.4.13	Asphaltene Contribution to Catalyst Deactivation	319
2.3.1.4.14	Impact of HPNAs on Catalyst Activity and Stability	319
2.3.1.4.15	Regenerated Hydrocracking Catalyst Use.....	320
2.3.1.4.16	Catalyst Removal for Non-free Flowing Catalysts.....	323
2.3.1.4.17	Recovering Spent Hydroprocessing Catalysts and Metal Reclamation	323
2.3.1.5	Reducing Hydrocracker Energy and Hydrogen Use.....	325
2.3.1.5.1	Advanced Process Control and Modeling	325
2.3.1.5.2	Cleaning	327
2.3.1.5.3	Heat Integration.....	328
2.3.1.5.4	Power Recovery	328
2.3.1.5.5	Process Heaters	329
2.3.1.5.6	Compressors	330
2.3.1.5.7	Impact of Catalysts	330

2.3.1.6	Hydrocracker Safety.....	331
2.3.1.6.1	Hydrocracker Safety Incidents.....	331
2.3.1.6.2	Emergency Depressurization: Triggering Criteria, Rates and Modes	333
2.3.1.6.3	Operational Status of Emergency Depressurizing Valves and Interlocks	336
2.3.1.6.4	Safely Performing Inter-reactor Sampling in Hydrocrackers.....	336
2.3.1.6.5	Sampling of Light Streams around High-Pressure Equipment	337
2.3.2	Mild Hydrocracking (MHC).....	337
2.3.2.1	Mild Hydrocracking: Feedstock, Conversion, and Product Quality.....	337
2.3.2.2	Converting a Cat Feed or Distillate Hydrotreater to a Mild Hydrocracker	339
2.3.2.3	Options for Improving the Cycle Length of Mild Hydrocrackers.....	343
2.3.3	Distillate Hydrocracking	344
2.3.3.1	Shifting from Maximum Naphtha to Maximum Middle Distillate Yields	344
2.3.3.2	Maximizing Diesel Production in VGO Hydrocrackers	347
2.3.3.3	Benefits of Moderate Pressure Hydrocracking in Clean Diesel Production.....	350
2.3.3.4	Adjusting CAT to Maximize Diesel Production.....	351
2.3.3.5	Reactor Revamp to Improve ULSD Production	352
2.3.3.6	Optimizing Saturation and Volume Swell in ULSD Service.....	353
2.3.3.7	Loading Hydrocracking Catalyst in the Last Bed of a ULSD Unit	354
2.3.3.8	Process Revamp for Added H ₂ S Removal to Meet ULSD Standards	354
2.3.3.9	Onstream Correlation Models to Continuously Predict Distillate Properties.....	355
2.3.3.10	Improving Diesel Cetane from Hydrocrackers	356
2.3.3.11	Hydrocracking Catalysts for Cold Flow Property Improvements	357
2.3.4	Integrated Processing Schemes	358
2.3.4.1	Vacuum Distillation Unit with Hydrocracker	358
2.3.4.2	Delayed Coker with Hydrocracker	359
2.3.4.3	Solvent Deasphalting with Hydrocracker.....	362
2.3.4.4	Mild Hydrocracker with FCC	370
2.3.4.5	Integrated Processes for Heavy Oil Upgrading	371
2.4	<i>Refining R&D Alert!</i>	376
2.4.1	Introduction	376
2.4.2	General Hydrocracking	383
2.4.2.1	Process	383
2.4.2.2	Catalyst	386
2.4.2.2.1	Novel Composition	386
2.4.2.2.1.1	Patents	386
2.4.2.2.1.2	Research	388
2.4.2.2.2	Preparation Method.....	388
2.4.2.2.2.1	Patents	388
2.4.2.2.2.2	Research	390
2.4.2.2.3	Other	391
2.4.2.3	Hardware	392
2.4.2.4	Integrated Operations	394
2.4.2.5	Reducing Energy and/or Hydrogen Use	395
2.4.2.6	Removal of HPNAs	396
2.4.2.7	Process Modeling and Control.....	397
2.4.2.7.1	Patents	397
2.4.2.7.2	Research	398
2.4.3	Product Selective Hydrocracking	400
2.4.3.1	Middle Distillates	400
2.4.3.1.1	Process	400

2.4.3.1.2 Catalyst	404
2.4.3.1.2.1 Support with Improved Porosity.....	404
2.4.3.1.2.2 Other.....	405
2.4.3.1.2.2.1 Patents.....	405
2.4.3.1.2.2.2 Research	408
2.4.3.2 Heavy Naphtha.....	409
2.4.3.3 High-octane Gasoline	412
2.4.3.4 BTX	413
2.4.3.4.1 Process.....	413
2.4.3.4.1.1 Patents.....	413
2.4.3.4.1.2 Research	415
2.4.3.4.2 Catalyst	416
2.4.3.5 LPG/Light Olefins	416
2.4.4 Resid Hydrocracking.....	418
2.4.4.1 Ebullated-bed Reactor.....	418
2.4.4.1.1 Patents.....	418
2.4.4.1.2 Research	420
2.4.4.2 Slurry-bed Reactor	420
2.4.4.2.1 Process.....	420
2.4.4.2.1.1 Patents.....	420
2.4.4.2.1.2 Research	422
2.4.4.2.2 Catalyst	424
2.4.4.2.2.1 Patents.....	424
2.4.4.2.2.2 Research	425
2.4.4.3 Other	429
2.4.4.3.1 Process.....	429
2.4.4.3.1.1 Patents.....	429
2.4.4.3.1.2 Research	432
2.4.4.3.2 Catalyst	433
2.4.4.3.2.1 Patents.....	433
2.4.4.3.2.2 Research	434
2.4.5 Hydrocracking Alternative Feedstocks.....	435
2.4.5.1 Fischer-Tropsch Liquids	435
2.4.5.1.1 Patents.....	435
2.4.5.1.2 Research	438
2.4.5.2 Renewable Feedstocks	439
2.4.5.2.1 Production of Fuels.....	439
2.4.5.2.1.1 Patents.....	439
2.4.5.2.1.2 Research	443
2.4.5.2.2 Production of Chemicals.....	447
2.5 Worldwide Installed Capacity.....	447
2.6 Construction	449
2.6.1 Recent Construction Activity.....	449
2.6.2 Completed Construction Projects	455
2.7 References.....	470